WASTEWATER TREATMENT

AND

POLLUTION CONTROL

BY

K A MURRAY
Sci. Nat., M.Sc., Ph.D.,
M.S.A.Chem.I., F.S.A.I.M.M.,
F.R.S.C., F.I.M.M., M. Inst. W.P.C.

00070043

Obtainable from
Water Research Commission
P O Box 824, Pretoria 0001
Republic of South Africa

ISBN 0 908356 55 2

DISCLAIMER

The views expressed in this publication are those of the author and do not necessarily constitute endorsement or recommendation by the Water Research Commission.

First Edition (1987):

Second Edition (1991):

Printed by Beria Printers
P O Box 48079, Hercules 0030
Republic of South Africa

PROLOGUE

Let us here give praise to enlightened men
Enobled by their courage and prescient wisdom
Venerating their precepts and honouring the search for truth
Yea verily aspiring to the pinnacle of a virtuous life

Let us help the striving swain by noble example
To benefit from the well-trod paths of yesteryear
To gain enlightenment and imaginative strength
To further mankind's knowledge of nature's laws and happenings

ACKNOWLEDGEMENTS

The author hereby records his thanks to the Water Research Commission for sponsoring the publication of this book and acknowledges the cooperation and encouragement given by the Executive Director, Mr P E Odendaal and also Mr H J Best, Managing Engineer, Department of Water Affairs.

Overt help in typing by members of the staffs of the Department of Water Affairs and the Water Research Commission is gratefully acknowledged, in particular typing done by Mrs C Wolmarans, Mrs S A van Eeden and Mrs R Joubert of the Department of Water Affairs and Mrs B Wilkins and Mrs L Meiring of the Water Research Commission.

Special thanks are due to Professor D C Midgley who, while Head of the Hydrological Research Unit at the University of the Witwatersrand, enabled the author to have access to the University's libraries and for providing office accommodation for the author when he visited the University.

The author's association with Dr S P Ligthelm of the Pollution Control Division of the Department of Water Affairs has been a happy one and fruitful of help in discussions and the procurement of illustrations executed by the Departmental drawing office. His friendly assistance is gratefully acknowledged. It is hoped that an Afrikaans translation of this book may result from his interest.

Thanks are due to the following for critical comments on particular industries dealt with in Chapter 15:

Dr S G Shuttleworth	– Tanning
Mr A Lewis	– Mining
Mr H H Myburgh	– Cellulose fibre
Mr G Kies	– Wine and Brandy
Mr P Josso	– Sugar

Photographs have been provided by the following:
Johannesburg City Council – Chief Scientific Officer, Mr D W Osborn;
National Institute for Water Research – Chief Director, Dr D F Toerien;
AECI Ltd – Senior Environmental Officer, Miss E N Schramm;
Department of Water Affairs – Water Pollution Control Officer, Mr G E McConkey.

The furnishing of these photographs and the interest shown is gratifying.

Dr J J Barnard of the Pollution Control Division of the Department of Water Affairs supplied very useful information on the disposal of solid wastes. His assistance in this regard is recorded with appreciation as is also the assistance and constructive criticism by Mr T D W Thompson of the Department of Water Affairs of the Chapter on "Water Rights".

Documents requested by the author were kindly supplied by the following:
Mr W A Lombard – South African Bureau of Standards;
Mrs M P Oliveira, Mr C C Nell and Mr R O Morris – Department of Water Affairs;
Mr J J C Heynike – Water Research Commission.

Finally, appreciation is accorded Mr R T Rudd, formerly Chief, Pollution Control, Department of Water Affairs, for creating a climate of interest that caused the author to embark on this project.

K A Murray
Author

Johannesburg

PREFACE

In 1981 it was agreed to sponsor the publication of a book to be written by Dr K A Murray on wastewater treatment and pollution control. The project had been conceived by him and he had hoped to have the copy ready for printing by about 1983 or, circumstantially, somewhat later. However, due to his remaining in employment with the Department of Water Affairs beyond his proposed retirement date, completion of the text has been delayed until now (1987).

The author's approach to his subject is historical, educational and empathic towards South African matters; his treatment being objective, adequately inductive and practical. He has omitted to belabour information which may readily be obtained in overseas texts and operators' manuals both in South Africa and overseas but, rather, has aimed to include helpful information on matters which are not generally known, particularly to new-comers in the field.

His outlook is primarily South African though his work contains much of interest on the international level. South African readers should find affinity with many aspects of the text.

As this publication covers a wide range of subjects and disciplines he has had to spend considerable time in libraries both here and overseas. These have included the following: – London: The British Library (British Museum and Aldwych branch), Holborn Public Library, Patents Office Library, Royal Society of Chemistry Library, Institution of Mining and Metallurgy Library; Boston (Mass., USA): Municipal Library; South Africa: University of the Witwatersrand (William Cullen Library, where he had access to the stacks, Africana Library, Law Library, Engineering Library), Seymour Reference Library and Municipal Reference Library (Johannesburg), State Library and Municipal Library (Pretoria). He has also had occasion to browse through and purchase relevant books in well-known bookshops in London, Oxford and Bristol in the UK; Boston, Cambridge (Mass.), Hanover (N.H.) and New York in the USA.

The author's style is erudite, free-flowing and easily comprehensible. This being so, the book should find favour with a broad readership.

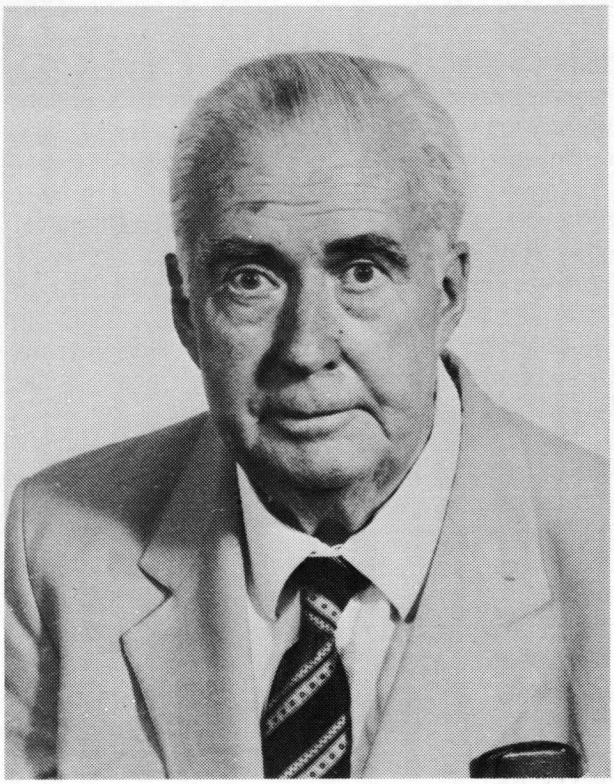
"Wastewater Treatment and Pollution Control" will be found of assistance to students at universities and technikons, wastewater treatment and pollution control personnel, in fact all persons who in the practice of a variety of disciplines are concerned with the disposal of sewage and industrial wastes and the prevention of pollution of the water environment.

In sponsoring this South African text it is considered that progress may derive from its study in a field of endeavour of particular importance to South Africa.

P E Odendaal
EXECUTIVE DIRECTOR
Water Research Commission

Pretoria
February 1987

SOME FACTS CONCERNING THE AUTHOR



The author KENNETH ANGUS MURRAY was born in Pretoria on March 29, 1911. He has been concerned with wastewater treatment and pollution control problems for over fifty years. His academic qualifications include the following degrees conferred by the University of the Witwatersrand – B.Sc. (chemistry and physics majors), B.Sc. (Hons.) with First Class Honours in Physical Chemistry, M.Sc. in chemistry; and a Ph.D. degree conferred by the University of South Africa.

He also holds qualifications in education and bacteriology, viz. – T_2 Teachers Certificate and a Higher Education Diploma (University of South Africa); and a Certificate in Bacteriology Applied to Chemistry (Battersea Polytechnic, London).

His experience in the wastewater treatment field started with the City Council of Johannesburg as Chemical Assistant to the late Dr Harold Wilson. He then carried out research on the colloids in sewage at University College, London, under the direction of the late Professor F G Donnan, C.B.E., F.R.S. This work was undertaken for the Water Pollution Research Board of the Department of Scientific and Industrial Research. This was followed by his being appointed as Municipal Biochemist to Germiston, in which capacity he was responsible, *inter alia*, for controlling the operation of the Rondebult Sewage Purification Works and Farm on commissioning and thereafter for a period of seven years.

He has had experience as an editor of scientific publications and is author or co-author of papers in the fields of wastewater treatment and analytical chemistry. He has supervised the research work of M.Sc. and Ph.D. candidates.

He has practised in the fields of education and research (as a university pedagogue); in wastewater treatment (as a municipal chemist and manager of a sewage treatment company); in the mining industry (as a manager of laboratories – Gold Fields of South Africa, Limited) and in water pollution control (as a water pollution control officer – Department of Water Affairs).

During World War II he served in the Royal Navy on secondment from the South African Naval Forces.

The author recently retired from service with the Pollution Control Division of the Department of Water Affairs.

CONTENTS

Page

Historical Introduction 1

CHAPTER

1. History of Sewage Purification Methods from 1868 onwards 7
2. Historical Development of Sewage Disposal Methods in South Africa 23
3. Chemical and Bacteriological Aspects of Sewage and Sewage Purification Processes 34
4. South African Organizations Dealing with Wastewater Treatment Problems 66
   (1) The Department of Water Affairs 66
   (2) The Institute of Water Pollution Control (Southern African Branch) 72
   (3) The National Institute for Water Research (NIWR) 74
   (4) The Water Research Commission 77
   (5) The Department of National Health and Population Development 80
   (6) The South African Bureau of Standards (SABS) 81
   (7) Provincial and Local Authorities 81
   (8) Industries 81
5. Overseas Organizations 82
6. South African Contribution to the Developing Field of Wastewater Purification 88
7. Problems Encountered in the Mining Industry in South Africa in Relation to Sewage Disposal 105
8. Practical Aspects of Wastewater Treatment and Pollution Control in South Africa 110
9. Water Rights 122
10. Provincial and Local Authorities: Responsibilities and Authority 130
11. Discharge of Purified Effluents into Watercourses 135
12. Analytical Methods: 145
    (1) Methods of Analysis of Wastewaters and Purified Effluents 145
    (2) Ionic Species in Effluents Inimical to the Environment in Regard to: Farming, Toxicity to Fish, Animals and Human Beings 154
13. River Water Usage: Adverse Effects Caused by Sewage Effluent, Industrial Seepage, Runoff and Atmospheric Discharges 161
    (1) Eutrophication 161
    (2) Increase in Salinity 168
14. The Hierarchical Use of Water in South Africa: Portents for the Future 171
15. Control of Pollution from Industrial Effluents (Major Water-using Industries): 182
    (1) The Mining Industry: Handling and Disposal of Effluents Arising from Mining and Mineral Recovery Operations 182
    (2) The Cellulose Fibre Industry: Problems and Achievements in the Control of Pollution from Wastewaters 206
    (3) The Iron and Steel Industry: Control of Pollution from Wastewater Arisings 219
    (4) Tanning and the Treatment and Disposal of Tannery Effluents 233
    (5) The Textile Industry: A Diverse Activity with an Array of Manufactured Products and an Olla Podrida of Effluents 248
    (6) Wastewater Problems in the Brewing Industry 259
    (7) Wine and Brandy Production and the Disposal of Attendant Wastes 270
    (8) Progress in the Control of Pollution in the Sugar Industry in South Africa 276
16. Disposal of Solid, Toxic and Hazardous Wastes 286
17. Marine Pipelines for Disposal of Sewage and Intractable Industrial Wastes 304
18. The Use of Land for the Disposal of Intractable or Poor Quality Effluents 312
19. Treatment of Sewage and Disposal of Effluent from Small Communities, Caravan Parks, Seaside Resorts, Hostels, Hotels, etc. 316
20. Water Boards and their Functions 333

APPENDIXES

A.1 Regional Standards for Wastewater or Effluent 337
A.2 Department of Health Guide: Permissible Utilization and Disposal of Treated Sewage Effluent 342
A.3 Regulations for the Erection, Enlargement, Operation and Registration of Water Care Works 350
A.4 Rainfall and Evaporation Tables 355

HISTORICAL INTRODUCTION

"No living being can be healthy while the products of his vital action are allowed to accumulate round him."

Dr Samuel Rideal[1]

It may be said, with some justification, that the standard of sanitary science practised by a nation is an indication of its standard of civilization.

In seeking early information on sanitation many writers have drawn on the Judeo-Christian Scriptures or the "Bible" as we know it and refer to the following:

Deuteronomy, Chapter 23, verses 12, 13, viz. – New English Bible version – "You shall have a sign outside the camp showing where you can withdraw. With your equipment you will have a trowel, and when you squat outside, you shall scrape a hole with it and then turn and cover your excrement. For the LORD your GOD goes about in your camp, to keep you safe and to hand over your enemies as you advance, and your camp must be kept holy for fear that He should see something indecent and go with you no further."

This information would seem to indicate a conditioned attitude towards aesthetics rather than sanitary justification.

A further quoted reference is to be found in Judges 3 verses 20 – 25, viz. – "Eglon called for silence and dismissed all his attendants. Ehud then came up to him as he sat in the roof-chamber of his summer palace and said, 'I have a word from God for you'. So Eglon rose from his seat, and Ehud reached with his left hand, drew the sword from his right side and drove it into his belly. The hilt went in after the blade and the fat closed over the blade; he did not draw the sword out but left it protruding behind. Ehud went out to the porch, shut the doors on him and fastened them. When he had gone away, Eglon's servants came and, finding the doors fastened, they said, 'He must be relieving himself in the closet of his summer palace.' They waited until they were ashamed to delay any longer, and still he did not open the doors of the roof-chamber. So they took the key and opened the doors; and there was their master lying on the floor dead."

It would appear from the above two quotations from the Bible that, in the first case, people were enjoined to follow a practice akin to that of carnivorous animals of digging up the earth to receive their excrement and then covering it over whilst the second quotation leads one to believe that in sumptuous buildings, roof-chambers or closets were set aside for relieving oneself. However, no indication of the method of disposal of the liquid and solid excrement is given.

However, it is not only the Judeo-Christian Bible which is lacking in a portrayal of sanitation – such lack is also evident in other scriptures.

The "Bible of the World"[2] contains the scriptural essence of eight great living source religions, viz. – Hindu, Buddhist, Confucianist, Taoist, Zoroastrian, Judeo-Christian and Mohammedan.

All these creeds represent different codes of living and constitute different routes to reach the Almighty. Each religion is but one of such paths that lead to God.

It is significant that the Vedic hymns of the Hindu scriptures were composed more than a millennium before the birth of Christ. Thus it would seem relevant to scan the pages of these scriptures to discover anything of consequence in the line of sanitation but, unfortunately, although much is recorded on the "Duties of Householders" and moral codes of living enshrined in the "Ordinances of Manu", nothing of consequence was found. In fact, all the eight scriptures quoted above, apart from the references in the Books of Deuteronomy and Judges in the Bible, are silent on the topic of sanitation.

However, interesting information has come to light through the activities of well-known archaeologists and their teams working in the Middle East and India.

According to Baldwin Latham,[3a] Alexandria, Carthage, Herculanium, Jerusalem, Nineveh, Rome and many other cities had a complete system of sewers and waterworks.

Perhaps the most famous of the sewers is the great sewer of Rome, the Cloaca Maxima, which was begun by Tarquin the Elder and completed by Tarquin the Proud about 600 BC.[4a]

Victor Duruy[5] states, "Of all Tarquin's works the most important was the Cloaca Maxima. Its foundations were sunk deep under the earth and its numerous branches brought the water and mud from the low districts of the city and led them into the Tiber. It was only when this immense work had been finished that the marshy plane which extended between the 'Seven Hills' was rendered healthy and dry.

Such was the height of the triple vault* of the main channel, which was built with long stones of peperino, laid without cement, that Agrippa entered it in a boat and Pliny asserts that a cartload of hay could have passed through it."

Notwithstanding, the fact is that many of the ancient civilizations had cities replete with running water and, additionally, made use of running water in latrines, e.g. Salamis[6] in Cyprus had an elaborate semi-circular, 40-seater Roman latrine near the Salamis gymnasium. The water entered the centre and then flowed both ways under the seats and in a trough below the knees to serve the purpose as it were of a bidet.

Rodolfo Lanciani's book[7] entitled "The Ruins and Excavations of Ancient Rome" is considered authoritative by Professor Brilliant, Professor of Art History and Archaeology at Columbia University and in a foreword he states that Lanciani's remarks about the Cloaca Maxima and other Roman sewers are of interest.

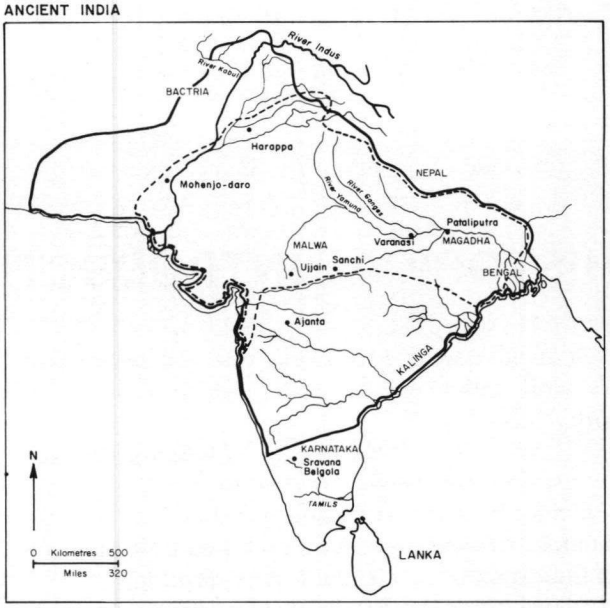
Lanciani states, "The Roman cloacae have been overpraised. It certainly is a marvellous fact that some of them were still in use a few years ago, after a lapse of 26 centuries, but they bid defiance to modern sanitary principles. First of all they served to carry off the sewage and the rainwater together. This double employment made it necessary to have large openings along the streets which exposed the population to the effluvia of the sewers. In the third place, the sewers emptied themselves directly into the Tiber, thus polluting its waters, which were used not only for bathing but also for drinking purposes . . ." "It must be borne in mind that the 'latrina' of Roman houses was conveniently placed next to the kitchen and the same cloaca was used for the sinks. Against such great dangers to public and private health the Romans had but two protections; the masses of water by which the drains were constantly flushed and the hilly nature of the city ground which allowed them to give the drains a steep gradient."

Civilization of the Indus Valley: The Cities of Harappa and Mohenjo-Daro

Sir Martimer Wheeler[8] in reporting on archaeological work in India and Pakistan has stated, *inter alia*, "The high quality of the sanitary arrangements at Mohenjo-daro could well be envied in many parts of the world today. They reflect decent standards of living coupled with an obviously zealous municipal supervision. Houses sometimes had a privy on the ground or public floor connected with attendant drains and water-chutes which in their turn gave on to the main sewers. Brick drains are characteristic of the Indus Valley civilization, both at Mohenjo-daro and elsewhere. They are elaborately designed even to the extent of having trim inspection holes."

*("The vaulting is formed by three concentric arches and the diameter of it is 30 feet")

ANCIENT INDIA



Sir John Marshall,[9] in reporting on the archaeological excavations carried out by the Government of India between the years 1922 and 1927, considered that the Mohenjo-daro antiquities dated not earlier than 3 250 BC or later than 2 150 BC.

E T H Mackay[10] reported in "Further Excavations at Mohenjo-daro" (Vol I), p. 95, "The room (40,41) made from the northern recess was also subdivided and, provided with paved floors and a well-made drain leading to a cesspit in low lane (Plate XLIII), appears to have been converted into a public latrine entered from the central street by a doorway 2 ft. 4 in. wide. A patch of carefully laid pavement still remains in the outer room at a level 8,3 ft. below datum. The making of a soakpit in such dangerous proximity to a well has been observed in other parts of the site in the last phases of this city".

p. 89, "An unusually well laid out pavement in room 8,9, which was entered from both the north and south, is six courses of brick in thickness so that it stands well above the floor level. It slopes down to the drain-hole of the usual upright, rectangular shape in the middle of its southern side and is bordered with bricks that were first hacked and then carefully rubbed down to about half their thickness – a somewhat unusual feature. Another pavement in the south-eastern corner of the house may have served as a privy; situated at the end of a long corridor along the front of the house, it was perhaps hidden from view by a matting screen of the kind in frequent use in modern Sindh."

p. 170, "Chutes were used for the drainage of both rooms and privies . . . they were mostly built in the thickness of the walls and probably served more than one floor" (Slopes were between 30° and 45° to the perpendicular).

p. 426, "These drain pipes with their very scientific joints are by no means peculiar to Mohenjo-daro.

They have been found in Knossos where they date to the MMI period (Evans, Palace of Minos Vol I pp. 141 – 142 Fig. 103)."

"At Ur Woolley has found drain-pipes about 3 ft. long and 6 in. in diameter, with a flange at one end which he dates to 3 500 BC (Antiquaries Journal Vol VI pl. LIX)."

p. 61 (General Summary), "The privies of Mohenjo-daro and especially the last, are extraordinarily like those unearthed by Frankfort in an Akkadian Building at Tel Asmar in Mesopotamia. There is the same paved room and the high recess at one end, cut in two by the drain-hole through which the effluents passed away . . ."

"Practically the only difference between the Babylonian privies and Mohenjo-daro is that a vaulted drain lay below the paving of the former, whereas at Mohenjo-daro the drains are open and empty directly into a channel in the street outside. There would seem to be but little difference in date between the Akkadian and the Indian examples."

Bray and Trump,[11] in the "Penguin Dictionary of Archaeology" published in 1970, when referring to Mohenjo-daro state, "The dating of this extraordinary site is still debated. Radiocarbon dates and connections with Mesopotamia suggest a span from 2 000 BC to about 1 750 BC."

Duckworth,[12] Disney Professor of Archaeology at the University of Cambridge has recorded, "The discoveries at Mohenjo-daro and Harappa and other sites in Sindh, the Punjab and Baluchistan of what is now generally known as the Indus civilization, brought to light a flourishing civilization supporting large, well-planned cities many centuries before the Aryan invasion of India . . ."

. . . "The excavations at Mohenjo-daro and Harappa revealed an ancient urban civilization – the Harappa culture as it is called – with densely peopled cities, carefully planned, with buildings of burnt bricks, elaborately laid out with wells, drains, bathrooms and lavatories, a civilization based on agriculture and trade. The crops grown were wheat, barley, rice, dates and cotton and the domesticated animals included the humped and unhumped cattle, buffalo, sheep, pig, dog, elephant and camel. The Harappa folk had wheeled vehicles, a system of weights calculated on the binary and decimal systems, and a pictographic form of writing not yet deciphered . . ."

From the foregoing it can be stated that a number of civilizations made provision for the disposal of human wastes from privies by reticulation through pipes or by the agency of brick chutes to cesspools, some of which in the form of soakaways were placed in the thick walls of the buildings to allow soakaway of liquid and periodic removal of the remaining solids.

However, none of these early civilizations had the remotest idea of microbiology and were content, at times, to have drinking water wells in close proximity to cesspools.

McNeill,[13a] Professor of History at the University of Chicago, deduced that the Indus civilization had two great urban capitals, one located at Harappa and the other several hundred miles downstream at Mohenjo-daro.

"Contact with Sumer" (i.e. Lower Mesopotamia, between Babylon and the head of the Persian Gulf), "where the world's first civilization arose c. 3 400 BC" McNeill contends, "is certain".

Unfortunately, the script used by Indus people has not been deciphered by modern scholars but McNeill contends that "cross dating with Sumer through seals and other imports at either end is possible." On this basis he considers that "Indus civilization flourished from 2 500 to 1 500 BC." Yet again dealing with the date of the Indus civilization, Masson-Oursel, De Willman-Grabosvska and Stern[14] state, –

"The date of the ancient civilizations of the Indus is not yet established. Marshall, who is reponsible for the excavations and for the principal work dealing with these questions, is inclined to give them the earliest possible date, the third or even the end of the fourth millennium BC . . ."

. . . "While some indications tend to make us date the Mohenjo-daro culture further and further back, others point in the opposite direction." . . . "So although the Indus culture is almost certainly pre-Aryan, it may perhaps not be as ancient as was at first supposed."

From the dates given for the Indus civilization, viz. –

Sir John Marshall	3 250 – 2 150 BC
Bray and Trump	2 000 – 1 750 BC
Professor McNeill	2 500 – 1 500 BC

it can be concluded that waterborne sanitation commenced 2 000 or more years BC and that the sewers of Rome, e.g. the Cloaca Maxima date from 600 BC.

But it is interesting to note that McNeill[13b] has emphasized that the first landmark of human history was the development of food production. This, he states, permitted an enormous multiplication of human numbers and laid the basis for the emergence of civilizations. The transition from hunting and gathering to farming and pastoralism he identifies as having taken place in the Middle East between 8 500 and 7 000 BC.

The second great landmark in mankind's history, McNeill contends, was the emergence of skilled and complex societies we call civilized. Man's earliest civilized communities, he avers, developed in the valleys of the Tigris-Euphrates and the Nile c. 3 500 – 3 000 BC and states that the Indus valley followed suit soon afterwards.

Sanitary Vanguard of Mankind

Despite the variable dating of the Indus civilization by the different authors quoted, it seems that this ancient civilization practised waterborne sanitation well before the Romans and it would be fair to agree with

Reynolds[15] in dealing with the twin cities of Harappa and Mohenjo-daro, that the inhabitants can be considered as part of the Sanitary Vanguard of Mankind.

Nevertheless, it should be stated that under the dunes of Skara Brae in the Orkney Islands to the north of Scotland, neolithic stone huts[16] have been found with crude drains leading from recesses in the walls; the recesses are considered to have been latrines. So much for the ancient past!

The Dark Ages, Middle Ages and the Emergence of the Renaissance

With the decline of the Roman Empire during the first five to six centuries A.D., due to barbarian attacks, civilization suffered many vicissitudes. Then followed the Middle Ages which only ended with the fall of Constantinople in 1453 when the Renaissance period came into being.

However, sanitary science had not developed and, in fact, a realization of the activities of micro-organisms only came with the development of the microscope during the lifetime of Antony van Leeuwenhoek (1632–1723) in Delft, Holland; followed by the work of Lazzaro Spallanzani (1729–1799) in Italy; Louis Pasteur in France who lived during the period 1822–1895; Robert Koch (1843–1910), the German bacteriologist and others such as Ehrlich and Metchnikoff that bacteriology was on its way as an important science and of great import to sanitation.

Following his discoveries, Koch was able to announce in 1876 that microbes were the cause of disease. Thereafter, the interest of the public was aroused!

But what of the period before Koch's discoveries? What progress had been made in the field of sanitation since the classical past?

Dr Lyon Playfair,[3b,4b] in an address to the Social Science Congress at Glasgow in 1874, is reported to have stated, –

"When the civilization of the Egyptians, the Jews, the Greeks and the Romans faded, the world passed through the dark ages of mental and physical barbarism. For a thousand years there was not a man or woman in Europe that ever took a bath. No wonder there were the wondrous epidemics of the Middle Ages which cut off one-fourth of the population of Europe, the Spotted Plague, the Black Death, the Sweating Sickness and the terrible mental epidemics which followed in their train, the Dancing Mania, the Mewing Mania and the Biting Mania."

Baldwin Latham[3c] gives a clear picture of the filthy living conditions of peasants and townsfolk. "In the towns", he stated, "the mechanics lived in rooms without glass windows, slept on straw beds and worked in workshops unheated by fires. Even in well-to-do houses rushes covered the earthen floors and got saturated with scraps of food, which remained to putrefy under a new layer of rushes scattered over it . . ." "Filth, instead of being abhorred, was almost sanctified." He further goes on, –

"Dr Edward Bascome states in his 'History of Epidemics' that up to the year 1760, 'extraordinary as it may appear there was not such a thing as a privy in Madrid; it was customary to throw the ordure out of the windows at night and it was removed by scavengers the next day."

However, following an ordinance by the King of Spain, many Madrid citizens copied the ancient Roman practice[7] and erected privies close to their kitchen fireplace.

It may be said that Madrid citizens were no worse than those of Edinburgh[3d] and ancient Rome whose housewives chose night-time to throw slops, etc. from the upper windows into the street drains – no doubt to the chagrin of any unfortunate person walking by at the time of such a zealous operation!

Dealing with the Historical Development of the Sewage Problem, Dunbar and Calvert[17] state, "Until well into the nineteenth century the sewage problem was one of which little or nothing was heard. Every man disposed of his filth as best he could. Cesspools for faecal matter were either recommended or tolerated by the authorities, but it was generally left to the individual householder to dispose of the contents . . ."

The water closet was "reinvented" in 1810 and the use of this mechanism gave rise to consequences unsuspected at the time. For instance, householders found it more convenient and less costly to cause their cesspools to overflow into the street drains.

Rivers such as the Seine below Paris became grossly polluted and the Emscher in Germany showed signs of pollution for the first time.

Reynolds[15b] relates an episode in which eight ruling princes and a large company of knights and nobles had been summoned by the Emperor Frederick to a Diet at the great Hall at Erfurt in 1183. Alas the weight of the guests caused the floor to collapse and many came to an untimely death in the vast cesspool below!

Garderobes

A garderobe (wardrobe) was an accepted euphuism for a medieval privy closet.

In large Halls of Residence and castles they were usually built within the thick walls, each with its own vertical shaft below a stone or wooden seat. Sometimes they were erected singly or in a block containing a number – each with its own shaft.

In some cases, depending on the architectural characteristics of a castle, for instance, e.g. a projecting turret the garderobe would be open-ended. Hardly, it might be said even as hygienic as the efforts of neolithic man at Skara Brae in the Orkneys (*vide ante*).

Mobile Toilets

It has been recorded as far back as 1770 that Edinburgh streets were perambulated by a man carrying a bucket and a great coat, with the cry "Wha wants me for a bawbee?" So for the expenditure of a halfpenny in the case of dire physiological need you could use his bucket and shielding cloak!

The first railway lavatory compartment was built in 1840 by the Great Western Railway for Queen Victoria.

Today, of course, (mobile) toilets are available on motor-coaches, trains and aeroplanes. But like the commodes and pots de chambre of old, the contents of the system have to be satisfactorily disposed of which, *inter alia*, means man-handling.

In the case of ships at sea, disposal of wastewater of all kinds, including lavatory discharges, presents no difficulties except when a ship is in port.

The Victorian Era

Santo Crimp[18] in the introduction to his book "Sewage Disposal Works" states, "In regard to sanitary science, the reign of Queen Victoria will ever stand out as a most important epoch. At the time of her accession, the sanitary condition of the people was deplorable in the extreme; during the earlier period of her reign matters became worse, as the town populations rapidly increased and practically no steps were taken to remove the refuse matters constantly produced, nor to lessen the pollution of the rivers . . ."

During Queen Victoria's reign bathrooms were installed at Buckingham Palace.[16b] On her accession in 1837 there was no bathroom in the palace. Parliament voted her £5 000 a year for her "toilette".

In 1844 no less than 53 overflowing cesspits were found under Windsor Castle. The Prince Consort, Albert, took steps to have the Hanoverian commodes replaced by water-closets together with the necessary drainage system. But this sanitary advance was stopped in its tracks by his demise and the rule of the widowed queen that all things must remain as they were before his death.

The Water-Carriage System

Water can be caused to flow in channels, canals, flumes, chutes and pipes. Early man in Sumer was able to make clay pipes by hand up to 3 ft. in length and 6 in. in diameter provided with flanges.

It is easy to understand these limiting dimensions as they were made by hand.

But in modern water and sewage undertakings plumbing is all important.

The availability of metal pipes, fittings and appurtenances in all shapes and sizes is a *sine qua non* as far as reticulation of sewage is concerned.

In the case of the Romans, mechanical flushing drains were not available and running water was the rule of the day. However, for many reasons, not least of all the saving of water, in modern times satisfactory flushing toilets are necessary.

In a book by Wallace Reyburn[19] it is stated, "Undoubtedly Thomas Crapper's greatest, most lasting contribution was the work he did in developing the modern W.C. cistern"

. . . "It would not be absolutely true to say that it was Thomas Crapper who invented the 'Water Waste Preventer' which for many years was the technical term for what is now our modern W.C. cistern." . . . but, "he perfected the cistern as toilet users throughout the world know it today"

Thomas Crapper worked closely with Thomas Twyford of Stoke-on-Trent. (The name of Twyford is well known for all types of sanitary ware.)

In 1861, after 13 years of industrious work as a plumber, Crapper was able to set up a works in London under the style and title of the "Marlboro' Works of Thomas Crapper and Co."

When Crapper started in 1861 he found himself at the beginning of a boom period for plumbers due to the vast extension of the network of London's intercepting sewers.

Reyburn[19] considers that the Dark Ages stretched well into the last century as far as the toilet was concerned and one of the worst aspects of that murky period, he states, was the smell. He asserts that body odours did not matter compared with the stench from the extremely inefficient drains. Apparently, it was necessary to evolve smell-thwarters and Reyburn indicates that a typical one was half a pomegranate stuffed with cloves, the forerunner of the present proprietary air freshener "airwick" and others.

Thomas Crapper would seem to have a place in the history of sanitary science, perhaps not on the same plane as scientists, engineers and medical men, but certainly in effecting the smooth and efficient running of a water-carriage system of sanitary disposal in making it aesthetically and practically acceptable in cities which had suffered the consequences of odours in the streets and stinking cesspools!

Sanitary Awakening

In England Sir Edwin Chadwick (1800 – 1890) made considerable contributions to the sanitary awakening of the nineteenth century by arousing the public to the deficiencies of individual community living. He was employed by the Royal Commission on the Poor Laws as an investigator and, subsequently (1834), was appointed Secretary to the Poor Law Commission. His chief contribution was his constant advocacy of having expertly trained personnel to be in charge of certain departments of local authorities in deference to entrusting control in the hands of politically elected persons.

His report on the "Sanitary conditions of the Labouring Population" (1842) was an historical

milestone in his efforts to improve water supplies, the drainage and cleansing of towns.

In a paper entitled "Contributions of Engineering to Health Advancement", Wolman[20] considers that Chadwick in England and Shattuck in the United States, both non-professional laymen, pressed vigorously for solutions to environmental problems and made great contributions to the sanitary awakening of the nineteenth century.

The Disposal of Sewage

Having arrived at a stage where, by the agency of a sewerage system, the wastewater could be removed from a community and be disposed of at some distance from the built-up areas, the problem of disposal arises.

The simplest and most convenient methods were used, viz.

(1) Discharge into rivers;
(2) Discharge into the sea;
(3) Disposal on land.

As the population of communities increased with a concomitant increase in the pollutional load, the first method (discharge into rivers), particularly, brought problems in its wake.

Prior to 1850 the main endeavours of those in a position to make enactments were aimed at reducing, if not eliminating, pollution in built-up areas and achieving more salubrious conditions in and around habitations generally. This being so, it was the general attitude of the authorities that it was preferable to discharge filth into rivers than to allow it to accumulate in proximity to dwellings within densely populated areas. However, as the pollutional load on the rivers increased, there was an awareness that the discharge of sewage, industrial and other wastes into rivers could pollute rivers to the detriment of the interests of others riparian to such rivers.

Sewage Purification

In 1865 a Rivers Pollution Commission was appointed in England. However, in 1868 this government commission was replaced by the Rivers Pollution Prevention Commission: Sir Edward Frankland was a member of this commission and from then onwards the problem of sewage purification was thoroughly examined and valuable contributions to the science of sewage purification continued to be made.

For this reason this book has been chosen to start with sewage purification methods from 1868 when Sir Edward Frankland became associated with its development.

REFERENCES

1. Rideal, S. "Sewage and the Bacterial Purification of Sewage", London, The Sanitary Publishing Co. Ltd, New York, John Wiley and Sons, 1901, p. 1.
2. Ballon, R.O. "The Bible of the World", Kegan Paul, Trench and Co. Ltd, London, 1946.
3. Latham, B. "Sanitary Engineering", E and F N Spon, London, New York, 1878, (a) p. 20; (b) p. 29; (c) p. 30; (d) p. 24.
4. Adams, S.H. "Modern Sewage Disposal and Hygienics", London, E. and F.N. Spon, New York, Spon and Chamberlain, 1939, (a) p. 71; (b) p. 1.
5. Duruy, V. "History of Rome and Roman People", Kegan Paul, Trench and Co., London, 1883, Vol. I, p. 132.
6. Bacon, E. "Archaeology. Discoveries in the 1960's", Praeger Publishers, New York and Washington, 1971, p. 144.
7. Lanciani, R. "The Ruins and Excavations of Ancient Rome", Bell Publishing Co., New York, 1979, p. 30.
8. Wheeler, Sir M. "Civilization of the Indus Valley and Beyond", Thames and Hudson Ltd, London, McGraw-Hill Book Co., New York, 1966, p. 24.
9. Marshall, Sir J. "Mohenjo-daro and the Indus Civilization", Arthur Prosbsthain, London, 1931.
10. Mackay, E.T.H. "Further Excavations at Mohenjo-daro", Being an Official Account of Archaeological Excavations at Mohenjo-daro carried out by the Government of India between 1927 and 1931 by E.T.H. Mackay, late Special Officer for Exploration, Archaeological Survey of India, 2 Vols: Vol. I Text; Vol. II Plates.
11. Bray, W. and Trump, D. "The Penguin Dictionary of Archaeology", Penguin Books, 1979.
12. Duckworth, G.N. "A Hundred and Fifty Years of Archaeology", Duckworth, 1977, pp. 260-261.
13. McNeill, W.H. "A World History", Oxford University Press, Oxford, New York, Toronto, Melbourne, 1979, (a) p. 32 *et seq*; (b) p. 3.
14. Masson-Oursel, P. de Willman-Grabosvska and Stern, P. "Ancient India and Indian Civilization", Kegan Paul, Trench, Truber and Co. Ltd, London, 1934, pp. 343-344.
15. Reynolds, P. "Cleanliness and Godliness", George Allen and Unwin Ltd, London, 1946, (a) p. 16; (b) p. 43.
16. Wright, L. "Clean and Decent", "A History of the Bath and the Loo", Routledge and Kegan Paul, London, Boston and Henley, 1980, (a) p. 4; (b) p. 100.
17. Prof Dr Dunbar and Calvert, H.T. "Principles of Sewage Treatment", Charles Griffin and Co. Ltd, London, 1918, p. 1.
18. Santo Crimp, W. "Sewage Disposal Works", Charles Griffin and Co., London, 1890, p. 1.
19. Reyburn, W. "Flushed with Pride" – "The Story of Thomas Crapper", Futura Publications Ltd, London and Falmouth, 1980.
20. Wolman, A. Paper No. 2611, Trans. Amer. Soc. Civil Engnrs, Centennial Transactions, Vol. CT, 1953, pp. 579-587.

Chapter 1 HISTORY OF SEWAGE PURIFICATION METHODS FROM 1868 ONWARDS

For reasons outlined in the "Historical Introduction", 1868 was selected as the starting point for the development of the science of sewage purification.

Langdon Pearse[1] has stated, "The basic principles of sewage treatment rest on a foundation in physics, chemistry, bacteriology and biochemistry". Perhaps, at this point in time, it would be more apt to vary this slightly by stating that the processes involved relate to physics, chemistry and microbiology wherein chemistry includes physical chemistry, organic chemistry and biochemistry, and microbiology includes the presence, activities and interrelations of bacteria, fungi, algae, protozoa and viruses.

The bacteria and associated enzymes which take part in sewage purification processes – whether aerobic or anaerobic are basically saprophytic but, naturally, attention has to be directed towards the fate of certain micro-organisms present in the processes and their existence or absence in the final effluent and, more particularly, the presence of pathogens in the effluent.

Royal Commission on Sewage Disposal (1898 – 1915)

Adrian,[2] in giving evidence before the Royal Commission on Sewage Disposal in 1898, dealt with the origin and growth of the general statute law relating to sewage disposal in England and Wales.

He stated that his survey of official and parliamentary publications had shown that there were three significant periods, viz. –

(1) *1842 – 1857* during which it would appear, "that it was of the first importance to secure the prompt removal of sewage from the neighbourhood of dwellings: That in consequence of doubts as to the effect upon the public health of the irrigation of large surfaces with liquid sewage, the best system of disposal was by underground pipes for subsequent distribution by hose or jets."

(2) *1858 – 1870* This period saw (i) "The abandonment of the notion of possible injury to health as a consequence of the irrigation of land by sewage; and (ii) the growth of the belief in the ideal system of sewage as being that which should aim at its profitable utilization by direct application to land, and should thus facilitate the protection of rivers from contamination."

(3) *1870 – 1898* To this period "is attributed, as a dominant idea which finds expression in official and parliamentary publications and in legislation, the opinion that the prevention of the pollution of streams is an indispensable requisite of every system of sewage disposal which can lay claim to efficiency."

Dealing with the first period (1842 – 1857) Adrian[3] cited the application of sewage by open irrigation to the Craigentinny Meadows of Edinburgh which operation started at the end of the 18th century.

In a nutshell, therefore, the chronological development of attitudes towards the disposal of sewage was:

(i) The prompt removal of sewage from the neighbourhood of dwellings; (ii) profitable disposal of sewage on land; (iii) A positive desire to prevent the pollution of streams by the utilization of efficient methods of disposal of sewage.

In the "Historical Introduction" reference was made to the Rivers Pollution Commission which was appointed in 1857 and reported in 1868. In 1868 a second Rivers Pollution Commission was appointed – Sir Edward Frankland was a member of this commission.

Sir Edward Frankland's Experiments

Sir Edward Frankland carried our laboratory experiments which have formed the basis of the modern development of biological sewage purification.

His experiments* were carried out with the aid of glass tubes c. 183 cm (6 ft.) high by c. 25 cm (10 in.) in diameter. These were placed in earthenware troughs and a glass tube was placed in the middle of each to allow the entry of air.

A layer of gravel some 7,62 cm (3 in.) in depth was placed in each tube and over this was superimposed a 152,4 cm (5 ft.) layer of soil under test. In cases where the soil layer was coarse it was covered by a 2,54 cm (1 in.) layer of fine sand to obviate the risk of coarse suspended matter in the sewage feed entering the filter.

*Reference to these is made by Dunbar and Calvert in their book "Principles of Sewage Treatment", Charles Griffin and Company, London, 1908, p. 119.

Frankland used gravel from Beddington Meadows near Croydon; soils from Barking, Dursley and Leyland, and sand from Hambrook.

The filters were dosed with London sewage every morning and evening: the daily dosages were as follows:

Filter	*Dosage rate (ℓ/m³ per day)*
1	c. 20,79 – c. 89,13
2	36,65
3	c. 20,79
4	23,76 – c. 77,25
5	c. 23,76

The duration of the experiment was about four months. The results were regarded as satisfactory, the filtration having provided effluents which were to all intents and purposes, colourless, odourless and were well nitrified. No clogging of the soil was observed.

The Rivers Pollution Commission concluded that with the best filters (494 m³/ha) 44 000 gallons of sewage per acre could be purified daily if the drains were laid at a depth of 183 cm (6 ft.)

In a short summary of the work done by the Rivers Pollution Commission of 1857 – 1865 and 1868 on the land treatment of sewage the Royal Commission on Sewage Disposal[4] in 1895 published the following statements:

"In any reference to sewage purification by land, the classical work of the Rivers Pollution Commission of 1868 demands special attention. After detailing the results of various laboratory experiments on the filtration of sewage through large glass tubes filled with different kinds of soil, the conclusion is drawn (Volume I, Final Report, p. 69) that: "The cleansing power of a soil seems to be more closely connected with physical condition, as regards porosity and fineness of division than with its chemical condition". Again, ". . . Our experiments also appear to show that if the soil is not overdosed with sewage, it will retain its efficiency for a long, if not unlimited period of time, and its pores will not be clogged up".

At the time, little was known about bacteria and the part played by them but the commissioners of 1868 stated, (Volume I, First Report, p. 70 –) "From all these experiments, then it appears that the action of the filter must not be considered as merely mechanical. The process carried on in it is also chemical. Filtration, properly conducted, results in the oxidation and transformation of offensive organic substances in solution as well as in the mere mechanical separation of the suspended solid matters which, when in motion, sewage conveys with it."

Again, in the section dealing with intermittent filtration (Volume I, First Report, p. 64) the following is recorded: "These experiments also show that the process of purification is essentially one of oxidation, the organic matter being, to a large extent, converted into carbonic acid, water and nitric acid."

Liebig, the renowned German chemist was interested in sewage since he was concerned with the conservation of nitrogen and the fertilizing value of sewage. Unfortunately, his support for a catalytic chemical theory delayed for some thirty years the acceptance of the important part played by micro-organisms.

None-the-less the importance of microbiology in relation to the purification of sewage was considered by a number of investigators.

As early as 1865 Mueller[5] postulated that the contents of sewage are mainly of organic origin and the changes which appeared to be chemical were in reality due to digestion by microorganisms.

Again in 1885 Emich[6] in Germany showed experimentally from investigation on water and sewage that no self-purification took place in samples sterilized by boiling and kept under aseptic conditions. In order to effect changes samples required to be allowed free access of air and without sterilization by heat.

He also found that direct oxidation with ozone and hydrogen peroxide was unimportant compared with the part played by biological processes.

Water Research Committee of the Royal Society

The Royal Society of London formed a Water Research Committee and Percy F Frankland reported to it on many of his researches, viz. –

First Report, 1892 of the Water Research Committee of the Royal Society covered "the present state of our knowledge concerning the bacteriology of water, with special reference to the vitality of pathogenic schizomycetes in water. (Reported by Percy F Frankland and Marshall Ward).

Second Report, 1893. This dealt with the vitality and virulence of *Bacillus anthracis* and its spores on potable water (Reported by P F Frankland and M Ward).

Third Report, 1894. This gave information "on the behaviour of the typhoid bacillus and of *Bacillus coli communis* in potable water." (Reported by P F Frankland and J R Appleyard) and, "The behaviour in potable water of anthrax bacilli taken directly from the animal body" (Reported by P F Frankland, C Templeman and H M Ward).

Fourth Report, 1895. This report apprised the committee "On the biology of *Bacillus ramosus* (Fraenkel) a schizomycete of the River Thames" (Reported by P F Frankland and H M Ward).

Sir Edward Frankland showed an interest in microbiological and other matters connected with the disposal of sewage as, for instance, "On the transport of solid and liquid particles in sewer gas" (Proc. Roy. Soc., 1877, XXV, 542). "On conditions affecting bacterial life in the Thames water" (Proc. Roy. Soc., 1895, LVII, 439).

However, the microbiological contributions of Sir Edward Frankland to the Proceedings of the Royal

Society in the microbiological field were far outweighed by his namesake Percy F Frankland and his wife Grace C Frankland, their book "Micro-organisms in water – their significance, identification and removal" (published in 1894) becoming a notable publication in the microbiological field.

Garner[7] has stated "Sir Edward Frankland, as a member of the 1868 Commission, was the first to submit sewage treatment to scientific investigation in the true sense. The early irrigation schemes had necessitated large areas of land, and Frankland's experiments were, therefore, devised with a view to increasing the volume of sewage which could be treated upon a definite area".

Investigations at the Lawrence Experiment Station, Massachusetts

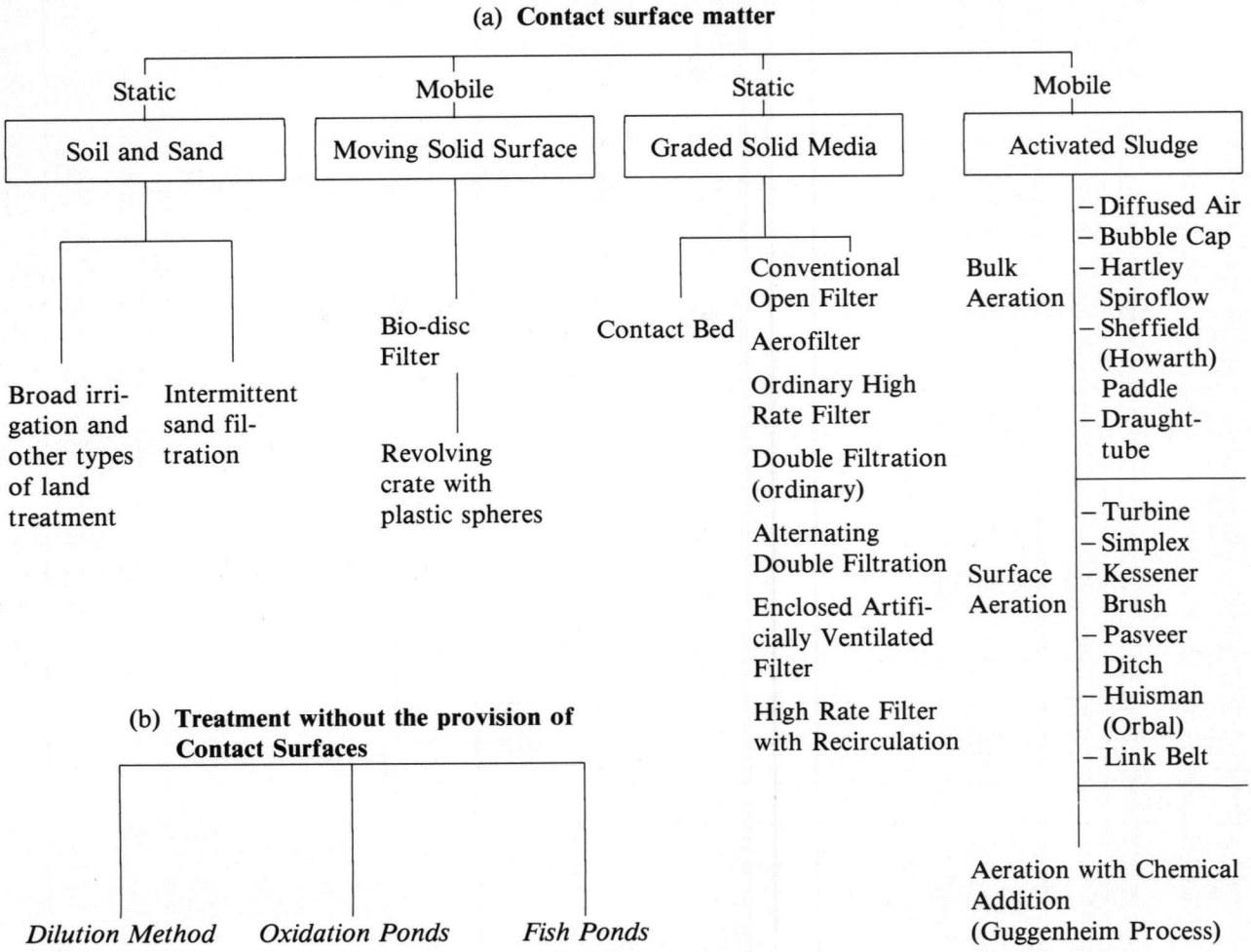
The real significance of intermittent filtration had thus become channelled in the direction of broad irrigation or sewage farming. However, by the application of Sir Edward Frankland's original experimental ideas to plant size units, investigators at Lawrence, Massachusetts, U.S.A., gave new direction to the emerging idea of biological filtration.

The Lawrence Experiment Station had been set up on the banks of the Merrimac River in Massachusetts in 1887 by the Massachusetts State Board of Health. Hiram F Mills (hydraulic engineer and a member of the Board), with the assistance of professors T M Drown (chemist) and W T Sidgwick (biologist) of the Massachusetts Institute of Technology, organized the investigation of pollution prevention problems with respect to the waters within the State. Allen Hazen was in immediate charge of investigations.

Ten cypress tanks, c. 5,18 m (17 ft.) in diameter and c. 4,9 m (16 ft.) deep, were filled with different filter media and sewage was pumped to them from the city's sewerage system. The filtration experiments lasted for two years and the first report was published in 1890.

These outdoor experiments, under all weather conditions, demonstrated that intermittent filtration could serve as a method for purifying sewage and emphasized the importance played by microorganisms in the purification process.

AEROBIC BIOLOGICAL TREATMENT PROCESSES



Rudimentary Methods of Sewage Disposal

Man has disposed of his egesta and other forms of animal ordure by burial in the earth and by deposition in water-bodies, including rivers, lakes and the open sea. These practices passed muster for small isolated communities but with the development of towns and the growth of populations and industries they set at defiance the cause of pollution prevention.

These methods are still in use today. However, unless properly controlled, they hardly commend themselves for approval in our world attempting to live in harmony with the pollutional load being continuously added to the environment by an exploding world population and concomitant expanding technologies.

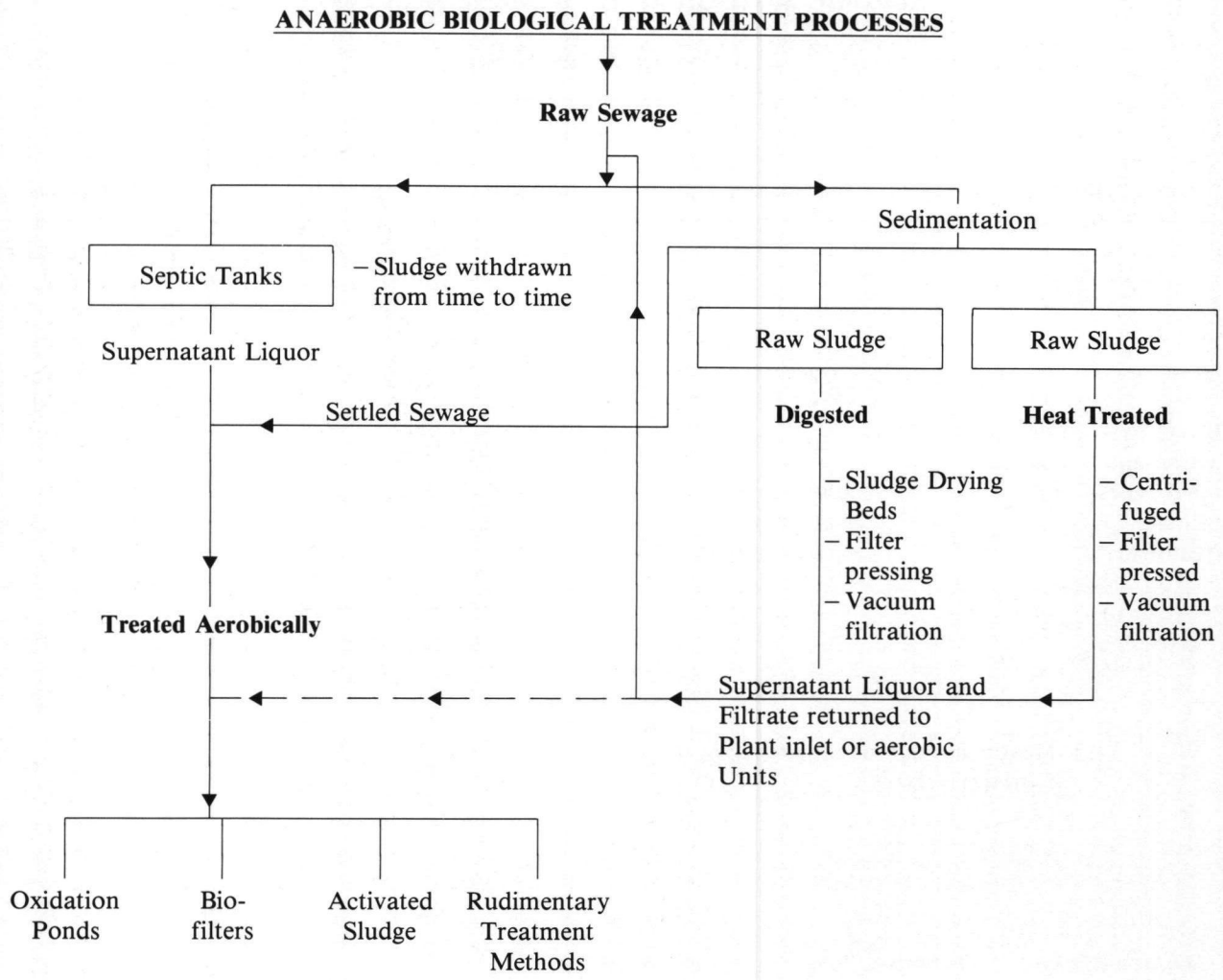
A schedule of aerobic sewage treatment processes is shown on previous page (p. 9) and a schedule of anaerobic processes is shown below.

1. ***Broad Irrigation and Sewage Farming***

Broad irrigation constitutes the application of raw sewage intermittently to an area of previously well-ploughed and prepared land. However, there was a tendency for local authorities to attempt profiting from the method by growing crops. Noteworthy, in this respect, were the Berlin (Germany) "Rieselfelder" and other German sewage farms which persisted in operation, probably due to the influence of Liebig who was concerned about the manurial value of sewage. The Rieselfelder of Berlin were well known and a variety of crops were grown. There was a school of thought which adopted the hypothesis that the growing of crops added to the efficiency of the purification process and the other that it interfered with the orderly operation of the broad irrigation process.

Normally, the land which, for large sewage flows was extensive had to be carefully prepared and laid out in suitably sized plots to facilitate adequate rotation of irrigation.

Levelling of certain areas was necessary, as well as underdraining and embanking of the soil. Main distributing carriers were constructed of concrete or stone and subsidiary distributing furrows, drainage canals and stormwater cut-off canals had to be carefully planned.



The raw sewage arriving at the sewage farm required pretreatment such as screening, trapping of oils and fat, and sedimentation prior to land treatment.

The main function of a sewage farming operation was the purification of sewage and this had to be the first concern of the sewage farm manager and his assistants.

In hot climates such as in South Africa, particularly where the outfall sewer was long and, in consequence, the sewage septic on arrival at the sewage farm, sewage farming gave rise to unpleasant odours. A notable example, originally, was the Klipspruit Sewage Farm of the Johannesburg City Council where Italian rye grass mainly, was grown for the grazing of cattle. However, later, at Rondebult where purified effluent from the Germiston Sewage Purification Works was distributed rotationally over paddocks planted with Italian rye grass and grazed by dairy cattle, the operation was free from odour. Seepage was collected in a tail dam.

2. *The Dilution Method of Sewage Disposal*

Self-purification: The dilution method of sewage purification and disposal depends for its efficacy on the so-called self-purification of natural waters. Self-purification may be regarded as the substantial or complete restoration by natural processes of a water-body to its pristine condition, following the introduction of a pollutional load sufficient to materially alter the physical, chemical and biological character of such water body.

Restoration of the status quo envisages, *inter alia*, transformations of pollutant substances to others having a less deleterious effect on the water environment than the original pollutants.

Assimilatory Capacity: By assimilatory capacity is inferred the extent to which wastewaters and effluents can be discharged into a body of water without significantly militating against the beneficial use of such water.

The above two concepts have to be taken into account when considering the dilution method of sewage disposal.

Even where purified effluents gain access to natural lakes or man-made impoundments, eutrophication can arise due to the presence of phosphate and nitrate in the effluents which is frequently the case with sewage effluents from plants not removing phosphate, the runoff from fertilized agricultural land, forest areas and feedlots.

Eutrophication as exemplified by the excessive growth of algae, water hyacinth, etc. naturally restricts the beneficial use of such a water body in which it occurs.

Adeney[8] has reported extensively in the Fifth Report of the Royal Commission on Sewage Disposal, Appendix VI p. 5 *et seq.*, 1908, on the "Nature and Rate of the Chemical changes which occur in Polluted Fresh and Salt Waters: and the Rate of Aeration of Fresh and Salt Waters."

In his book[9] "The Principles and Practice of the Dilution Method of Sewage Disposal" he quotes the work done by him for the Royal Commission and treats his subject more concisely.

He states[10] that the five conditions upon which the mechanism of the aeration of fresh and sea waters, under open air conditions primarily depends are as follows:

(1) Area of water exposed to the air;
(2) Temperature;
(3) Humidity of the air;
(4) Salinity (in the case of tidal waters);
(5) Wind, causing both an increase in area exposed and an acceleration of evaporation per unit area.

He placed great stress on continuous downward "streaming" as being effective in causing mixing to depths of c.3 m (10 ft.) and more.

His conclusions, in dealing with the changes which take place in polluted waters, are as follows:

"(1) The fermentation of the harmful organic impurities in true solution and in the colloidal state in sewage polluted river waters takes place in the continued presence of an excess of dissolved oxygen, in two distinct and progressive stages of bacterial fermentation.

(2) The first stage of fermentation results from the peculiar mode of nutrition of saprophytic bacteria in the presence of an excess of dissolved oxygen; and the second stage from the peculiar mode of nutrition of nitrifying bacteria in the presence of dissolved oxygen.

(3) The products of the first stage of fermentation are chiefly carbon dioxide, ammonia and water; but coloured organic products are also formed, although in much smaller proportions.

(4) During the second stage of fermentation, the coloured organic substances and ammonia formed during the first stage of fermentation, and the ammonia originally present in the sewage liquor, are oxidized to carbon dioxide and nitrates.

(5) Offensive putrefactive products are only formed during the first stage fermentation, when the supply of oxygen becomes exhausted. They do not occur in a second stage of fermentation. This stage of fermentation ceases entirely if the supply of dissolved oxygen becomes exhausted.

(6) Free gaseous nitrogen does not appear amongst the products of a first stage fermentation, when the latter proceeds in the continued presence of an excess of dissolved oxygen.

(7) The course of fermentation changes that occur during the self-purification, in the presence of an excess of dissolved oxygen, of river water polluted by sewage matter in true solution and in the colloidal state, proceeds in accordance with a definite law, which way he enunciated as follows:

The quantities of oxygen consumed, and the products formed, on the completion of each stage of aerobic fermentation are constant for similar volumes of the same polluted water. This law is applicable to all polluted waters, tidal and non-tidal undergoing purification by bacterial fermentation provided that the dissolved oxygen is in excess of the fermenting matters."

3. ***Pond Systems***

(i) *Fish Ponds:*

Fish ponds have been used as an "offshoot" of the dilution method of sewage purification. Installations of note were those at Munich and Strassburg in Germany.

At Strassburg it has been recorded that 1 hectare of pond area will purify the domestic sewage from 2 000 contributors. However, in autumn and winter it was found necessary to dry out the ponds and remove the remaining solids. Hence, it is necessary to have an alternative method of treatment such as irrigation on land for this period during which the ponds are out of commission for cleaning.

The fish from the Munich ponds were sold on the open fish market. It has been stated that the fish from the Munich fish ponds tended to display skeletal deformation akin to rickets but their flesh was unaffected.

Normally, with fish ponds it is necessary to arrange for dilution with water to the extent of at least three times by volume. The depth of ponds had an average depth of some 61 cm (2 ft.)

At Middelburg (Transvaal) the Municipal Council constructed fish ponds for another purpose namely to breed fish for stocking the Middelburg Dam to assist anglers.

In this case the ponds were set in the final effluent stream from the Council's activated sludge plant treating the town's sewage.

In the actual operation of fish ponds fed with settled sewage certain difficulties have been encountered such as maintaining adequate oxygen tension in the system, deposition of sludge and the development of untoward growths which reduce the oxygen available to the waterbody, the presence of toxic substances and the maintenance of a satisfactory biological balance from a fish production point of view.

(ii) *Oxidation ponds:*

Oxidation ponds depend for their efficacy on the adequate supply of oxygen from the atmosphere to the liquor in the system of ponds. This infers adequate sizing to prevent overloading and shallow depths to encourage downward streaming of air.

In South Africa pond systems are only allowed for small domestic sewage flows. A system which has been found acceptable consists of a primary pond with a retention period of 20 days followed by a secondary pond with a retention period of 10 days, followed, in turn, by three tertiary ponds, in series, each with a retention period of 5 days. The depth of the secondary and tertiary ponds shall be approximately 1,2 metre while a primary pond can be slightly deeper.

The final effluent from a pond system is not suitable for discharge into a watercourse but may be used for irrigation of certain fodder crops and timber trees. Fodder crops (e.g. lucerne) so irrigated should be dried before being fed to animals.

An irrigation dam with a retention period of at least 10 days should be provided to hold back effluent during rainy periods.

After the lapse of five years a new primary pond requires to be installed and the original taken out of circuit, dried out and cleaned for subsequent use.

Precautions require to be taken to prevent run-off from the pond area during rainstorms. This can take the form of cut-off canals or contour walls.

Where an oxidation pond system becomes overloaded and creates a smell nuisance, it is possible to overcome this by recycling final effluent back to the primary pond and also ensuring that no short-circuiting takes place in ponds.

Seepage from pond systems should be prevented as far as is practically possible.

4. ***Chemical Precipitation***

Martin,[11] in his book wherein he reviews the evidence collected by the Royal Commission on Sewage Disposal, states – "The introduction of chemical precipitation like that of sewage farming was largely inspired by the hope of profit."

He pointed out that, at the time, it was hoped that by the small addition of appropriate chemicals (e.g. lime, ferrous sulphate, alum) it would be possible to concentrate the fertilizing constituents of sewage in a solid and less voluminous form. The necessity for flooding large areas of land, it was felt, would be obviated, by the use of chemicals.

However, anticipation was based on fallacy since Frankland* informed the Royal Commission that – "There is about one-seventh part of the polluting matter in sewage in suspension, and the remaining six-sevenths are in solution; so that all remedies should be directed against the matter in solution rather than the matter in suspension – ".

Martin[12] points out that precipitation always results in the production of a large amount of sludge with a moisture content of about 90 per cent. It is stated that† a large number of patents were taken out

*Given in evidence, 14 December, 1898, before the Chairman and members by Sir Edward Frankland: Item 3000, First Report of Royal Commission on Sewage Disposal.

†Cameron and Aikman, – "Johnston's Elements of Agricultural Chemistry", 20th Ed.

with reference to the preparation of portable manures from sewage.

The chemical treatment of sewage was in vogue in England during the period 1880 to 1890 and a revival of the process took place in the United States about 1935.

However, with the arrival of biological methods of treatment such as biological filters and the activated sludge process this method, as a neo-semi-complete method of treatment, has been phased out. However, it can be used as a pretreatment method to reduce the load on biological treatment plants.

Basically chemical treatment constitutes a method for increasing the settlement of particles in suspension and inducing flocculation of colloidal material whereby adsorption of further material results from the gelatinous and voluminous settling flocs thereby leaving a clarified supernatant liquor, after terminal sedimentation, with 50 – 55 per cent removal of total organic matter and 80 – 90 per cent removal of bacteria.

Barwise[13] gives the following list of processes suggested for the chemical precipitation of sewage at the end of the 19th century, viz. –

Process	*Main ingredients*
Ferrozone	Crude alum, copperas, and magnetic oxide.
Alumino-ferric	Crude alum with a trace of iron salt.
A.B.C. process	Alum, blood and clay.
Amines process	Lime and herring brine.
Bacillite process	A disinfectant such as carbolic acid plus a precipitant.
Hanson's process	Black ash waste, consisting of sodium sulphide and calcium sulphate.
The phosphate process	Aluminium phosphate in hydrochloric or sulphuric acid.
The electrolytic process	The sewage is electrolysed using iron electrodes.
The Hermite process	Electrolysed sea-water is added to sewage.

Hodgson,[14] reporting on sewage and trade wastes treatment in America, Great Britain, Holland and Germany in 1938, listed the following coagulants as being used in chemical precipitation, viz. –

(1) Alum;
(2) Copperas and lime;
(3) Ferric sulphate and lime;
(4) Chlorinated copperas and lime;
(5) Ferric chloride;
(6) Ferric chloride and lime;
(7) Ferrous chloride and lime;
(8) Lime;
(9) Sulphuric acid and sulphur dioxide.

The above processes depend for their success on the precipitation of insoluble voluminous flocculent precipitates which cause clarification by adsorption on settling.

Alum: In the case of alum the reaction involved is as follows (as for aluminium sulphate $Al_2(SO_4)_3 - 18H_2O$):

$$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 \rightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2$$

Added (Al sulphate), Ca bicarbonate, Ca sulphate, Aluminium hydroxide present in sewage.

Where calcium bicarbonate represents the calcium and magnesium bicarbonate alkalinity of the sewage expressed as the calcium salt. Aluminium hydroxide, $Al(OH)_3$, acts as the clarifying agent.

Lime: For precipitation with lime the reactions involved are as follows:

$$Ca(OH)_2 + H_2CO_3 = CaCO_3 + 2H_2O$$
$$Ca(OH)_2 + Ca(HCO_3)_2 = 2CaCO_3 + 2H_2O$$

The lime requires to be added in excess to ensure complete reaction with carbonate and bicarbonate present in the sewage. Here the $CaCO_3$ acts as the flocculant.

Copperas and Lime: Using copperas and lime (the so-called "iron and lime" process) the following takes place:

$$FeSO_4.7H_2O + Ca(HCO_3)_2 = Fe(HCO_3)_2 + CaSO_4 + 7H_2O$$

Then with the addition of lime the following reaction takes place:

$$Fe(HCO_3)_2 + 2Ca(OH)_2 = Fe(OH)_2 + CaCO_3 + 2H_2O$$

The ferrous hydroxide [$Fe(OH)_2$] is then oxidized (by dissolved oxygen in the sewage) to produce ferric hydroxide $Fe(OH)_3$, viz. –

$$4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$$

The ferric hydroxide becomes the clarifying agent.

Ferric sulphate: Ferric sulphate, which is not as readily available as ferrous sulphate (copperas), serves as a good coagulant without the addition of lime.

Ferric sulphate and lime: Where ferric sulphate is used in conjunction with lime the following reaction takes place:

$$Fe_2(SO_4)_3 + 3Ca(OH)_2 = 3CaSO_4 + 2Fe(OH)_3$$

Chlorinated copperas: With chlorinated copperas (i.e. ferrous sulphate added to chlorine in solution giving rise to a mixture of ferric chloride and ferrous sulphate) the following reaction occurs:

$$6FeSO_4.7H_2O + 3Cl_2 = 2FeCl_2 + 2Fe_2(SO_4)_3 + 42H_2O$$

Ferric chloride and lime: The addition of ferric chloride and lime to sewage gives rise to ferric

hydroxide, which precipitates, viz. –

$2FeCl_3 + 3Ca(OH)_2 = 3CaCl_2 + 2Fe(OH)_3$

Ferrous chloride and lime: Ferrous chloride, which may be prepared by treating scrap iron with chlorinated water, may be used in conjunction with lime. This gives rise to ferrous hydroxide which is then converted to insoluble ferric hydroxide by aeration, viz. $Fe + Cl_2 = FeCl_2$

$4FeCl_2 + 4Ca(OH)_2 + O_2 + 2H_2O = 4CaCl_2 + 4Fe(OH)_3$

Sulphuric acid and sulphur dioxide: Methods using sulphuric acid and sulphur dioxide depend for their efficacy on the flocculation of suspended particles in sewage at the iso-electric point (i.e. the point of zero charge on the colloid and colloidal-like particles). At the iso-electric point the stability of the suspension is at a minimum and the particles precipitate.

Methods of Sludge Disposal

Chemical precipitation gives rise to large amounts of sludge which have to be disposed of.

Rafter and Baker[15] have given the following practicable methods for disposing of sludge:

(1) Discharge into sludge basins and from thence conveyed to adjacent areas for agricultural use.
(2) By deposition in large open basins surrounded by embankments and allowing it to remain until most of the water has evaporated and drained away, after which it may be carted away for fertilizer purposes or landfill.
(3) Liquid sludge may be spread directly onto agricultural land and be ploughed into the soil as soon as possible.
(4) Sludge may be mixed with combustibles (e.g. saw-dust, bark, etc.) and burned.
(5) Sludge may be mixed with suitable additives and be composted.
(6) Direct incineration as in the case of garbage.
(7) By compression into solid cakes in a filter press for use as a fertilizer.
(8) By discharge into a very large body of mobile water.

For isolated situations some of the above methods would be suitable depending on the locality but others would not be suited to the South African scene.

Methods 1 and 2. These methods would not be allowed by the State Department of Health.

Method 3. This method is practised in some areas in Europe. At Pietermaritzburg (Natal) digested sludge is sprayed (by jet) onto land and ploughed in on a rotational basis of land usage. However, undigested sludge would be disallowed.

Method 4. This method has proved uneconomic in South Africa.

Method 5. This method has been practised by a number of local authorities e.g. Pietersburg (Transvaal).

Method 6. This method has not received favour.

Method 7. This method could be used if steam is used in the filter-press and the Department of National Health is satisfied that adequate heat sterilization takes place. However, such application is dubious in South Africa.

Method 8. This method is being practised by the Durban Corporation. Other seaside municipalities e.g. East London and Cape Town discharge sewage directly into the sea by marine pipelines subject to certain prelimanary processing of a rudimentary nature.

The chemical treatment of sewage removes the suspended material in sewage. The sludge so created presents a problem and the supernatant liquor, after chemical treatment, requires to be purified further.

Therefore, chemical methods cannot be used as complete treatment methods but can serve a useful purpose in sewage purification works in reducing the load on the biological plants in operation.

Artificial Filters

Garner[16] in dealing with intermittent downward filtration in the "Historical development of sewage purification processes", remarks, "We know that where a sufficient area of suitable land is available at reasonable cost there is no doubt that 'intermittent downward filtration' affords a satisfactory system of purification, provided steps are taken to minimize the difficulties which Frankland foresaw".

It has been noted that greater success was achieved with sandy soil than with heavy soil in purifying sewage. Thus the possibility of constructing artificial sand filters arose.

In 1880 Baldwin Latham carried out experiments with sand filters.

But Garner[17] asserts, "We are, however, indebted to the Massachusetts State Board of Health experiments, which began about 1886, for the development of artificial filters upon scientific lines and the demonstration of their practicability."

Rideal[18] quotes from a publication by Kinnicut[19] concerning the operation of coarse sand filters at Worcester, Mass., U.S.A., where the process of intermittent filtration was capable of purifying c. 455 m^3 (100 000 gallons) of domestic sewage per acre (0,405 hectare) per day (184 m^3/ha) and at a reduced feed-rate of 20 000 to 30 000 gallons per day (c. 91 – 136 m^3 per day) the effluent was considered as pure as spring water.

Attempts to Increase Filtration Capacity

Attempts were made by those experimenting with artificial filters to "filter" sewage at a higher rate than was possible by land treatment.

Many types of media, including stone, gravel, coke and clinker were used, but one of the snags encountered was the distribution of the sewage and its rapid passage through the filters.

Dibdin* attempted to overcome these drawbacks by his "contact bed" system wherein he caused the sewage to be treated on a "fill-and-draw" basis and not on a continuous flow basis. The sewage was allowed to fill a tank in which media had been placed. After standing for some time, the contents were withdrawn from the bottom of the contact tank/filter which was then allowed to stand empty for a while to become re-charged with air before refilling with further sewage.

In his early experiments Dibdin used chemically precipitated sewage and the results were very promising.

Dibdin carried out successful treatment of sewage at Sutton. Subsequently, Manchester adopted the process followed by many other local authorities.

Later clogging of contact beds with consequent deficient aeration were encountered probably due to operators pushing the system beyond its capacity due to exaggerated claims of its capability. To overcome this, Dibdin experimented with primary contact tanks filled with slates laid horizontally with layers spaced at one to two in. (c. 2,5 cm – 5,0 cm) distances apart.

However, contact beds went out of favour in view of the developments in the field of percolating filters.

*W J Dibdin, in his book "Purification of sewage and water", The Sanitary Publishing Company, Limited, London, 1st and 2nd Editions, 1897 and 1898, p. 64 refers to a "contact bed" as a "bacteria tank". The term "contact tank" has also been used by sewage works operators.

Percolating Filters

Corbett of Salford devoted time and thought to the even distribution of sewage in a filter and, also, the adequate distribution of air.

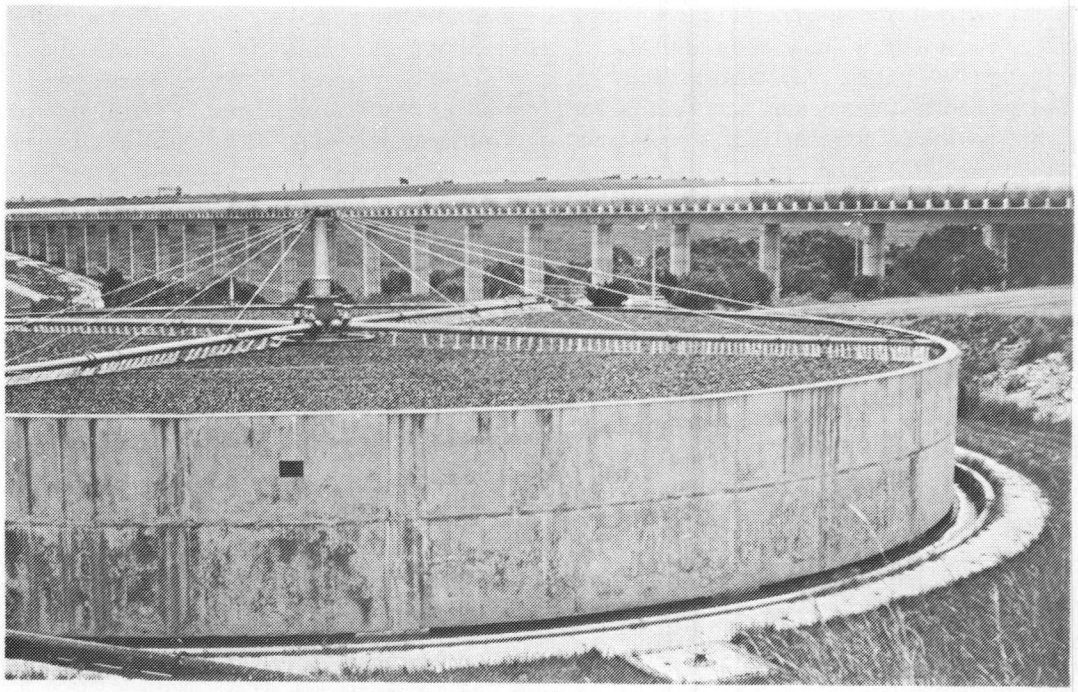
He experimented with perforated pipes and channels placed on or above the filter. In 1894 he investigated the possibilities of revolving distributors and, also, fixed jets.

At about the same time Stoddard of Bristol had been using a method of distribution in which sewage was added to the top of a filter in the form of rain by means of ridged plates perforated at the top ridges. The filters were filled with c. 5 – 7,5 cm (2 – 3 in.) size media consisting of cinders or ash. Stoddard advocated the removal of as much suspended matter as possible from sewage before being fed to the filters.

At this stage many types of filter were designed and, also, many appurtenances to ensure the following:

(1) Even distribution of settled sewage on a filter,
(2) Adequate aeration within a filter;
(3) Intermittent application of sewage to a filter.

This resulted in designs of biological filter beds in operation today.



Modern biofilter – outfall sewer in background.

It will be realized that in the climate of development of biofilters as, also, was the case with chemical precipitation, conditions were conducive to the creation of new devices and methods and the patenting thereof. This was later perpetuated after 1912 when the Activated Sludge Method of sewage treatment was discovered by Ardern and Lockett.[20] However, many of these innovations should not divert attention from the orderly basic development of the science of sewage treatment.

Activated Sludge Process

By 1914 normal sewage works practice consisted of screening, detritus removal, ordinary sedimentation or chemical precipitation, percolating filters followed by humus tanks.

At this stage Garner[21] remarks that "Scientific explanations had lagged behind innovations rather than given rise to them. It came, therefore, as a surprise when early in 1914, Ardern and Lockett showed that purification could be effected without the aid of filters. Practice, in this instance, followed upon careful research, with the result that sewage disposal as a science has been raised to a much higher level than formerly".

Both percolating/trickling filters and the activated sludge process operate in the presence of an abundance of air. In the case of filters, clotting and deposition of zoogleal slime takes place in the upper section of the filter media followed by nitrification in the lower section of the media.

The term "filter" is a misnomer that dates back to the early days of land treatment when it was thought that mechanical filtration of sewage took place in the soil. Actually, in a so-called filter we are dealing with a large number of contact surfaces upon which microorganisms have their being and are sustained by the nutrients in the sewage which is allowed to spread over such contact surfaces. The environment, of course, must be aerobic, hence adequate ventilation or access of air to the contact surfaces is necessary. Through the agency of the microorganisms, matters in solution and suspension are transformed chemically and escape with the effluent discharged at the bottom of a filter.

In the case of the activated sludge process the activated sludge acts as the clotting and nitrifying agent *per se* without the necessity for solid media for attachment.

Croghan[22] has stated that "the real problem in sewage disposal is widely accepted as being that of sludge . . .". Here of course, he is referring to raw sludge.

Sludge Digestion

A great deal of work has been carried out by Buswell and Fair in the United States and Imhoff in Germany on the anaerobic digestion of sludge. In this type of treatment air is excluded and an alkaline anaerobic digestion encouraged.

Imhoff (1905) developed a double storey tank or "clarigester" which functioned as a combined sedimentation tank and sludge digester. This was superseded by separate sludge digestion wherein the solids were caused to settle in one tank and were withdrawn for digestion in a separate sludge digester.

The sludge gas generated in a digester is collected in a gasometer in many cases and used to heat the contents of the digester and so improve the digestion.

Sludge gas* may also be used in gas engines coupled to alternators for generating electricity for use at a sewage works.

The digested sludge can be dewatered and used as a fertilizer. However, with mesophilic digestion and digestion at ambient temperatures the sludge may contain parasitic helminths and so cannot be used indiscriminately as a fertilizer.

Innovative Methods and Procedures

Degener's Lignite Method:[23] This consisted in adding finely-ground lignite to sewage, about 5 kg to 4,5 m^3 (20 lb. to 1 000 gal.) sewage. After intimate contact of the lignite with the sewage iron sulphate or alumina, c. 1,4 kg per 4,5 m^3 (3 lb. per 1 000 gal.) was also added. The final precipitate was filter-pressed and the product used as a fuel for electric power stations.

Though somewhat novel the process which has been used in Germany is much more expensive to run than the conventional sewage purification process. Degener's method has been used in a number of German towns e.g. Potsdam, Spandau, Tegel and Soest, and depends for its efficacy in removing putrescibility from sewage on the adsorption capacity of fine lignite. None-the-less it was an advance on the methods of chemical precipitation extant at the time.

Heat Treatment Methods: When sewage is heated above 60°C denaturation of proteins will occur followed by their flocculation and irreversible coagulation. At 70°C sterilization takes place and above 80°C enzymes are inactivated.

However, the heat treatment of sewage from a large community could not be contemplated as a viable method but, for the treatment of the considerably lesser volumes of sludges created in the processing of sewage, heat treatment has been applied with success. Sludges which have been treated include raw sludge (primary sludge), humus and activated sludge (secondary sludge), and digested sludge (tertiary sludge).

The advantages claimed for the heat treatment of sludge are that the sludge can be dewatered quickly by mechanical equipment: dewatering is unaffected

*Cyanide solution has been manufactured from sludge gas in a plant at Klipspruit near Johannesburg and this has been supplied to certain gold mines for use in their gold recovery process.

by the weather and the area of ground taken up by the plant is comparatively small.

Heat treatment methods are essentially unit chemical engineering processes applied to sludge but they can be applied equally well to other suspensions and slurries.

Two heat treatment processes which have been applied to the treatment of sludges are the "Porteous Process" and the "Zimpro Process".

Porteous Process: Sludge, from which screenings have been removed or, alternatively, disintegrated therein is first passed to storage tanks from where it is pumped by means of a ram pump through a heat exchanger into heating vessels. During this procedure one of the heating vessels is emptying and transfers its heat to the sludge entering the heating system.

Heat is applied to the vessels by means of steam jets at the bottom of the heating vessels. The key to the economical operation of the process is the heat exchanger which recovers some 80 per cent of the heat requirements.

The heat treatment period is approximately ¾ hour during which the temperature is of the order of 182°C (360°F) for most of the time.

After discharge from the plant via the heat exchanger the sludge is first passed into decantation vessels from which the supernatant liquor is withdrawn and the settled sludge is thickened, and then filter-pressed and dried. The final dried cake is used as a fuel for the boilers. The decant liquor and filter-press filtrate are returned to the settled sewage for aerobic treatment in the sewage purification works activated sludge or bio-filtration units.

Plants have operated by the Porteous Process at Horsham, Halifax and Luton in England. The sludges treated have been raw sludge, activated sludge, humus and digested sludge, and combinations of these primary, secondary and tertiary sludges.

Zimpro Process: The Zimpro Process (formally called the Zimmermann Process) is essentially a wet oxidation process based on concepts somewhat similar to those of the Porteous Process, but of more advanced design. Operating temperatures used are within the range 250°C – 300°C. At Milnerton in the Cape Province the sewage purification works was, originally, a conventional one with biological filters and sludge digesters.

Subsequently, a Zimpro plant of modern chemical engineering design was installed and the sludge digesters were converted to act as storage reservoirs for raw sludge. The reactors are constructed of titanium to resist corrosion from chlorides present in the sludge. The treated sludge from the Zimpro plant dries well and without odour and fly nuisance. Comminuted Zimpro dried residue sludge is used agriculturally and horticulturally.

Another Zimpro plant is in operation at Kwa-Debeka in Kwa-Zulu. This deals with sludge derived from domestic sewage and sanitary pail contents. However, due to the septicity of the sludge it does not operate without odour, but, no doubt, this could be overcome by a rearrangement of plant facilities.

Bio-disc Filters: It has been mentioned that with percolating or trickling filters settled sewage is caused to flow through media consisting of crushed graded material, i.e. the media is stationary and the sewage flows downward through the media.

In the case of the bio-disc filter the reverse takes place viz. – the media in the form of discs of durable material rotate on a common shaft – at a slow rate – through the sewage. As time goes on a slime builds up on the discs which acts in the same way as the slime on the media in a percolating filter. Bio-disc filters have been used in combination with septic tanks – such combinations are free from odour and have been used in a number of situations in South Africa e.g. at holiday camps, near factory offices, etc. The largest bio-disc installation is at Medunsa (Medical University), Ga-Rankuwa.

Activated Sludge – Methods of Aeration

Many methods have been employed for aerating sewage e.g. Sheffield method using paddles, Hartley Spiroflow method, compressed air (using diffuser plates, bubble caps or open pipes), surface aeration, Huisman disc aeration (orbal system), Kessener brush aeration, Pasveer ditch cylindrical metal "brush" aeration, deep shaft aeration, draught tube, Simplex method.

But these methods are merely new techniques and a variation of the early diffused air methods and do not really constitute fundamental advances in the science of sewage purification.

Disposal of Residual Organic Solids

Humus: The disposal of humus has not presented insurmountable difficulties. The common practice has been to settle the suspended solids (humus) in the biofilter effluent in humus tanks and return some of this to the incoming sewage at the head of the works in as fresh a condition as possible. Surplus humus can be conveniently dried on sand drying beds. After drying, the dried humus may be used as a fertilizer.

However, it is well to note that dried humus on re-wetting (due to rain, for instance) may give rise to an unpleasant smell.

Raw Sludge: The disposal of raw sludge presents a distinct problem. This can be overcome by subjecting the sludge to alkaline anaerobic digestion. However, there are cases where sludge digestion is not practised and resort is had to a number of disposal methods, viz. – (1) Barging to sea; (2) Discharge by marine pipeline to sea; (3) Composting with other wastes; (4) Heat treatment.

Surplus Activated Sludge: The disposal of surplus activated sludge has been dealt with in a number of ways, viz. – (1) Aerobic digestion; (2) Anaerobic

digestion together with raw sludge; (3) Broad irrigation; (4) Lagooning; (5) Heat treatment.

Digested Sludge: Digested sludge, on discharge from a digester can be dewatered by a number of methods, e.g. on sludge drying beds or by vacuum filtration after preconditioning with chemicals.

Combustion/Incineration Methods: (i) At Kwa-Mashu (Black Township) in Durban, raw sludge is thickened by hydrocyclone, coagulated with poly-electrolyte, centrifuged in a horizontal centrifuge and incinerated in a "Heresov-type" furnace.

(ii) At the Central Wastewater Treatment Works of the Durban Corporation the raw sludge was incinerated in a fluidized bed combustion furnace. However, due to certain operational and other difficulties this method of sludge disposal has been discontinued and the City Council has been granted permission by the Department of Water Affairs to dispose of sludge by deep sea marine pipeline.

However, none of the methods cited for the disposal of residual organic matter represents an advance in the science of sewage purification but merely the application of available technology and of methods of economical and practical convenience.

Artificially Ventilated Filters

Due mainly to Prüss in Germany, deep enclosed artificially ventilated filters were installed at a number of sewage purification works, e.g. The Emschergenossenschaft of Essen had a number in operation and the Enclosed Sewage Treatment Company (Proprietary) Limited of Johannesburg had installed one in Glasgow (Scotland) and on numerous mines in South Africa as well as at Germiston for the Municipality at the Rondebult Sewage Works and at Bloemfontein.

Dekema and Murray[24] compared the performance of a c. 23 metre (75 ft.) diameter enclosed artificially ventilated filter with c. 3,7 metre (12 ft.) depth of media with a conventional open one of the same diameter but with c. 1,8 metre (6 ft.) depth of media.

The filters were of thick concrete construction fitted with revolving distributors and were fed with the same settled sewage at the Rondebult Sewage Purification Works in Germiston.

Air was supplied to the enclosed filter by means of a fan. From the results obtained over a three year period it was concluded that the enclosed filter was able to treat, to the same degree of purity, 2,15 times as much settled sewage per unit volume of media as the open filter.

The period of investigation was three years. The sewage contained industrial wastes.

Despite the favourable comparison, enclosed artificially ventilated filters did not gain favour. Vosloo was able to show, at Springs, that there was no economic gain by using enclosed artificially ventilated filters when compared with open filters having a depth of media 3,7 metres (12 ft.) as in the case of enclosed filters and taking into account the cost of roof construction, fan operation and in-built royalty costs as Prüss' patent rights had been assigned to the Enclosed Sewage Treatment Company (Proprietary) Limited.

Hence, today, 3,7 metres (12 ft.) deep filters are quite commonly installed by local authorities and mining companies e.g. Boksburg Municipality and Kloof Gold Mining Company Limited.

Multiple Filtration

Dekema and Murray[25] carried out investigations over a period of two and a half years with an experimental biofiltration plant erected at the Rondebult Sewage Purification Works in Germiston.

They employed double filtration with enclosed artificially ventilated filters capable of application on a large scale.

Taking the capacity of a 1,8 metre (6 ft.) deep open filter bed as 1,0 they arrived at the following performance ratios, viz. –

Open filter 1,8 metre (6 ft.) deep 1,0
Enclosed artificially ventilated filter 3,7 m (12 ft.) deep 2,3
Double filtration process using enclosed artificially ventilated filters 3,2

The double filtration process was patented in South Africa, Great Britain and the United States.

Alternating Double Filtration

Systematic investigations have been carried out by Wishart, Tomlinson, and Mills on the treatment of settled sewage in percolating filters in series with change in the order of the filters. From work carried out at Minworth, Birmingham (England), Mills[26] has concluded that from the results of the continuous operation of the large scale experimental plant at Minworth for four consecutive years, settled sewage can be treated by the process of alternating double filtration at four times the rate of treatment at which similar sewage can be treated by single filtration. This means – from Mills' published results[27] – that the performance of two filters operated as single filters in parallel can be doubled by operating them according to the alternating double filtration process. The experimental plant comprised four circular filters and four upward flow humus tanks (primary and secondary).

The Minworth experiment appeared to be an endeavour to show that biofiltration could face up to the inroads of the activated sludge process and, of course, to indicate to local authorities with existing bio-filters how they could increase the capabilities of their plants.

According to Jenkins,[28] the process had been invented by O'Shaughnessy of the "Birmingham, Tame and Rea District Drainage Board," "who noticed that the excessive growth on the surface of a

filter could be rapidly removed by applying to the filter a partially treated sewage effluent''. The inference drawn was that with two filters, operating one on sewage and the other on a partially treated effluent, at least one filter could be kept in a clean condition.

The double filtration method at Germiston, however, was not conceived on such entirely altruistic lines. Basically the work was aimed at bypassing the Prüss patent or, rather, avoiding royalties which would become due when the proposed extensions to the Rondebult Sewage Purification Works took place. In this the Council was successful by having its patent application granted. This was for a double filtration process incorporating enclosed artificially ventilated filters. At this stage Springs Municipal Council won a High Court action brought by the Johannesburg assignee of the Prüss patent against the Municipal Council for infringement of the patent. This court action was based on the fact that the said Council had operated a deep enclosed filter – but without artificial ventilation after having employed such artificial ventilation initially. In the action in the Witwatersrand Local Division of the Supreme Court it was shown that the system of an enclosed artificially ventilated filter was not novel in terms of Patent Law. The plaintiff's application failed. None-the-less Springs Municipality favoured deep open filters.

Anaerobic Digestion followed by Biofiltration: At Bloemfontein (Orange Free State) Lunn, while City Engineer, installed a substantial enclosed artificially ventilated filter which was coupled to the overflow from a septic tank. Lunn maintained that the effluent from the filter was satisfactory and the system free from odour and nuisance.

Today this combination does not exist though the enclosed filter, separately, does. The function of the septic tank has been altered.

High Rate Filtration with Recirculation: Other attempts at increasing the performance of filters have emanated from the United States and Great Britain.

In these high rate filtration systems filter effluent is recirculated either before or after settlement in a humus tank and returned either to mix with the settled sewage or with raw sewage prior to sedimentation.

Jenks Process: The Jenks process enjoyed a certain popularity in the United States and a limited application in South Africa just before and during World War II (1937 onwards). The Jenks system of biofiltration consisted in passing settled sewage diluted with recirculated effluent through a shallow filter some 0,9 metre (3 ft.) deep filled with large-size media [e.g. c. 7,5 cm (3 in.) size].

The large-size media prevented clogging of the filter and the shallowness meant that the pumping head was not excessive.

The ratio of recirculated effluent to sewage favoured by Jenks was 4 or 5, i.e. four or five volumes of recirculated effluent to one volume of settled sewage.

The Jenks process never really got a foothold in Great Britain or South Africa. In the United States it proved useful in treating sewage at army camps.

It would also serve as a pretreatment or auxilliary process for dealing with industrial effluents.

Continuous Filtration with Recirculation of Part of the Effluents

In reporting on experimental work carried out over a period of years by the Water Pollution Research Board, Mills[29] stated that with single filtration a certain filter "could not treat 60 g.y.d. but on recirculation it survived a net rate of more than 200 g.y.d." This infers an increase in performance due to recirculation of at least 3,3 times.

In this investigation at Birmingham settled sewage was treated in two plants in parallel – one by the conventional method of single filtration – and the other by filtration followed by recirculation of an equal volume of settled filter effluent.

Improving the Performance of Treatment Processes

The factor of importance in sewage purification is the cost per unit volume of sewage treated.

Just prior to World War II and during World War II attention was directed towards increasing the performance of biological filters.

Inland local authorities in South Africa favoured the use of biological filtration as opposed to the activated sludge method for a number of reasons, viz. – (1) Biological filters were considered not so susceptible to the influx of adverse industrial wastes as was the case with the activated sludge process; (2) Due to the attitude of the South African public, occasioned by the olfactory effect of the dry climatic conditions, smell was an emotive factor that could not be disregarded. This being so, surface aeration methods were considered as possible sources of aerial pollution.

At the Bruma Sewage Purification Works (now non-existent) in Johannesburg, some fifty years ago (1931 – 1932) under the direction of Hamlin and Wilson large pilot plants operating on the "Diffused Air", "Hartley Spiroflow" and "Simplex" systems of aeration indicated that it was possible to overcome the odour nuisance using the diffused air method of aeration. However, this process did not meet with entire favour – at the time – due to the economic disadvantage of operating compressors at (6 000 ft.) 1 829 metres above sea level *vis-à-vis* the ready availability of suitable media for filters and the simplicity of operation of filters for the work-force available.

A disadvantage of biological filters in South Africa, depending on locality, is the growth of filter flies (*Psychoda alternata* and *Psychoda severenii*) which, however, can be controlled.

In the past decade there has been a swing towards the activated sludge method of sewage purification since by creating anaerobic zones and zones of reduced and increased aeration in an activated sludge plant it is possible to reduce the content of nitrogen and phosphorus in the final effluent thereby reducing the drawback of eutrophication in impoundments into which the effluent finally flows.

Notable examples of mode-alteration in the activated sludge process to eliminate phosphate and nitrate are those implicit in (1) the "Bardenpho" and "Phoredox" processes of J.L. Barnard; (2) the method of Roberts and Kerdachi at the Umhlatuzana sewage works of the Pinetown (Natal) municipality where, by constant attention to dissolved oxygen concentrations in the single aeration basin of the activated sludge plant using oxygen probes controlling aerator sequences, anaerobic, anoxic and aerated zones are created; (3) the large plant operations of the Johannesburg City Council at its Northern and Goudkoppies works operating in conformity with the *modus operandi* suggested by Professor Marais of Cape Town University; (4) Large plants operating on the Bardenpho process at the Pretoria City Councils' Onderstepoort Sewage Purification Works and the new Durban abattoir at Cato Ridge – run by the South African Abattoir Corporation.

Other large activated sludge plants attempting to reduce phosphate in the effluent are those of the Pretoria (Daspoort) Sewage Works and the Roodepoort City Council.

In the United States the "Phostrip" method has been used for nutrient removal.

Whether all these attempts with mode alteration of the activated sludge process will produce an effluent which will meet with the phosphate requirement of 1 mg P/ℓ called for in the Water Act is, at this stage, an open question, though success has been achieved in a number of cases notably those of Johannesburg.

However, Boksburg Municipality, at the Vlakplaats Sewage Purification Works, operating a large biofiltration plant working on gravity-feed has been able to control the phosphate concentration in the effluent by chemical means.

Other methods aimed at improving the performance of the activated sludge method have been by the addition of iron salts as in the Guggenheim Process in the United States; addition of marl tried out by O'Shaugnessy at Birmingham (England); and the addition of iron and aluminium salts and of methanol to reduce the amount of nutrients in the final effluent.

However, these are more in the nature of palliative procedures to overcome the eutrophication and activated sludge settling problems rather than true modifications of the process.

Nevertheless, ingenuity has been shown in recent years in methods of applying the process as is evidenced by the Pasveer Ditch and Huisman (orbal) methods.

Package Units

To cater for small communities and other conurbations e.g. construction camps, caravan parks, hotels, factories, office blocks, compounds, underground in mines as well as temporary expedients for new developing suburbs of towns where sewerage facilities are not available, package units have been installed. Some are so constructed (in metal) as to be used in new situations.

Package units are usually of the extended aeration activated sludge type. However, package units using biofilters have also been used but to a very much less extent.

Extended aeration activated sludge methods have not been confined to package units and plants of up to 2 250 m^3 per day capacity have found favour in South Africa. The system is meant to handle raw-screened-detritus-free sewage hence the need for the extra-long period of aeration necessary. The surplus activated sludge can be disposed of on drying beds or in lagoons.

Recent Developments

A great deal of attention has been paid by research workers in the last five years or so to optimizing the activated sludge process.

In many cases recourse has been had to modeling for both process design and process control. A substantial amount of work sponsored by the Water Research Commission has been carried out by Ekama and Marais at Cape Town.

Marais has made significant contributions for some years in applying mathematical considerations to aerobic purification processes. One of the first to apply mathematics to sewage purification processes was Professor G M Fair (originally from South Africa) who, together with C Imhoff of the Ruhrverband in Germany was more concerned with sludge digestion (i.e. anaerobic processes).

Today automation has made great advances and provided a model can be developed for a particular sewage works automatic control of the plant based on the model is possible.

However, an alternative procedure might be to aim at "standardizing" the influent in large storage tanks and arranging for this to be fed to a less sophisticated plant at a uniform rate.

Automation of plant, of course, ensures against the untoward effects of strikes by workers in strike-ridden countries. However, it is well to remember that even a simple automatically-raked bar screen at the entrance to a sewage works can be put out of action by a large object such as a stone or by a collection of textile material arriving at the screen.

For sewage purification to become an exact science the extent of the processes involved must be capable of exact measurement by a definite parameter.

At present sewage purification may be regarded as

a normative science – far advanced from its position before 1868 but endeavouring to aspire to that of a true science.

Patents

As methods of treatment progressed so we find that patents were taken out by inventors in a number of countries.

Early patents were taken out for the preparation of portable manures from sewage. As percolating filters developed we find patents being taken out for different types of filters and for variations of the activated sludge process; as well as various hook-ups of processes, both aerobic and anaerobic. This leads one to inquire whether registration of such patents is in the best interests of a developing science and ratepayers throughout the sewered world.

British Patent Law:

In dealing with the origins of the patent system, Brett[30] recounts –

"In 1565 Jacobus Acontius was granted a monopoly by letters patent for a 'grinding machine' on the grounds that, – nothing is more honest than that those who by searching have found out things useful to the public should have some fruit of their rights and labours as meanwhile they abandon all other modes of gain, and are at much expense in experiments, and often sustain much loss".

In terms of the United Kingdom Patents Act 1977 it is required that these conditions must be satisfied; these are that the invention must, –

(a) be new
(b) involve an inventive step, and
(c) be capable of industrial application.

The Patents Act of 1977 provides for a unified system of appeals and the establishment of a Patents Court with High Court status.

The Act also aims to reflect the requirements of the European and other International Patent Conventions.

South African Patent Law:

According to Gerntholtz[31] British patent laws have influenced South African patent law.

Webster,[32] dealing with "Patents, Trade Marks and Designs in Africa" as set out in Patent Act No. 37 of 1952, as amended by Act No. 28 of 1953 and Act No. 50 of 1960, states that –

"To be patentable an invention must be a process, machine, manufacture, composition of matter, or an art, whether producing a physical effect or not. The invention must be useful, new and not obvious. Certain new and distinct varieties of asexually reproduced plants, not tuber propagated are patentable . . ."

"Novelty is negatived by:

(a) Prior knowledge or use in South Africa by others, secret knowledge and secret user not on a commercial scale being excluded;
(b) prior marking in the Republic otherwise than for reasonable technical trial or experiment by the applicant or anyone from or through whom he derives his title;
(c) disclosure in a South African patent specification not more than fifty years old;
(d) a prior publication of which there was a copy in South Africa at the application date;
(e) a prior *printed* publication even if it was not available in the Republic, but only if it was published less than fifty years before the application date; and
(f) a claim in a South African patent specification which was not yet open to inspection at the application date but bears a prior date [section 1 (ix)].

There is no examination as to novelty, except in the case of plant patents".

United States Patent Policy:

The United States Constitution provided for the prompt establishment by Congress of a method for the protection of intellectual property. Patents are property. They are tangible forms of intellectual ideas and concepts that can be bought, sold, leased, and, most important of all, used.[33]

To control the use of patents, a variety of patent policies has been devised during a period of some 200 years.

Schimmel[34] states, "Patents are granted only for inventions in machines, methods, manufactures, composition of matter, designs and asexually produced plants. An invention to be patentable must be novel, useful and unobvious . . ."

He states further, – "The belief held by many that an inventor has an exclusive right in his invention is a fallacy. Independent of statute law, no such right exists. While an inventor may enjoy that right as long as he keeps his invention secret, the moment he discloses it by making and selling that which is invented, he abandons his exclusive right . . ."

A significant feature of the United States attitude towards patents is that the protection of intellectual property by the procurement of enforcement of enforceable patents encourages industry to develop new technology, thereby stimulating sales, profits, the economy and the creation of new jobs.

The American patent system is said to have been "the primary factor in making the United States the foremost nation in agriculture, manufacturing and inventing".[35] The United States Patent Office operates a vigorous examination system thereby affording protection to an inventor. Unfortunately, in South Africa the grant of a patent is only permissive and requires to be upheld in a Court of Law should the patent be infringed.

Before accepting the representations of agents of any "new" or patented methods in the sewage purification field it is well to delve into the literature, old books and other old publications in the discipline since it may be found that someone, somewhere, sometime has thought of the same idea, though, perhaps, in a different context leading on to the thought "that there is nothing new under the sun" and what seems new is but something old dressed up anew.

Notwithstanding we should be guided by the American experience!

REFERENCES

1. Pearse, L. "Functional Outline of Processes of Sewage Treatment" – in "Modern Sewage Disposal", Anniversary Book of the Federation of Sewage Works Associations, Langdon Pearse, Editor, New York, 1938.
2. Adrian, A.D. Royal Commission on Sewage Disposal, 1898, First Report, Evidence 22 June 1898, H.M. Stationery Office, London 1901, pp. 1-2.
3. Adrian, A.D., Loc. cit. p. 2.
4. Royal Commission on Sewage Disposal, 1898, Fourth Report, Part I General Report, H.M. Stationery Office, London, 1904, pp. 33-34.
5. Mueller, Landwirthsschaftliche Versuch-stationen, XVI, 273.
6. Emich, Chem. Zentralblatt, 1885, 333.
7. Garner, J.H. "Trans. Internat. Conf. Sanitary Science, London, 1924, p. 204 et seq.
8. Adeney, W.E. Royal Commission on Sewage Disposal, Fifth Report, Appendix VI, Section 1, H.M. Stationery Office, London, 1908, pp. 5-109.
9. Adeney, W.E. "Principles and Practice of the Dilution Method of Sewage Disposal, Cambridge University Press, 1928.
10. Adeney, W.E. Ibid, pp. 37 and 39.
11. Martin, A.J. "The Sewage Problem – A Review of Evidence Collected by the Royal Commission on Sewage Disposal", The Sanitary Engineering Co. Ltd., London and D. van Nostrand Co., New York, 1905, p. 61.
12. Martin, A.J. Loc cit.
13. Barwise, S. "The Purification of Sewage", Crosby Lockwood and Son, London, 1899, pp. 91-92.
14. Hodgson, H.J.H. "Sewage and Trade Wastes Treatment – in America, Great Britain, Holland and Germany, Government Printer, Adelaide, Australia, 1938, pp. 523-526.
15. Rafter, G.W. and Baker, M.N. "Sewage Disposal in the United States", D. van Nostrand Co., New York, Sampson Low, Marston and Co. Ltd., London 1900, pp. 207-208.
16. Garner, J.H. Ibid.
17. Garner, J.H. Loc. cit.
18. Rideal, S. "Sewage and the Bacterial Purification of Sewage", The Sanitary Publishing Co. Ltd., London, John Wiley and Sons, New York, 1901, p. 181.
19. Kinnicut, "The Purification of Sewage by Bacterial Methods", J. New England Water Works Association XV, 2.
20. Ardern, E. and Lockett, W.T. "Experiments on the Oxidation of Sewage without the Aid of Filters", J. Soc. Chem. Ind., 1914, **33** (10). c.f. also "Symposium on the Evolution and Development of the Activated Sludge Process of Sewage Purification in Great Britain", J. and Proc., Inst. Sewage Purif., 1954, Part 3.
21. Garner, J.H. Loc. cit.
22. Croghan, E.H. "The Evolution of Modern Sewage Disposal", Trans. Proc. S. Afr. Soc. Civil Engnrs., 1933.
23. Dunbar and Calvert, H.T. "Principles of Sewage Treatment", Charles Griffin and Co. Ltd., London 1908, pp. 223-227.
24. Dekema, C.J. and Murray, K.A. "Deep Enclosed Artificially Ventilated Filter Beds v. Ordinary Open Filter Beds – A Comparison under Working Conditions", J. and Proc., Inst. Sewage Purif., 1942, 311-317.
25. Dekema, C.J. and Murray, K.A. Ibid, pp. 318-326.
26. Mills, E.V. J. and Proc., Inst. Sewage Purif., 1945 (2) 35-49.
27. Mills, E.V. Loc. cit.
28. Jenkins, S.H. J. and Proc., Inst. Sewage Purif., 1945 (2) 51.
29. Mills, E.V. J. and Proc., Inst. Sewage Purif., 1945 (2) 105.
30. Brett, H. "The United Kingdom Patents Act 1977", ESC Publishing Limited, Oxford, 1978, p. 1.
31. Gerntholtz, R.O.P. "Principles of South African Patent Law and a Comparative Reference to German Patent Law", Juta and Co. Ltd., 1971, p. 8.
32. Webster, G.C. "Patents, Trade Marks and Designs in Africa", Juta and Co. Ltd., 1961, p. 60 et seq.
33. Marey, W. A.C.S. Symposium Series 81, 1978, Washington, D.C.
34. Schimmel, A.C.S. Advances in Chemistry Series 46, 1964, Washington, D.C.
35. Perry, J.H., Editor-in-Chief "Chemical Engineers Handbook", McGraw-Hill Book Company, (First Edition).

Chapter 2 HISTORICAL DEVELOPMENT OF SEWAGE DISPOSAL METHODS IN SOUTH AFRICA

Introduction

In many countries pit privies, bucket sanitation systems and septic tanks have been used for the disposal of human urine and faecal wastes. On the other hand the disposal of wastewater from kitchen sinks, ablution rooms and from the washing of clothes, scrubbing of floors, etc. (collectively referred to as "slop water" or "slops") has been disposed of by the agency of French drains or soak-aways and absorption on land by irrigation; and when combined with human body egesta, by cesspool or septic-tank systems. In this respect South Africa was no different from other countries.

As towns developed, particularly in the inland areas, the bucket system was used. This meant providing sanitary lanes in townships to facilitate the late-night collection of full buckets and the delivery of empty, sterilized buckets to sanitary closets abutting on such sanitary lanes. This involved a local authority in the maintenance of a large work-force of sanitary labourers which effected deliveries at night by means of mule-drawn transport vehicles. Usually the clean as well as the used, empty buckets were carried on mule-drawn carts and the sanitary pail contents in specially designed tanker-carts drawn by mules.

This system worked reasonably well, provided the closets were of satisfactory construction, positioned with their back-flaps next to a sanitary lane well away from dwellings, the buckets kept sterile and ingress and egress of flies prevented. However, it was not convenient for residents, particularly in wet or otherwise inclement weather. Also, it meant that the Medical Officers of Health had to pay particular attention to prevent the spread of typhoid/enteric fever and certain other intestinal diseases which could be spread by the domestic/house-fly (*Musca domestica*).

Sanitary-pail contents were, and in certain poorly endowed communities still are, disposed of at depositing sites in deep trenches with continuous coverage of earth. However, when the layer of earth cover over the so-called "night-soil" is not great, infestation by rodents can occur.

In Durban it has been recorded that in 1902 – 1903 in the outer or suburban zone, including one half of the houses on the Berea, no slop water or bath water was collected – these were disposed of on the premises.

In some 293 houses (having 410 pails) where in each case there was at least half an acre (0,2023 hectare) of ground, garden burial of night-soil was resorted to. For this purpose the Durban Council employed 10 Calcutta or Madrassi coolies, who were supervised by a sirdar. Each man was said to be able to deal with the pail contents of 30 houses per day. The procedure adopted was to dig a hole in a secluded part of the grounds, to mix the pail contents with earth and to cover them with at least 12 inches (30,48 cm) of earth.

As multi-storey buildings developed in towns it became a problem to devise suitable arrangements for maintaining hygienic bucket systems and so we find that in a town – such as it was then – Johannesburg had to consider the installation of a suitable waterborne system of sewage disposal for the town centre.

In dealing with the history of sewage disposal in South Africa, Hamlin and Wilson[1] in 1951 considered that the development of sewage disposal fell into three distinct periods, viz. – (a) 1898 – 1915; (b) 1916 – 1935 and (c) 1936 to that date (1951). With this we can agree, but to bring the history up to date there must be, of course, (d) the post-World War II period up to the present.

Period 1898 – 1915

Hamlin and Wilson considered that the first step on the path of sewage disposal in South Africa was due to the introduction by Donald Cameron of Exeter, of the septic tank.

Note: Donald Cameron, City Surveyor of Exeter in 1895, introduced his "septic tank" process for the treatment of a portion of the sewage of Exeter. The number of contributors was of the order of 1 500 – 2 000 on the combined system of sewerage with a daily flow of about 50 000 gallons (227 cubic metres).

The watertight tank was buried in the ground and the arched top covered with turf. Raw sewage, without screening, was allowed to enter the septic tank 5 feet (1,52 metres) below the surface of the contents in the tank to ensure quiescent entry and to prevent entry of air or escape of foul air or gas.

After passing through a grit chamber 10 feet (3,04 metres) deep by 7 feet (2,13 metres) long and of the same width as the tank (18 feet) (5,48 metres), the sewage flowed over a submerged wall rising to a height one foot (0,305 metre) below the surface of the liquor in the tank and thence into the main portion of the tank which was 56 feet 10 inches (17,32 metres) long, 7 feet 6 inches (2,28 metres) deep and 18 feet (5,48 metres) wide with a capacity equal to about one day's supply of sewage, 53 800 gallons (2 445 cubic metres). The average retention time was about 24 hours.

The septic tank method of sewage treatment was installed by the British military authorities at various military camps in South Africa.

The first Municipal Scheme planned in South Africa was designed by Thomas Stewart for Wynberg (Cape) in 1898. This consisted of septic tanks, percolating filters and land treatment. The final effluent found its way into Princes Vlei which overflowed to discharge into the sea in False Bay. However, due to the Anglo-Boer War, construction of the scheme only started in 1902 and sewage arrived at the works only in January 1905.*

However, the first Municipal scheme to be put into operation in South Africa was that designed by the City Engineer of Bloemfontein (O.F.S.) for this capital city of the Orange Free State. Designed in 1901, construction work commenced in 1904 and sewage arrived at the works in November 1904, some two months ahead of the Wynberg works. This scheme consisted of septic tanks, primary and secondary filters, followed by irrigation of 246 acres (99,6 hectares) of cultivated land.

Subsequently, other inland towns, notably Pietermaritzburg (Natal), Johannesburg and Pretoria (Transvaal), became interested and actions were taken by these local authorities to deal with the disposal of their respective sewages.

Water-carriage System Proposed for Johannesburg 1902

Arising from the instructions of the General Purposes Committee and the Public Health Committee, the Medical Officer of Health reported[3] on August 27, 1902 on the adoption of a water-carriage system for the urbanized districts. The Medical Officer of Health's recommendations were based on the grounds, (1) that a sewerage system would have to be provided for the removal of slop water; and (2) there was abundant evidence that in communities served by pail closets, the incidence of enteric fever and similar diseases was, as a rule, very much greater than in communities served by the water-carriage system.

The Town Engineer subsequently submitted reports on December 9, 1902 and February, 1903 embodying his proposals for the "Disposal of Sewage" and "Sewerage and Stormwater Drainage".

Subsequent to this, one of the councillors, Mr D C Greig, proposed that the sewage should be treated by chemical precipitation as done by the City of Glasgow at that time. However, evidence was adduced to show "that a well-conducted sewage farm need occasion no nuisance". On the other hand, it was argued that chemical precipitation did not result in an effluent satisfying the purity required by an inland town.

Early in October 1903, the Town Engineer submitted a report on two alternative sites for a sewage farm. As the site selected was beyond the Municipal boundary, it was found necessary to advertise for objections to the use intended and a "Government Enquiry" was held to hear objections which might be raised.

Drainage Sections: Due to the topography of the Municipal Area, the town was divided into sections for drainage purposes.

In planning Johannesburg's first sewerage scheme, it was noted that the south-western district constituted the most thickly populated Municipal Area and consequently this area received the greatest attention as far as sewerage was concerned. By June 30 1906, it was reported that contracts were well in hand for the construction of the sewerage system to deliver sewage to the Klipspruit farm.

Sewage Disposal: The Main Outfall Sewer to Klipspruit was some 14,5 kilometres long. The area of the farm as purchased in 1904 was 2 642 acres (1 069 hectares).

The outfall sewer was completed and sewage was delivered at the farm in November, 1907. Initially, the raw sewage was disposed of by broad irrigation. However, in March 1908, complaints of smell nuisance were received from Messrs Herrington and Ainsworth. An action for damages was brought by Herrington in 1909. The case was heard before Mr Justice Bristowe in the High Court in June, 1909. Herrington's claim for damages failed but the Court granted an interdict against the Municipality. The interdict was suspended to May 31, 1910 to enable the Council to take steps to abate the nuisance.

Following this court judgement, the Town Engineer and Medical Officer of Health made the following recommendations:-

(1) That a properly qualified and experienced Manager be appointed. His duties to be defined in writing and to include:
   (a) the gauging and recording of the flow of sewage;
   (b) keeping the statistics with regard to the areas under irrigation;
   (c) keeping of meteorological and other observations;
   (d) the keeping of an Official Diary;
   (e) the control of the effluent from the Native Wash site at Klipspruit; and

*Morris[2] has stated that the Wynberg Sewage Purification Works was a failure as it became necessary to revert to broad irrigation.

(f) the responsibility for proper observations being taken during the night.

(2) That the farm be securely fenced round to prevent trespass and damage to the sewage carriers, with consequent overflow and possible nuisance.

(3) (a) That the whole of the irrigable portion of the farm as well as those parts below the treatment area, viz. – 1 580 acres (639 hectares) be ploughed with as little delay as possible and thereafter reploughed as often as required.

(b) That reploughing be carried out to such an extent that an ample sufficiency of ploughed land is in constant readiness for the sewage to be dealt with.

(4) That the 600 feet (183 metres) tree belt between the lower boundary of the land under irrigation and the lower boundary of the farm be carefully preserved and kept ploughed in such a manner as will best guard against the possibility of overflow of sewage; and that a belt of blue-gum trees, about 100 feet (30,5 metres) wide, be planted along the boundaries of the farm.

(5) That during irrigation, four-fifths of the land should be at rest and one-fifth under sewage.

(6) That the carriers be completed and the main carriers increased in size.

(7) That detritus chambers and continuous sedimentation tanks be constructed without delay.

(8) That outlet pipes with wooden plugs be inserted at suitable points in the carriers to facilitate effective distribution of the sewage on the land.

(9) That catchwater drains be cut to prevent stormwater from the higher ground flowing over the ploughed areas.

(10) That intercepting drains be constructed within the sewage-irrigated area near its lower boundaries and above the 600 feet (183 metres) belt in such a manner as to receive and discharge on to the reserve land any accidental overflow of sewage.

(11) That in view of the finding of the Royal Commission on Sewage Disposal, 5th Report, pp. 29-30, that two or three grains of lime per gallon (approx. 30-40 milligrams per litre) be added to the tank liquor to reduce the amount of suspended solids and the offensive character of the liquor.

(13) That osiers and other suitable grasses be grown, especially in the lowlying parts where there is considerable moisture, as well as, under suitable conditions, may be considered advisable, always on the understanding that the innocuous disposal of the sewage is the first essential function of the farm and is not to be made secondary to agricultural considerations.

(14) "That in order to facilitate efficient future working, it should be clearly laid down that the Farm Manager is primarily responsible to the Town Engineer . . .".

These recommendations ended with the statement that "it must be made clear to Mr. Spencer" (the recently appointed Farm Manager) "that agricultural considerations must be made secondary to the proper disposal of sewage."

It will be noted that despite the Council satisfying the Court with the above practicable and reasonable recommendations that difficulties arose from seepage some 30 years later (cf. the case Jerolim Vucinovich vs. Johannesburg City Council, May 1 1939, dealt with in chapter 11 entitled "Discharge of Purified Effluents into Watercourses").

The original proposals for dealing with sewage arriving at Klipspruit called for the construction of screens, detritus tanks and septic tanks and the effluent from the septic tanks to be irrigated over 1 000 acres (405 hectares) of land. But the detritus tanks and septic tanks were not installed. Added to this the "night-soil" from mines* in the area was discharged into the main outfall sewer.

On arrival at Klipspruit, on average the flow consisted of 47 per cent normal sewage, 33 per cent highly concentrated septic "night-soil" and slops plus some 20 per cent infiltration water. By 1928 the average flow was 5 million gallons (22 730 cubic metres) per day and no additions had been made to the works save Travis tanks† installed after the first two years of operation. These were quite inadequate for the duty they were called upon to perform. It is not surprising, therefore, that odour problems eventuated at Klipspruit!

Pietermaritzburg Commissions a Sewage Disposal Works (1908)

F. Walton Jameson designed a sewage works for Pietermaritzburg which consisted of screens, hopper-bottomed sedimentation tanks, percolating filters and separate sludge digesters. The filter-bed effluent was to be disposed of by irrigation on land.

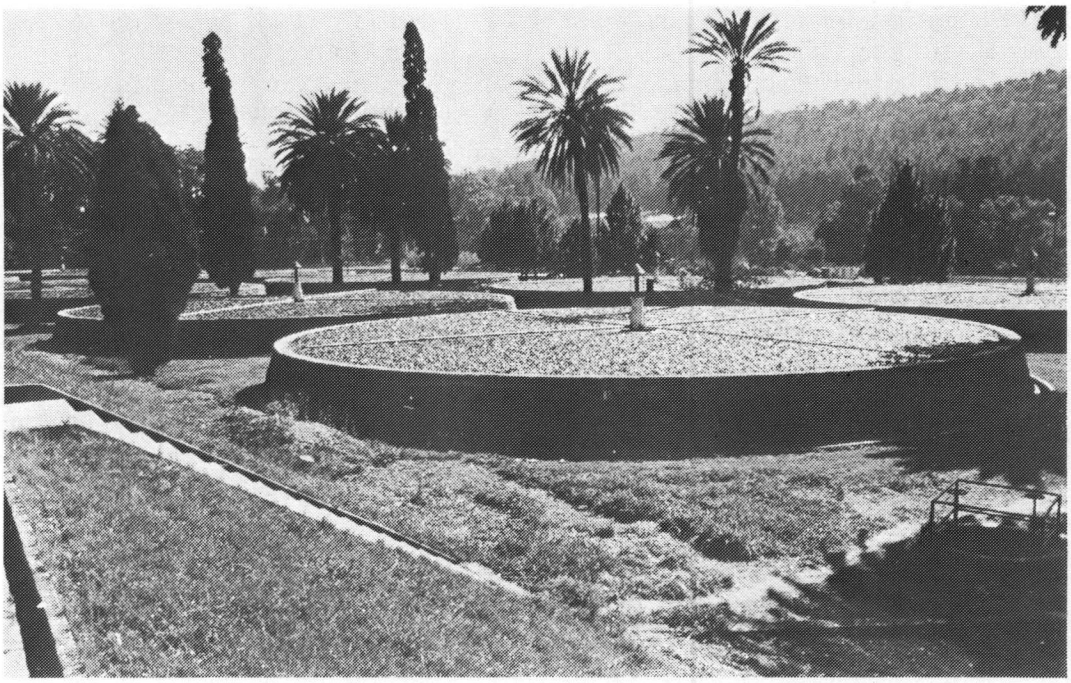
**Mines Sanitation:* It was reported by a special inspector for mines sanitation on 3rd September 1904, that there were 35 operating mines within the Johannesburg municipal area. "Night-soil" from the mines came from two sources, viz. –

(1) Surface dwellings of white employees and compounds provided for Black mineworkers;

(2) From underground.

In the early days disused drives, stopes and other old workings did duty as sanitary conveniences. However, in 1904 pail closets were provided at suitable and convenient points on each working level and special sanitary workers brought the contents of the pails to the surface for disposal.

†Travis patented his sedimentation tank in 1891 and use was made of this so-called hydrolytic tank at Hampton in 1903. Like the Imhoff tank it combines the processes of sedimentation and digestion of sludge in one structure.



Daspoort, Pretoria: Original biofilters

This works was significant in that it was one of the earliest works incorporating separate sludge digestion based on the precepts of O'Shaughnessy's work at Birmingham (England).

Before the commissioning of the Pietermaritzburg works Walton Jameson moved to Pretoria as City Engineer for which local authority he designed a sewage purification works in 1910. Unfortunately, after his departure from Pietermaritzburg the works he had designed became derelict and the city disposed of its sewage, after preliminary screening, by broad irrigation.

Pretoria's Daspoort Sewage Purification Works (1910)

On coming to Pretoria from Pietermaritzburg Walton Jameson designed a sewage purification works on lines similar to his Pietermaritzburg design. The Pretoria works situated in Daspoort constituted what is now generally referred to as a conventional works incorporating screening, detritus removal, sedimentation, biofiltration (percolating filters) and separate sludge digestion.

Marshall Lundie who became the City's Biochemist took a keen interest in the operation of the plant. He had previously been on the staff of the Grootfontein College of Agriculture.

One matter that he paid particular attention to was the digestion of sludge from sewage to which "night-soil" had been added. He found that unless the sanitary pail contents were adequately washed and diluted with water it was not possible to maintain satisfactory alkaline anaerobic digestion.

Lundie maintained that unless the faecal solids were washed clear of adsorbed urine etc., digestion of the sludge at the sewage purification works was upset. He concluded from his investigations in Pretoria that "night-soil" should be washed with at least 10 volumes of suitable water before discharge into an intake leading to the sewage purification works.

Early Developments at Cape Town

Morris[4] has stated "Current water supply and sanitation problems are better understood when viewed in historical perspective. It is instructive to turn the clock back some three centuries and snatch a glimpse of conditions prevailing at the "CAAPSE VLEK" or "CAAPSE UYTHOEK", as the settlement was named for some 150 years, and then to follow the city's subsequent progress in providing these essential services".

Organized night-soil removals are not likely to have been carried out in early times at the Cape. Slaves were required to tip bucket contents into the sea and, by design or inadvertence, sanitary pail contents also found their way into the canals.

Nuisances caused by the misuse of canals for waste disposal culminated in action being taken from 1850 onwards to cover over open canals to prevent this abuse. But progress in this direction was slow.

In 1882 the Cape Town Municipality which had come into being in 1867 took over the responsibility for water supplies, slaughtering, washhouses and sewage disposal. During the period 1896 to 1910 five new reservoirs were constructed in addition to the

reservoir at Newlands constructed and maintained by the Cape Town District Waterworks Company.

Thereafter, the water supply being assured a sewage disposal system for Cape Town came into being. Prior to the installation of a sewerage system "night-soil" buckets were conveyed by train nightly to a depositing site at Bellville.

In 1895 W T Olive, a consulting engineer, was commissioned to design a sewerage system for Cape Town. Almost co-incidentally the Green Point and Sea Point Municipality introduced a waterborne sewage scheme which provided for final discharge into the sea.

In 1913 the municipalities of Cape Town, Sea Point, Woodstock, Maitland, Mowbray, Rondebosch, Claremont and Muizenberg were unified to become a greater Cape Town.

Unification accentuated sanitary problems and D E Lloyd Davies, the City Engineer, was set the task of planning a waterborne sewage disposal system for the inner southern suburbs.

From the foregoing it will be realized that during this period of time, 1898 to 1915, i.e. the period between the end of the Anglo-Boer War and the start of World War I, only 5 sewage disposal schemes had been put into operation for inland local authorities, viz. – Bloemfontein, Wynberg, Johannesburg, Pietermaritzburg and Pretoria.

However, during this period sea outfalls had been constructed at Cape Town (Green Point and Sea Point), Muizenberg, and Kalk Bay.

Durban Converts to a Water-carriage System (1894)

Durban was proclaimed a borough in 1854 and became a city in 1935. Up to 1887 Durban was less important than Pietermaritzburg,[5] the latter being the capital of the Colony. Today the reverse is the case and whilst being a very important seaport, Durban has many established industries.

In the early days water was obtained from wells but, in due time, a number of river water supply schemes came into being on the rivers Umbilo (1887), the Umhlatuzana (1889) and the Umlaas (1890).

With the commissioning of the Umlaas scheme in 1890 the total water supply was of the order of 5 000 cubic metres per day and this served a population of 23 724 of whom about 48,6 per cent were Whites.[6(a)(b)]

As the water supply was assured at this time consideration was given to the phasing-out of the "bucket system" of sanitation and inaugurating a water carriage system. On the recommendation of J Fletcher, the Borough Engineer and pursuant on the passing of the enabling Act in 1891, the first sewerage scheme was commissioned in 1894. The outfall sewer was constructed along the side of the North Pier. The discharge of raw sewage into the sea via this pipeline continued until 1969.

Period 1916 to 1935

On May 31 1910, the Act of Union was passed. Prior to unification the Union of South Africa, as it became, consisted of the Cape Colony, Natal, Orange River Colony and the Transvaal. Prior to Union the treatment of sewage and disposal of effluent came within the jurisdiction of the Department of Health of the individual colonies. But, now, control became vested in a Public Health Department for the whole Union.

To attain this metamorphosis the Union Health Act No. 36 of 1919 was duly passed. In terms of this Act the Chief Health Officer of the Department of Health had a heavy responsibility since he had to ensure that in the case of any sewage disposal scheme that "The best known or the only or most practicable and available methods" were being used.

This resulted in the Chief Health Officer of the Union disallowing the discharge of effluent from a sewage purification works into a watercourse. In fact, a hypersensitive attitude towards this matter resulted in the Department of Health stipulating that, in all cases, local authorities had to ensure that not less than 100 acres (c. 40,5 hectares) of suitable ploughable land were available for every million gallons treated (i.e. 112,3 cubic metres per hectare) per day.

Later the Department realized, at the time of the Vucinovich vs. Johannesburg Municipality Supreme Court Action, that where land was irrigated at the above rate seepage was likely to occur and so minimum areas of land were prescribed for different qualities of effluent up to 400 acres (c. 162 hectares) for each million gallons of sewage (i.e. c. 28 cubic metres per hectare). This requirement-schedule seems to have been based on an *ad hoc* form of reasoning wherein caution was being exercised from a health point of view – the aim being to contain all sewage liquors on a sufficiently large area of land and to prevent the escape of any polluted water to adjoining land and watercourses.

During this period (1916 – 1935) World War I took place (1914 – 1918). This resulted, *inter alia*, in the establishment of new industries with effluents to be satisfactorily dealt with. One such industry was African Products Manufacturing Company, Limited, which was established in Germiston and manufactures starch and other products from maize. Later, National Chemical Products, Limited, started production of ethyl and butyl alcohols and dry ice from molasses on a nearby industrial site. The effluents from both these industries were disposed of, initially, by broad irrigation on the nearby municipal "slop farm".

During this period (1916 – 1935) a number of local authorities commissioned sewage disposal works. These included Stellenbosch, Kimberley, Queenstown and Johannesburg.

Lloyd-Davies designed a sewage purification

works for Cape Town which was commissioned in 1921. It consisted of screens, Imhoff-type tanks, brushwood percolating filters and humus tanks. The settled effluent from the humus tanks was irrigated on land. Digested sludge from the Imhoff-type tanks was dried on drying beds and used as a fertilizer on the sandy Cape Flats area.

E H Croghan was appointed Biochemist in charge of the works in 1924.

The brushwood filters were not considered to have been a success.

It is significant that by 1932 E J Hamlin had been appointed Assistant City Engineer of Johannesburg with responsibility for sewerage and sewage disposal matters while H Wilson had been appointed as City Biochemist.

Hamlin had transferred from Stellenbosch where he had designed the sewage purification works and H Wilson who had previously been in the employ of Reading (England) and Wolverhampton and was familiar with the activated sludge process developed by Ardern and Lockett at Manchester.

Much of the progress which eventuated in the period 1936 to 1951 was catalysed by the enthusiasm, energy and dedication of these two men who, later, were responsible for the inauguration of the Southern African Branch of what was then the Institute of Sewage Purification and later became the Institute of Water Pollution Control.

By 1932 Johannesburg had three new sewage works in operation in addition to the original Klipspruit works thus making a total of four. These new works were the Antea, Bruma and Cydna works. A further works which was given the name Delta was in the planning stage.

The Antea, Bruma and Cydna works were biofiltration plants. The Antea and Cydna works had circular filter beds with rotating sprinklers, whereas at the Bruma works aerobic purification of sewage was effected by means of rectangular filter beds with automatic mobile sprinklers operated by waterwheels. These beds at Bruma were similar to those in use at Birmingham by the Birmingham Tame and Rea District Drainage Board. H T Clausen, who had been appointed Superintendent of Sewage Disposal Works for Johannesburg had had previous experience with the Board in Birmingham.

At Bruma from 1932 onwards much valuable investigational work was done particularly with regard to the activated sludge process which was proposed for the final Delta sewage purification works.

Three experimental activated sludge plants were started up during October 1933, viz. – Diffused Air, Hartley Spiroflow and Simplex plants. Difficulties were experienced with bulking of activated sludge due to the growth of filamentous bacteria. Also the two mechanically aerated plants, Simplex and Hartley Spiroflow, gave rise to unpleasant odour. This was not the case with the diffused air plant, provided sufficient aeration was maintained.

Arising from these investigations over a period of 8 months operation work was started in 1933 on the construction of the Delta works. This works was provided with a diffused air activated sludge plant, a ventilated sedimentation tank building, with ozone treatment of the extracted air before discharge to the air environment outside.

Croghan[7] has stated that he "was instrumental in having completed in May 1930, at the sewage disposal works of the southern suburbs of Cape Town, an experimental activated sludge plant". The plant, he averred, "represented the first introduction to South Africa of this modern feature of sewage plant design".

On the other hand Wilson[8] was of opinion that the first activated sludge plant to be commissioned in South Africa was at the Boksburg-Benoni Hospital in Boksburg. This plant, unfortunately, was not allowed to work satisfactorily as disinfectants and discharges from the operating theatre, etc. were allowed into the drains leading to the works and this, according to Wilson – whose advice had been sought to improve the performance of the plant – resulted in a die-off of the organisms essential for the activated sludge process.

Period 1936 – 1951

During 1936 a number of new sewage purification works were in the offing. A new works for treating the combined sewage from Germiston and Boksburg was designed by A Kinmont (later to become City Engineer of Durban and later still, a Chief Adviser to the Water Research Commission in Pretoria). This works was commissioned in 1937. A feature of the works, which incorporated an enclosed artificially ventilated filter (patented by Prüss) and an open filter placed in juxta position to one another, was the large sedimentation hall enclosing the screens, detritus channels, sedimentation tanks and sludge sumps.

At about the same time Springs Municipality commenced a treatment plant with enclosed artificially ventilated filters. But, after considering the chemical results obtained by Vosloo and O'Reilly of the municipal chemical staff and also the work of Meyling at Klipspruit on deep enclosed artificially ventilated filters Archibald, the Town Engineer, opted for open 12 ft. (3,65 metres) deep filters for future extensions.

At about this time also Benoni, Brakpan and Krugersdorp constructed conventional sewage purification works to meet their requirements.

Many of the mining companies, outside municipal areas, also installed sewage purification works and during World War II the Public Works Department and certain engineering firms constructed sewage treatment facilities at prisoner-of-war camps, air and army bases and hospitals throughout the country.

During this period Hamlin and Wilson together with their respective staffs spearheaded research and investigational work, the results of which spun-off to other centres in the country. This also led to a general sharing of ideas and experiences through meetings of the Southern African Branch of the Institute of Sewage Purification.

Hamlin and Wilson[9] maintained that organized research in the field of sewage purification in South Africa did not commence until about 1932 though they admitted that prior to this date, Lloyd-Davies of Cape Town had published the results of short trials of the performance of brushwood filters and Croghan had studied the growth of a number of crops irrigated with sewage.

Research work carried out by engineers, chemists and biologists in the employ of the Johannesburg City Council during this period, included –

(1) Comparison of an open 6 ft. (1,829 metres) deep filter with a Prüss enclosed artificially ventilated filter 12 ft. (3,65 metres) deep.
(2) The effects of temperature on purification in biological filters.
(3) The effects of depth of media, various grades and kinds of media.
(4) The ventilation of biological filters.
(5) The effect of horizontal ventilation zones on the purification by biological filters.
(6) The conversion by high pressure catalysis of sludge digester gas to methyl alcohol.

Period 1952 to the Present

During the last thirty years or so significant developments in the field of wastewater treatment and pollution control have taken place in South Africa. These include, –

(1) The promulgation of the Water Act (Act 54 of 1956).
(2) The creation of a Department of Water Affairs.
(3) The establishment of the National Institute for Water Research in 1958, followed some time later by –
(4) The Water Research Commission which has sponsored many research projects in the field of water, sewage and effluent treatment throughout the country.
(5) A country-wide adoption by local authorities of the water-carriage system.
(6) The use of pond systems for the treatment of sewage where the daily volume of sewage does not exceed 700 cubic metres.
(7) An increase in the use of the activated sludge process representing a noticeable swing from the previous preference for the biofiltration process of sewage purification using percolating filters.
(8) The introduction of composting methods for municipal organic wastes and sewage sludge, the popularity of which has somewhat attenuated.

1. The Water Act (Act 54 of 1956)

With the promulgation of the Water Act the land requirements for effluent disposal of the Department of Health fell away as purified effluents of acceptable quality were now allowed to discharge into watercourses.

However, it bacame necessary to stipulate the quality criteria required for discharge of such effluents. Consequently, "Regional Standards" for effluents were prescribed by Government Notice No. 553 of 1962. These were promulgated in terms of Section 21 of the Water Act.

Two separate standards were laid down, viz. –

(1) *Special Standard* which applies to effluents discharged into clear mountain or trout streams. A schedule of districts where these rigorous requirements apply has been set out indicating the rivers or their tributaries at any point between the source of the river or tributary and the place specified in the schedule.
(2) *General Standard* which applies to all areas of the Republic of South Africa except those specified in the schedule where conformance with the Special Standard is implicit.

The methods of testing or analysis are specified by the South African Bureau of Standards.

2. The Department of Water Affairs

This has evolved over the years from its early beginnings as the Department of Irrigation which later, became the Department of Water Affairs. Then, for a short period, with the rationalization of Government departments it merged with the Department of Forestry and the Environment Branch of the Department of Industries and was designated the Department of Water Affairs, Forestry and Environmental Conservation – a rather cumbesome title which was changed to the Department of Environment Affairs. It has reverted to its title of Water Affairs.

Naturally, with the promulgation of the Water Act in 1956, local authorities and industries were brought to a realization of their obligations to the community as far as the prevention of pollution is concerned and in order to administer the Water Act, the Department has created a multidisciplinary Branch headed by a Managing Engineer controlling a Pollution Control Division which had been upgraded from that of the Industrial Water Section of the Division of Water Utilization.

The Pollution Control Division deals with applications for the use of water for industrial purposes which, *ipso facto*, includes the use of water for sewage disposal and the disposal of effluents arising from such use.

Anyone wishing to establish an industry using water, including seawater, is required to inform the Department of Water Affairs of his/her proposals

for dealing with the effluents arising from such industry or factory.

If on average more than 250 cubic metres of public water per day or more than 300 cubic metres on any one day are to be used, it is necessary for the industry concerned to obtain a permit from the Minister of Water Affairs (Note: The Water Act has been revised and these volume limits have been reduced considerably).

There are five possible sources of water supply, viz. –

(1) A private source of supply such as a borehole;
(2) A municipal supply where the municipality is able and willing to supply the quantity of water required;
(3) A supply from a public stream or river not in a Government Water Control Area;
(4) A supply from a public stream or river in a Government Water Control Area;
(5) Where purified sewage effluent is used by an industry the supplier of such effluent requires a permit in terms of the Water Act.

From the foregoing it will be realized that, –

(1) Water is a commodity that must be wisely used;
(2) Rivers must be adequately safeguarded from pollution by effluents from sewage purification works or industries;
(3) Abstractions from and discharges into rivers are controlled.

This being so, from 1956 onwards an awareness by local authorities and industrialists of their responsibilities towards controlling the use of water and the quality of the effluents discharged became evident and coupled with this was the necessity to re-circulate purified effluents for re-use where possible.

3. National Institute for Water Research

In 1947 the Council for Scientific and Industrial Research (CSIR) created within its National Chemical Laboratory a Water Treatment Unit.

On his retirement from the post of City Biochemist in Johannesburg H Wilson was appointed, for a contract period, as Principal Research Officer to start-up this Unit and with the appointment of G J Stander as Officer-in-Charge in March 1950, Wilson was retained as Advisory Officer to the Unit.

The purpose of the Unit was to investigate the treatment of water supplies, sewage and industrial wastes. Its function also included surveys of the effects of industrial and other developments upon the quality of water supplies and related effects on plant and animal life in streams.

The unit was initially established in a temporary building on the campus of the University of the Witwatersrand, Johannesburg but later when it became the National Institute for Water Research (NIWR) it moved to a new permanent building forming part of the scientific research complex of the Council for Scientific and Industrial Research (CSIR) at Scientia, Pretoria where it has remained.

With the establishment of the NIWR the emphasis on research moved somewhat from Johannesburg to Pretoria though a great deal of reliable investigational and research work continues to be done by the staff of the Cydna Laboratory and the engineering staff of the Johannesburg City Council. In a number of instances this has been done in concert with the Water Research Commission.

4. Water Research Commission

Dr G J Stander retired as Director of the NIWR to take up a challenging position with the Water Research Commission where he became the Chairman and Chief Executive Officer. The inception and continued functioning of the Commission owes much to his energy, dedication and imaginative skill, to the extent that today it has achieved a position of prestige in the fields of water supply, wastewater treatment and pollution control.

The Commission aims to identify problems in particular fields which are of national concern and having identified them, with the counsel of interested bodies and experienced persons, sponsors scientific investigation of such problems by selected teams of research workers and publishes their findings.

In order to disseminate information concerning its work it circulates the "SA Waterbulletin" – a "News Letter" and publishes regularly original research papers in its publication "Water SA" which has established itself as a journal of standing in this field of water research.

The Commission has sponsored a great deal of work on the removal of nutrients from sewage purification works effluents to overcome the problem of eutrophication of water impoundments. Also a great amount of effort has been devoted towards practicable means which may be used for containing the progressive increase in salinity of certain rivers, in particular, the Vaal River, the water of which is impounded by the Rand Water Board and is supplied to the Witwatersrand.

The Commission has also sponsored work in connection with the marine disposal of sludge in Durban, and the treatment and disposal of a number of industrial effluents including effluents from the textile, tanning and food processing industries.

The Commission has also given particular attention to eliminating pollution from mining operations which has included research on the desalination of pumped mine water.

5. Adoption of the Water-carriage System

There has been a complete trend away from bucket sanitation. Some of the smaller communities have installed sewerage systems and have employed oxidation pond systems for treating sewage.

In some cases where the community is financially

unable to sewer a town resort is had to sewering the more densely populated area(s) (e.g. the town centre) and enjoining residents of the less densely populated areas to provide conservancy tanks which are emptied by municipal tanker services, in which case the sewage is transported to the sewage treatment facility which may take the form of an oxidation pond system or extended aeration activated sludge plant.

On the other hand a tanker service alone may be used. Tankers may be specially constructed, motorized tanker units with high-rate pumping equipment or simple tractor-drawn tankers. Usually a tanker service is provided for households at regular intervals (e.g. 1 month) or on call by the householder.

Eventually a stage is reached where it is more economic and desirable to dispense with a tanker service and to install a complete sewerage system for a town. But, in doing so, a point to consider is whether the costs involved can be incurred without prejudice to the ratepayers of a town who may or may not be in a position to face-up to the increase in rates such a change would entail.

In isolated situations householders provide their own sanitary systems in the form of septic tanks[10,11] coupled to french drains. However, it will be realized that such a set-up can only be satisfactorily employed on large stands. Medical Officers of Health in suburban communities usually disallow such a system on land of less than 0,405 hectare (1 acre) in extent.

A combination of septic tank plus bio-disc ("rotating disc") unit[12] has proved satisfactory for dealing with the sewage from institutions, office blocks, holiday camps, etc. In this type of hook-up the overflow from the septic tank is treated by the bio-disc unit to give a satisfactory effluent. This type of combination also has the advantage of not giving rise to unpleasant odours and, also, does not give rise to noise. The septic tank, of course, has to have a portion of the digested sludge removed from time to time.

The bio-disc unit can be covered. This makes it less subject to the vagaries of the weather affecting its performance.

6. Pond Systems

Pond systems have been the subject of much research by scientists of the NIWR notably Meiring, Drews, van Eck and Stander.[13,14]

When viewing this method of sewage purification in a facile way the impression created is that a pond system represents a cheap method of sewage purification and disposal both from the point of view of construction costs and, also, running costs.

In practice it has been found that such a system, no matter how well designed, is not capable of producing an effluent of General Standard quality throughout each year and it becomes necessary to utilize the effluent for irrigating timber trees or crops such as lucerne. In which latter event the Department has the requirement that such lucerne must be dried thoroughly before feeding to animals.

Oxidation ponds should not be situated near residences and must be adequately fenced off to prevent the entrance of unauthorized persons, or animals. It is also desirable to enclose the pond area with a belt of evergreen trees. (e.g. fast growing eucalyptus varieties). This is necessary to prevent the dissemination of odours and also to absorb any seepage from ponds which are not watertight due to faulty construction.

Pond systems are usually located well outside the built-up area of a town.

7. Swing from Biofiltration to Activated Sludge Treatment

During the early days of sewage purification in South Africa it was considered wise to select a site for a sewage purification works such that the sewerage system and such works could be operated entirely on a gravity flow system.

However, pumping is now resorted to both in the sewerage system and at sewage purification works and so, due to the ready availability of electric power at reasonable cost the activated sludge method of treatment has received more favour.

The National Institute for Water Research (NIWR) has carried out research work on extended aeration activated sludge methods of treatment.[15,16]

Barnard[17] has reported on methods for the removal of nutrients in activated sludge units. Due to his efforts in this direction a great deal of interest has been generated in the use of activated sludge methods to prevent eutrophication of impoundments.

A great deal of interesting work on large-scale operating activated sludge plants has been reported by Osborn[18] and members of the staff of the Cydna Laboratory of the Johannesburg City Council.[19(a)(b)(c)(d)]

The extended aeration activated sludge method of treating sewage first came into prominence in South Africa in the form of "package units" which appeared in a number of proprietary designs with various forms of aeration. Application of this method of treatment was sought by the suppliers of such plants for solving the sewage disposal problems of isolated hotels, institutions, schools, compounds, hostels, large construction projects and underground in mines.

Unfortunately, many package units, after commissioning, were not maintained in a regular and satisfactory manner and received little attention by experienced personnel. Added to this, no provision was made for the units to deal with sudden changes in the number of contributors such as occur during holiday periods, with the result that the quality of the effluent suffered and effluent of General Standard quality was not produced.

However, the possibilities of a well-run activated

sludge plant became apparent. It was realized that biological filters were capital cost-intensive to install though running costs were negligible, whilst with activated sludge the capital outlay was less whilst the running costs were greater and depended on the cost of electric power.

Owing to the relatively reasonable charges for electricity a switch to the activated sludge method was made by many local authorities including those of Johannesburg and Pretoria.

When it was found that by varying the oxygen tension in solution to create anaerobic, anoxic and aerated zones, it was possible to remove nitrates and phosphates from the system. It was considered that by modifying the activated sludge process it would be possible to discharge an effluent conforming with the new state requirement that the concentration of orthophosphate as P should not exceed 1,0 milligram per litre.

Thus, at this point in time, there has been a swing towards the use of the activated sludge process in preference to biological filters.

Whether it will be possible with activated sludge plants to meet the requirement that the phosphate content shall not exceed 1,0 milligram per litre expressed as P is not certain at this stage though it is claimed by some, including Roberts and Kerdachi, that the Umhlatuzana plant at Pinetown achieves this standard.

8. Composting of Urban Organic Wastes

In 1952 the South African Soil Association Board appointed a Committee for the Utilization of Municipal Wastes. This committee concluded *inter alia* that organic wastes economically processed to compost could make a valuable contribution towards rehabilitation of impoverished soils.

During the period 1940 – 1945 many local authorities showed an interest in composting particularly from refuse and night-soil. However, after World War II due to the increase in labour costs many operations were closed down. Also, due to a fall-off in organic compostable wastes in municipal refuse due to more modern methods of food marketing and increases in labour and transport costs, composting has fallen off in popularity except in a number of cases (e.g. Worcester and Bellville) where organic agricultural wastes are available in sufficient quantity.

P R Krige, when working at the National Institute for Water Research, made a study of overseas composting practice and during 1954 visited Europe, Great Britain and the United States and visited a number of composting plants. On his return he created much enthusiasm for the composting process. However, since his death some years ago the enthusiasm has greatly decreased.

Van Vuren[20] had shown that urban wastes could be converted into compost by the "pit" or "cell" method. Following this, Krige[21(a)(b)] experimented with a mechanized research plant which was designed with the collaboration of the NIWR and the National Mechanical Engineering Institute of the CSIR. The plant worked automatically and continuously and passed on into the plant the organic waste from which bottles, "tins" etc. had been removed and to which either "night soil" or sewage sludge was added. The compost plant consisted of a drum (32 feet) 6,7 metres long and (10 feet) 3,05 metres in diameter. This was set at an inclination of 2 degrees and rotated at a speed of 0,5 revolutions per minute. Provision was made for injecting air from a manifold to 32 nozzles placed at regular intervals around the drum. Prior to discharge the stabilized compost which spilled out at the lower end of the drum was classified by passing through a ($1^1/_2$ and $^3/_4$ inch) 3,81 cm and 1,905 cm mesh screen. The average period of detention of the mixed wastes in the drum during composting was about one week.

Cillie[22] has stated, "The performance of four different types of mechanized compost plants which are operated in the Western Cape are being evaluated by the NIWR. The indications are that a rotary drum type of stabilizer is preferable".

It should be realized that composting is an aerobic biological process and is exothermic to the extent of preventing fly breeding. The process proceeds naturally in the presence of air and of micro-organisms (e.g. obligate aerobic bacteria, actinomycetes and fungi) and a suitable substrate material, adequate aeration and the presence of moisture. However, under flooded conditions it will not operate.

During World War II, when there was a shortage of fertilizers, composting had a great deal of merit but the incentive has somewhat evanesced as fertilizers are no longer in short supply and organic wastes are now only available in sufficient supply at a few centres.

REFERENCES

1. Hamlin, E.J. and Wilson, H. J. and Proc., Inst. Sewage Purif., 1951, Part 3 pp. 243-257.
2. Morris, S.S. "Water and Waste Management in the Cape Town Metropolitan Area", Paper No. M, 1970 Conf., Inst. Water Poll. Control, p. 5.
3. Johannesburg Municipality, Report of the Medical Officer of Health for the year 1902-1903, p. 10.
4. Morris, S.S. Ibid p. 2.
5. Brookes, E.H. and de B. Webb, C. "A History of Natal", Univ. Natal Press, 3rd impression 1979, p. 158.
6. (a) Macleod, D.C. "The City Engineers Department, Durban, After 100 Years", Paper submitted to 55th Biennial Conf. Instn. Mun. Engnrs., Southern Africa, Durban, 1982, p. 4.
   (b) Kinmont, A. "The Sewage Disposal Problem in Durban", Paper presented to 1965 Conf. Inst. Sewage Purif., Durban, 4 May 1965, p. 2.
7. Croghan, E.H. "The Evaluation of Modern Sewage Disposal", Trans. Minutes Proc. S. Afr. Soc. Civil Engnrs., 1933.
8. Wilson, H. Private communication, 1934.
9. Hamlin, E.J. and Wilson, H. Loc. cit.

10. Malan, W.M. "A Guide to the Use of Septic Tank Systems in South Africa", NIWR Research Report 219, 1964.
11. Gross, E.R. "A Septic Tank Disposal System", New Jersey Agricultural Experiment Station, New Brunswick, N.J., Circular 381, December 1938.
12. Pretorius, W.A. "The Rotating-Disc Unit: A Water Treatment System for Small Communities", J. Inst. Water Poll. Control., 1973, pp. 721-724.
13. Meiring, P.G.J., Drews, R.J.L.C., van Eck, H. and Stander, G.J. "A Guide to the Use of Pond Systems in South Africa for the Purification of Raw and Partially Treated Sewage", NIWR Special Report, WAT 34, January 1968.
14. Stander, G.J., Meiring, P.G.J., Drews, R.J.L.C. and van Eck, H. "A Guide to Pond Systems for Wastewater Purification", Proc. Jerusalem Internat. Conf. on Water Quality and Pollution Control, June 1969, pp. 125-163.
15. Drews, R.J.L.C., Malan, W.M., Meiring, P.G.J. and Moffatt, B. "The Orbal Extended Aeration Activated Sludge Plant", J. Inst. Water Poll. Control, 1972, 44 (2), 221-231.
16. Drews, R.J.L.C. "Guide for the Operation of Orbal Activated Sludge Plants", NIWR Technical Guide K 36, 1976.
17. Barnard, J.L. "A Review of Biological Phosphorus Removal in the Activated Sludge Process", Water SA, 1976, **2**, 136.
18. Osborn, D.W., Pitman, A.R. and Venter, S.L.V. "A Review of Biological Phosphorus Removing Activated Sludge Plants in Johannesburg", Technology Transfer Seminar of Inst. Water Poll. Control and Water Res. Comm., Pretoria May 17 1979, pp. 60-79.
19. (a) Osborn, D.W. and Nicholls, H.A. "Optimization of the Activated Sludge Process for the Biological Removal of Phophorus", Proc. Water Tech., Pergamon Press Ltd., 1978, 10 (1/2), pp. 261-277.
    (b) Pitman, A.R., Venter, S.L.V. and Nicholls, H.A. "Practical Experience with Biological Phosphorus Removal Plants in Johannesburg", Wat. Sci. Tech., Pergamon Press Ltd., 1983, 15, pp. 233-259.
    (c) Venter, S.L., Halliday J., and Pitman, A.R. "Optimization of the Johannesburg Olifantsvlei Extended Aeration plant for Phosphorus Removal", Prog. Wat. Techn., Pergamon Press Ltd., 1978, 10 (1/2), pp. 279-292.
    (d) Nicholls, H.A. "Modification of Extended Aeration Plants in Johannesburg, South Africa, to achieve Denitrification", Prog. Wat. Tech., Pergamon Press, Ltd., 1977, **8**, (4/5), pp. 639-652.
20. van Vuren, J.P.J. "Soil Fertility and Sewage", Faber and Faber, London, 1946.
21. (a) Krige, P.R. "The Utilization of Municipal Wastes. Report on the Processing of Urban Wastes in a Mechanized Composting Plant", NIWR Research Report 211, 1964.
    (b) Nell, J.H. and Krige, P.R. "The Disposal of Solid Abattoir Wastes by Composting", Water Research, Pergamon Press Ltd., 1971, **5**, 1177-1189.
22. Cillie, C.G. "The Composting of Urban Wastes", NIWR Technical Guide K19, 1971.

Chapter 3 CHEMICAL AND BACTERIOLOGICAL ASPECTS OF SEWAGE AND SEWAGE PURIFICATION PROCESSES

1. Colloids in Sewage and the Significance of Physico-chemical Methods in the Treatment of Sewage and Industrial Wastes

Colloids

A colloidal system consists of at least two phases, namely, a *dispersed phase* (internal phase) made up of finely divided particles and the *dispersion medium* (external phase) within which the dispersed particles are distributed.

Colloids can be of the hydrophobic ("water hating") or hydrophilic ("water loving") types where water is the dispersion medium. Where a liquid, other than water, is the dispersion medium the corresponding terms are lyophobic and lyophilic. These are also referred to by the alternative names of suspensoids and emulsoids.

Zsigmondy distinguished particles according to their visibility, viz. – amicrons, submicrons and microns – where amicrons were not visible even by the aid of an ultramicroscope, submicrons were visible ultramicroscopically but not microscopically and microns were visible microscopically.

The line of demarcation between amicrons and submicrons is not a definite one since it depends on the difference between the refractive indices of the particles and of the liquid. A size-classification can only be an approximate index.

Some of the differences between these two types of colloids are as follows: Lyophobic colloids such as metal sols (e.g. gold) and arsenic trisulphide are systems wherein physical properties of the sols differ only slightly from those of their dispersion media. On the other hand, in the case of hydrophilic colloids (e.g. proteins) the properties of the dispersion medium are modified very considerably by the dispersed phase (e.g. glue) giving rise to a high viscosity.

Another distinction between suspensoids and emulsoids is that the former are easily flocculated by the addition of electrolytes whereas in the case of emulsoids a large amount of electrolyte is required – giving rise to the so-called "salting out" effect that occurs with proteins.

In the case of suspensoids the flocculation is irreversible whilst with emulsoids addition of water to the system subsequent to flocculation causes it to revert to a dispersed state.

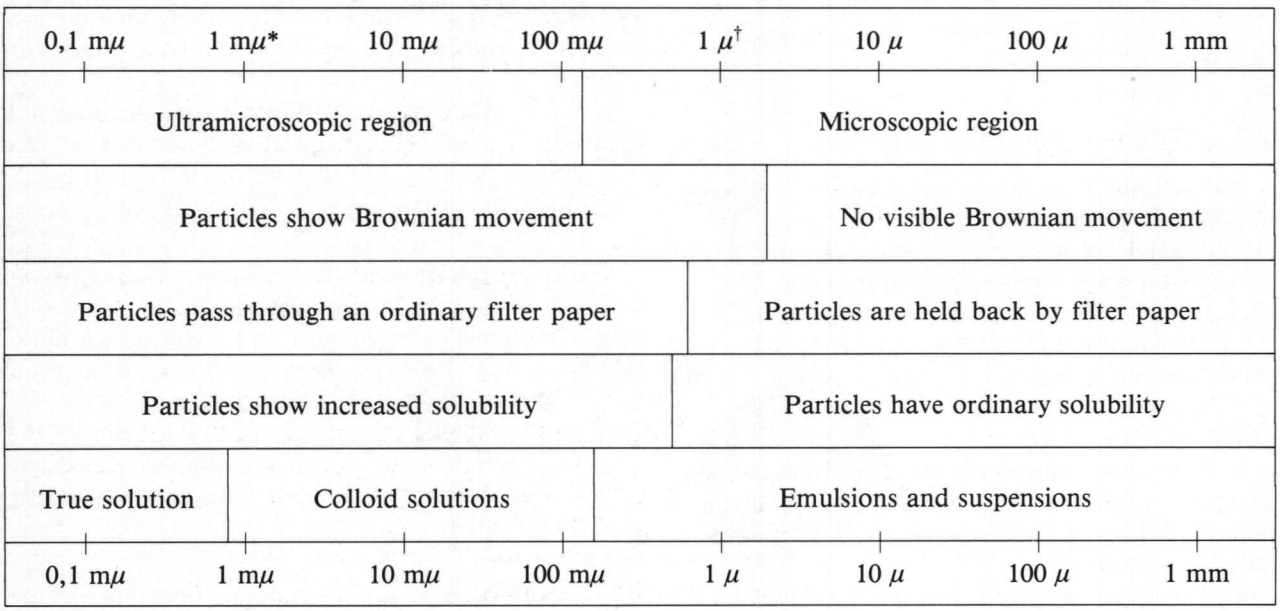
Disperse systems can be found in the following binary aggregation states:

Name	Disperse phase	Dispersion medium	Occurrence
Sol	Solid	Liquid	Gold (finely divided) in water, arsenic trisulphide in water.
Emulsion	Liquid	Liquid	Milk, mayonnaise, paraffin in water.
Foam	Gas	Liquid	Froth on beer, soap and detergent foam.
Solid Sol	Solid	Solid	Blue rock salt, gold, ruby, glass, various gemstones.
Solid Emulsion	Liquid	Solid	Minerals with liquid inclusions, opal, pearl.
Solid Foam	Gas	Solid	Minerals with gas inclusions, lava, pumice, charcoal.
Solid Aerosol	Solid	Gas	Smoke, volcanic dust, ammonium chloride fumes.
Liquid Aerosol	Liquid	Gas	Fog, cloud, mist.

Disperse systems can be characterized roughly as follows:

Type of dispersion	Range of particle size	Characteristics of particles
Coarse	Greater than, 0,5 μ	Particles are microscopically visible but cannot pass through filter paper, dialysing or ultrafilter membranes.
Colloidal	0,5 to 1 mμ	Visible by ultramicroscope, pass through filter paper but are held back by ultrafilter membrane.
Molecular solution	Less than, 1 mμ	Particles easily filtered through filter paper, ultrafilter membrane. Not visible even by ultramicroscope. Diffuse and dialyse rapidly.

The range of properties in relation to the physical size of the particles is diagrammatically illustrated as follows:



Note: *The millimicron (mμ) is often written $\mu\mu$;
†The use of the symbol μ is not favoured by "The Symbols Committee of the Royal Society". The symbol μm is recommended and the symbol nm instead of mμ.
Micron $\mu = 1 \times 10^{-4}$ cm = 10 000 Å;
millimicron m$\mu = 1 \times 10^{-7}$ cm = 10 Å;
Angström unit (Å) $= 1 \times 10^{-8}$ cm $= 10^{-10}$ m $= 10^{-1}$ nm.

Some Significant Properties of Colloidal Solutions

(1) Many particles suspended in water are negatively charged, e.g. platinum, gold, copper, iron, quartz, felspar, manganese, clay, alcohol, oxygen (bubbles), hydrogen, shellac, silk, cotton, lycopodium, carmine, paper.

However, when these substances are suspended in turpentine oil the particles are positively charged.

(2) It is possible to flocculate one colloid by adding another having an opposite charge.

(3) It is possible to coagulate a colloid by the addition of an electolyte. The greater the valency of the coagulating ion the greater the effect.

(4) It is possible to protect a hydrophobic colloid from coagulation by electrolytes by the addition, in sufficient amount, of a protective colloid (e.g. a hydrophilic colloid such as a protein).

(5) However, at low concentrations of added protein (e.g. gelatin) the reverse effect is produced, either coagulating the hydrophobic sol or making it more sensitive to the action of electrolytes.

(6) Many properties of protein sols are at a minimum at the iso-electric point. These include electric mobility, stability, osmotic pressure, swelling, membrane potential, precipitation by alcohol, viscosity and conductivity. It is also possible for a property to be at a maximum at the iso-electric point as is the case with sedimentation

volume and surface tension.

The iso-electric point of a protein, therefore, may be determined by plotting these properties as a function of pH value. Other substances which occur in sewage such as bacteria are also known to exhibit iso-electric points which may be determined by similar methods to those of proteins.

(7) Fine particles of quartz (1 μ – 5 μ in size), when coated with a protein sufficient to give a layer one molecule thick, behave like the protein from a colloidal point of view. This phenomenon has been used to observe the electric mobility of proteins at different pH values and so determine their iso-electric points (i.e. the point, in each case, of zero charge).

(8) Likewise, the sedimentation volume of a protein or protein-coated quartz particles shows a maximum at the iso-electric point provided hydration is not markedly dependent upon a change of pH value.

Sewage as a Polydisperse System

The adverse or polluting constituents of sewage* may be broadly divided into four categories, viz. –

(1) Floatable matter, e.g. grease, fat, oil which forms a scum on a sedimentation tank;
(2) Suspended matter which is readily settleable, e.g. in a sedimentation tank, Imhoff cone, etc.;
(3) Finely dispersed matter which is not readily settleable;
(4) Matter in true solution.

The overflow from a sedimentation tank contains suspended particles, some of which are colloidal and others outside the colloidal range. (It also contains matter in solution).

But, for all practical purposes, provided the sedimentation tanks have been correctly designed and are not overloaded, the suspended matter in sedimentation tank overflows may be regarded as being of a colloidal nature and the purification of this fraction which represents about 96 to 98 per cent of the sewage flow constitutes the nub of the problem of sewage treatment.

Rate of Settlement of Particles: Stokes' law gives the rates of fall of a small uniform sphere in a viscous fluid. When a small sphere falls under the force of gravity through a liquid it attains a limiting velocity which is given by the following expression:

$$V = \frac{2gr^2 (d_1 - d_2)}{9\eta}$$

where V is the terminal velocity, or rate of fall of the sphere;
g is the acceleration due to gravity;
r is the radius of the sphere;
d_1 and d_2 the densities of the sphere and the liquid respectively and
η is the coefficient of viscosity of the liquid.

V will be in cm/s if g is in cm/s^2, r in cm, d_1 and d_2 in g/cm^3 and η in dyne-s/cm^2 or poises.

The above formula due to Stokes has been used for the fractional sedimentation of polydisperse suspensions/systems (e.g. quartz and clays in water) to obtain reasonably monodisperse suspensions. For instance, to obtain a quartz suspension in the size range 1 μ – 10 μ merely involves settling a polydisperse quartz suspension for periods of time which according to Stokes' formula will cause settlement of all particles with diameters more than 10 μ or less than 1 μ and removing and discarding the appropriate layer from the settlement vessel from time to time, making-up with distilled water and re-settling. This, of course, is somewhat time-consuming since the procedure needs to be repeated a resonable number of times.

(*Note:* Pure quartz particles 1 μ in diameter fall 10 cm in 27,605 h (at 25°C) and particles of 10 μ diameter fall the same distance under similar conditions in 16 min and 34 s).

Sedimentation and Coagulation: Two types of coagulation have been discribed,[1] viz. –

(1) Perikinetic coagulation, in which aggregation of particles takes place on contact to form secondary aggregates which settle; and
(2) Orthokinetic coagulation resulting from settling particles coming in contact with suspended particles and so causing further aggregation and settlement.

Sedimentation: Mills[2] has pointed out that in large-scale sedimentation where comparatively great depths are traversed by settling particles, orthokinetic coagulation may seem to be very important in view of the opportunities for collision of particles with increasing depth. Nevertheless, Mills[3] has concluded, in the light of experimental work by Ridenour[4] "that orthokinetic coagulation does not affect the settling of crude sewage solids". This, he concludes, "is in harmony with the fact that crude sewage solids are both charged and hydrated whereas for coagulation of any type the particles must be to a certain extent both dehydrated and discharged".

Mills concludes that the simple nature of the dispersates of tank effluents shows that in a sedimentation tank only simple sedimentation proceeds.

Sewage Disperate: In order to separate dispersed material in sewage from the dispersion medium dialysis was resorted to by early investigators, notably Fowler and Ardern, O'Shaughnessy and Kinnersley, Biltz and Kröhnke, Jones and Travis.

However, dialysis is a time-consuming process and has been displaced by electrodialysis. Murray[5] later

*This refers to screened, detritus-free sewage.

investigated changes undergone by sewage during electrodialysis: the sewage had previously been centrifuged according to the method of Mills to obtain a more truly colloidal fraction.

Lumb[6] has reported on a method which he developed at Halifax (England). This consisted in adding hydrochloric acid to an appropriate volume of sample to precipitate the suspended matter at the iso-electric point for which Halifax sewage was found to be at a pH value of 3,0 to 3,3. After precipitation the sample was gently stirred for 7 to 10 min until well-defined flocs had formed. After being set aside for 24 h, the deposit was collected in a tared Gooch crucible, washed with N/1 000 HCl (pH value 3,0), dried and weighed.

An alternative variant procedure was to centrifuge the sample for 5 min, re-suspending the deposited solids in N/1 000 HCl and re-centrifuging for 15 min.

This, he stated, "gives suspended, plus colloidal plus pseudo-colloidal matter. Suspended matter is separately estimated (adding a little chloroform to prevent self-flocculation if the examination is to be delayed), and deducted, thus giving colloidal and pseudo-colloidal matter".

Lumb further used an ultrafiltration technique to separate the dispersate from the dispersion medium to determine the matter in true solution.

He has pointed out the deficiencies in his methods for determining the truly colloidal matter in sewage.

From the foregoing it becomes apparent that it is possible by ultrafiltration to separate the matter in true solution from all types of suspended particles and whilst it is possible to cause precipitation of all types of suspended matter by the judicious addition of a coagulant at the iso-electric point, the isolation of the truly colloidal matter is a more difficult prospect.

Detergents: Apart from human ejecta such as faeces and urine, domestic sewage contains wastewater from dishwashing, laundering and ablution (wash basins, baths and showers).

Thus domestic sewage or wastewater, in addition to faeces and urine from toilets, contains soap and detergents together with the suspended dirt and grease that goes with all cleansing operations.

Soap: Soaps consist of the sodium and potassium salts of the higher fatty acids. Aqueous soap solutions can be obtained in three distinct forms, viz. – the sol form containing the ionic micelle, a clear gel and a white opaque solid (i.e. a curd).

Soaps have been in use for washing for a considerable time. However, during this century fat shortages resulted in efforts being directed towards the development of "synthetic" detergents.

Detergency: Detergency may be defined as any procedure for the removal of dirt from the surface of a solid by means of a liquid.

Soaps, detergents and dyes are regarded as colloidal electrolytes. McBain[7] has defined colloidal electrolytes as "electrolytes that are partially associated and that form conducting micelles when dissolved in water".

Durham[8] has stated that, although detergency is a mosaic of many diverse phenomena, in all cases the detergent molecule has a dual character namely that a part of the molecule is hydrophilic while at the same time possessing chemical groups which are hydrophobic.

The possession of both hydrophobic and hydrophilic tendencies was termed by Hartley[9] as "*amphipathy*".

Builders: With the development of synthetic detergents the use of builders became widespread. A builder may be defined as a compound with no surface-active properties of its own but which improves the performance of synthetic detergents. Among the additives found to effectively improve the performance of synthetic detergents were phosphates.

The presence of phosphates in detergents is hardly welcome from a sewage purification point of view, as the presence of nitrate and phosphate in an effluent gives rise to eutrophication in water impoundments. But a point to bear strongly in mind is that all detergents (i.e. including ordinary soap and builders) are deflocculating agents and this being so, their presence in sewage will inhibit the sedimentation of suspended solids in sedimentation tanks at a sewage purification works.

This is further borne out by the statement of Dean[10] that many detergents and related compounds are used as dispersing agents to keep powdered particles from sticking together in the presence of solvents.

It will be recalled that Sir Edward Frankland drew attention to the fact that about one-seventh of the polluting matter in sewage is in suspension and the remaining six-sevenths is in solution (cf. Chapter 1 under "Chemical Precipitation").

An average adult male excretes about 1 500 mℓ of urine daily. The composition of urine is variable and depends on the food intake, the nature of the food, e.g. high or low protein content, and the degree of endogenous and exogenous metabolism.

However, it may be said that the twenty four hourly output of urine on an adequate mixed diet would approximate as follows:

Total N, 16 g; urea N, 14 g; ammon. N, 0,5 g; amino-acid N, 0,6 g; creatinine N, 0,6 g; uric acid N, 0,2 g; phosphate P_2O_5, 1 – 5 g; Na, 3 – 6 g; Cl (as NaCl), 10 – 15 g.

Most of the constituents of urine are in solution, though protective colloids are also present.

The normal faeces of an adult has a water content of 65 to 80 per cent. Approximately one-third of the solids (dried) is represented by bacteria.

Dry faeces has the following composition: Nitrogen, 5 – 10 per cent; "Fat", 10 – 20 per cent; Ash, 10 – 20 per cent.

The characteristic smell of faeces is due to the presence of indole and skatole (methyl indole). Mercaptans (e.g. methyl mercaptan, CH_3SH) and H_2S may also contribute to the odour as well as contributing to the corrosion of concrete sewers when acted on by certain bacteria in the presence of air and moisture (cf. Chapter 15, the section dealing with the Mining Industry).

At the time of Sir Edward Frankland the colloids in sewage were not a reality and were included with matter in solution.

From all the foregoing it is clear that in domestic sewage there are a number of well-defined constituents, viz. –

(1) Large particulate material which can be removed by screens;
(2) Granular matter ("detritus") which can be removed by so-called detritus tanks or channels by flow adjustment;
(3) Solids which can be removed by sedimentation or by centrifugal action;
(4) Colloidal and colloidal-like matter which is not removed by sedimentation in normal sewage works practice;
(5) Oil and grease which can be skimmed off the surface of the sewage in the sedimentation tanks or removed by specially designed oil and grease collection devices. (Other floatable matters which have passed through the screens form part of the scum layer, e.g. match sticks, hair, etc.).

The above matters which have been isolated at a sewage purification works have to be processed separately, viz. –

Screenings: These are normally incinerated, buried or, in the case of certain local authorities, incorporated with the solid wastes collected by the public cleansing department.

Detritus: If the material recovered as detritus is sand it can be washed and used by the building trade.

In South Africa, where separate sewerage systems for sewage and stormwater are installed, the amount of detritus is not great and is disposed of as a solid waste in such a way as to obviate nuisance.

Raw sludge and scum In a conventional sewage purification plant the scum is added to the raw sludge from the sedimentation tanks and fed to the digesters for anaerobic digestion. (*Note:* The accumulation over a long period of match sticks, hair, etc. as scum in a digester, together with undigested grease, can result in damage to the digester structure by restricting the escape of sludge gas.)

Settled sewage In a conventional sewage purification plant the supernatant overflow liquor ("settled sewage") from the sedimentation tanks is treated in biological filters or by the activated sludge process. Recently, however, the extended aeration activated sludge process has become popular thereby dispensing with sedimentation tanks except for the settlement of activated sludge prior to discharge of purified final effluent.

Up to the present, the purification of sewage has been by biological means i.e. harnessing various groups of micro-organisms to effect the necessary transformations to purify the sewage. The main methods used have been either aerobic as exemplified by biological filtration and the activated sludge process and by anaerobic methods as seen in septic tank methods and sludge digestion (mainly mesophilic alkaline anaerobic digestion and to a lesser extent thermophilic digestion).

But, with advances having taken place in chemical and physico-chemical methods and the need to conform to more stringent effluent quality standards, some attention has been given to the use of such methods *per se* and in combination with biological treatment methods.

Chemical, Physico-chemical and Biological Treatment

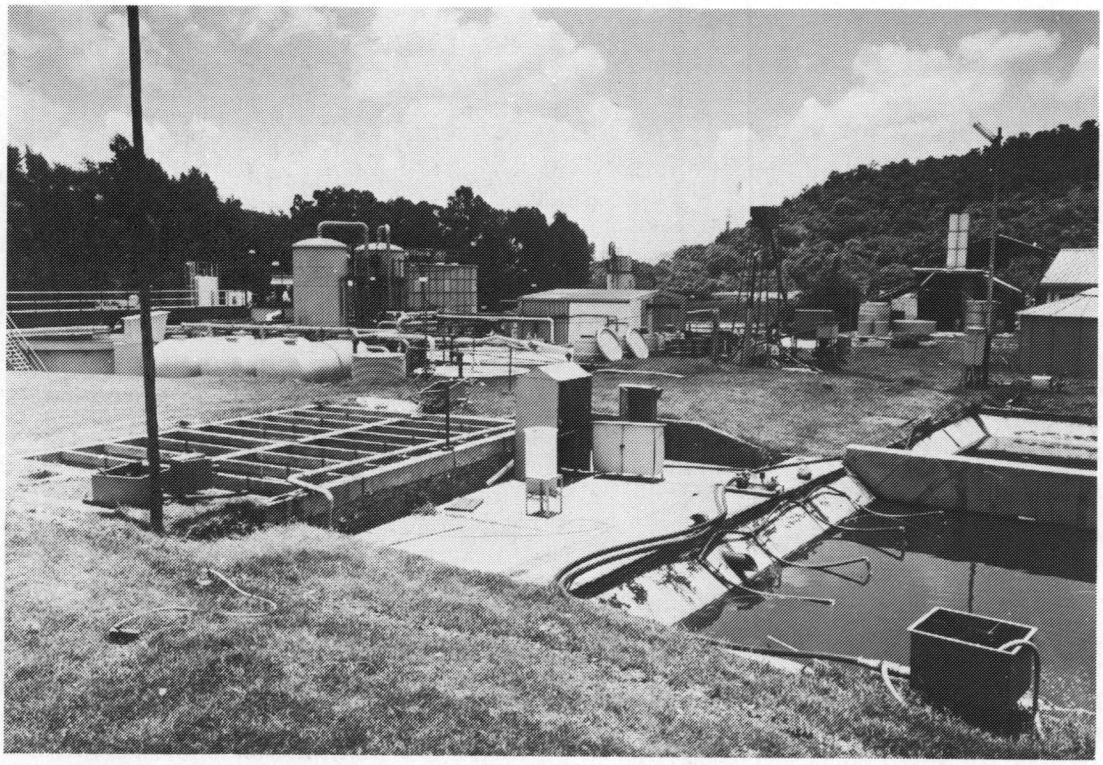
Chemical and physico-chemical unit process operations available for the treatment of industrial effluents and sewage include the following, – coagulation of suspended matter by the addition of chemicals followed by sedimentation or centrifugation; heat treatment and incineration; electrolysis; electrodialysis; activated carbon adsorption; ultrafiltration; reverse osmosis; ion exchange, dissolved air flotation; foam fractionation, solvent extraction; air stripping.

For the reclamation of water by the so-called "advanced treatment" resort is had to a selection of these unit process operations. A unit operation which may be suitable for one industrial effluent may not be applicable to another type of effluent.

Stander, van Vuuren and Dalton[11] have described the methods used by them for producing pure wholesome water from sewage at the Daspoort Sewage Purification Works of the Pretoria City Council.

A demonstration water reclamation plant with a capacity of 4 550 m^3/day (1 000 000 gal./day) was constructed on the site of the Daspoort Sewage Purification Works and received sewage from this works.

The hook-up of unit process operations used by the authors consisted of chemical pretreatment to remove coagulable organic matter and phosphate; foam fractionation to remove detergents; air strip-



Stander Reclamation Plant, Daspoort, Pretoria.

ping to remove ammonia. The excess lime used for coagulation was subsequently removed by precipitation with carbon dioxide and any remaining organic matter and detergents were removed by adsorption on powdered activated carbon. The spent carbon was then recovered by coagulation using chlorinated copperas (ferrous sulphate) as coagulant.

The above sequence of operations could apply equally well to primary effluent (settled sewage) or secondary effluent.

Middleton[12] has drawn attention to a programme of "Advanced Treatment of Municipal Waste Waters in the United States of America" in view of the passage of the Water Quality Act of 1965. He pointed out that conventional processes used in the past would not provide the degree of treatment required for pollution control needs and the growing re-use of wastewaters. He has given information concerning the following physico-chemical projects aimed at improving effluent quality, viz. –

(1) Clarification/carbon process at Rocky River;
(2) Physico-chemical pilot plant at Lebanon, Ohio (also using carbon columns) and
(3) The major advanced plant at Lake Tahoe.

Middleton has quoted from Culp* the following results for the Lake Tahoe Advanced Treatment Final Effluent as follows:

*Culp, Russell L. "How Practical is Advanced Treatment of Wastewater", paper presented at 20th Annual Conference of Sanitary Engineering, Univ. Kansas, Lawrence Kansas, 17 January, 1970.

Plant performance for conformance for 100 per cent of the time expressed as milligrams per litre – B.O.D. less then 0,35; C.O.D. less than 22; Suspended Solids, 0; Phosphorus less than 0,27; pH value 6,6 – 8,7; Coliform bacteria, Median less than 2; No consecutive samples greater than 22.

Truesdale[13] considers that, in future, more stringent effluent standards beyond the scope of tertiary treatment may be necessary and to achieve such standards it will be necessary to employ the so-called advanced treatment processes. Of these he deals with activated carbon, electro-dialysis and ion exchange.

He states[14] that a system using activated carbon following coagulation, flocculation, sedimentation and filtration is marketed in the UK and elsewhere as a complete treatment plant.

Among the advantages claimed for physico-chemical plants are savings in space and better control of processes based on physico-chemical principles than is possible with biological processes. The question of costs is a debatable one though, in certain cases, there may be savings.

As far as industrial effluents are concerned, as with sewage, consideration should be given to a combination of physico-chemical and biological treatment methods for a particular effluent. Biological treatment is satisfactory for removing soluble organic matter, particularly ammoniacal and albuminoid nitrogen. Physico-chemical methods are necessary where effluents are toxic or are non-biodegradable.

Removal of Phosphorus

Lime, aluminium sulphate and ferric sulphate are commonly used as flocculants and may be used alone or in combination with polyelectrolytes. However, polyelectrolytes alone are not successful in flocculating sewage.

These three flocculants can be used for removing phosphate in industrial effluents and sewage. Middleton[15] considers that for reliability and for removal of 95 to 99 per cent of phosphorus, chemicals must be used. He states, further, that "Field experience on large demonstration and full-scale plants shows that ferrous, ferric and aluminium salts can be equally effective as phosphorus precipitants in waste water".

Removal of Nitrogen

Black[16] has indicated that there are three physico-chemical processes available for effectively removing nitrogen from sewage and effluents, viz. – (1) Air stripping; (2) Oxidation with ozone; (3) Ion exchange using clinoptilolite*.

He states that for air stripping a large amount of air is required. He quotes an amount of 2×10^3 cubic metres of air per cubic metre of sewage, which he states is large.

Middleton[17] also states that the usage of air in the process is large. Black[18] indicates further that two major problems encountered are (i) odour; (ii) calcium carbonate scale deposition (especially after liming). Furthermore, the process is stated to be unreliable in cold weather.

Water Reclamation

Water reclamation methods have been applied to maturation pond effluent at Windhoek (South West Africa/Namibia); activated sludge effluent at Lake Tahoe (California – Nevada border, USA); river water from the River Rhine (Holland) and river water in the River Trent (England). The methods used are briefly as follows:

Windhoek: Effluent from maturation ponds (supplied with biofilter effluent) is used. This effluent contains algae and has a pH value of 9,0 which is reduced to 7,5 with carbon dioxide. The algae are removed by flotation after addition of aluminium sulphate. Foam fractionation is now used to remove detergents, etc., followed by lime coagulation and breakpoint chlorination prior to sedimentation, filtration through rapid sand filters and granular activated carbon beds. The final reclaimed water is blended into the available drinking water supply in the ratio of one (1) volume reclaimed water to two (2) volumes drinking water.

Lake Tahoe (also referred to elsewhere in this chapter): Activated sludge plant final effluent is coagulated with lime at a pH value of 11 and flocculated by aeration with polyelectrolytes to remove lime sludge by sedimentation. The supernatant water, still at a pH value of 11, is passed on for ammonia stripping. Thereafter, carbon dioxide from sludge incinerators is added to lower the pH value to 9,6 thus precipitating calcium carbonate and resulting in a pH value of 7,5. Aluminium sulphate is now added and the water is filtered on multi-media beds. The filtrate is then passed through a granulated activated carbon bed and finally disinfected with chlorine.

River Rhine: The treatment of water abstracted from the River Rhine for Amsterdam involves aeration, rapid filtration, aeration, chlorination, artificial recharge, aeration, adsorption, rapid filtration, slow filtration, aeration and chlorination – to a degree a concatenation of repeating sequences.

River Trent: A hook-up of processes has been as follows: High rate biological filtration, coagulation, sedimentation, sand filtration, granular activated carbon adsorption and disinfection.

Apart from the above water reclamation projects where the final reclaimed water is considered to be pure wholesome water suitable for drinking there are notable examples where effluents of lesser quality are used in industry. A number of these are as follows:

Johannesburg: Almost 50 years or so ago purified sewage effluent was supplied to the Orlando Power Station for cooling purposes. Osborn[19] elucidated a number of drawbacks experienced in the early stages of the change-over from Rand Water Board water to purified sewage effluent.

Later, Osborn[20] reported that "up to $7{,}7 \times 10^4$ cubic metres per day of effluent is used in Johannesburg for power station cooling purposes".

Durban: The Mondi Paper Company Limited, at their Durban operation, use water from the Southern Wastewater Treatment Works of the Durban Corporation.

Secondary sewage effluent from an activated sludge plant is processed by the company as follows: The sewage effluent is dosed with activated silica, hydrated lime and alum. Flocculation is allowed to proceed within the pH range 5,0 to 5,5. After clarification the pH value is adjusted to 7,5 with sodium hydroxide and then follows sand filtration, foam fractionation and, finally, activated carbon adsorption.

Details of the process are given by Giampietri and Voysey.[21] (cf. Chapter 15, the section dealing with "The Cellulose Fibre Industry").

Springs: Secondary effluent after sand filtration is used by the South African Pulp and Paper Industries Limited (SAPPI, Ltd.) at their Transvaal mill at Enstra, Springs. The purified sewage effluent is supplied by two sewage purification works of the Springs Municipality.

*Clinoptilolite is a zeolite material. However, its exchange capacity is low.

The sequence of process operations follows that reported by Stander, van Vuuren and Dalton[11] (cf.) though somewhat attenuated by the omission of ammonia stripping, foam fractionation, chlorination and activated carbon adsorption treatment.

The treatment includes addition of slaked lime to a pH value of 10,8 to 11,0, removal of flocculated material by settlement or flotation, addition of carbon dioxide, settling at pH 9,5, re-carbonation to the desired pH value and final sand filtration (cf. Chapter 15, the section dealing with "The Cellulose Fibre Industry").

(Refer also to Chapter 15, "The Iron and Steel Industry"; "The use of purified sewage effluent").

Comment:

From the foregoing it can be inferred that it is possible by a combination of chemical, physico-chemical and physical processes to produce pure wholesome water from raw sewage. But at increased costs which can only be justified in particular circumstances.

Two significant processes are coagulation with lime and adsorption on activated carbon. Coagulation with lime has the incorporated advantage that phosphate can be removed in the sludge but this, in turn, is bulky and requires to be disposed of satisfactorily.

After coagulation and clarification by settlement and finally by sand filtration there is little doubt that activated carbon, either as powder (as investigated by the National Institute for Water Research) or granulated solids, serves a very useful purpose in the final stage/s of purification. Fortunately, the spent material can be revivified by heat and, in practice, make-up with new activated carbon is of the order of 10 per cent. However, activated carbon has to be imported, at present, and so its use would make sewage purification and industrial wastewater treatment dependent on imports which is undesirable for a continuous environmental and health service. Lime, on the other hand, is readily available due to substantial deposits being available in the Republic.

Electrodialysis has made strides by the use of anion permeable and cation permeable membranes arranged alternately in an electrodialysis cell. This process has applicability for the desalination of brackish water and tests, using electrodialysis, have been in progress by Delta Manganese (Proprietary) Limited on effluent from one of their operations at Nelspruit (E. Transvaal) to improve the quality of their effluent.

Ion exchange has been in common use for some time for demineralizing water or capturing valuable constituents such as uranium compounds and gold as well as for the removal of toxic or undesirable ions.

Reverse osmosis is another physico-chemical process which may be used for improving the quality of effluents. Whether this process can be satisfactorily and economically applied on a large scale to large quantities of wastewater (e.g. mineralized mine effluents) is not certain at this stage.

Ultrafiltration has suffered in its application due to the clogging/blinding of membranes. However, due to advances in the development of membranes and technological advances in methods of cleaning and replacing membranes on a continuous basis has made the application of the process for the treatment of certain effluents (e.g. textile factory effluents) a possibility.

In some of the physico-chemical processes (e.g. ion-exchange, electrodialysis, ultrafiltration) the pollution is transferred from the wastewater to a discard stream which has to be disposed of. The volume of this concentrated waste stream is considerably less than the original wastewater and can be evaporated. However, even the disposal of the evaporated solids becomes a problem.

Disinfection is the final process which has to be included in any sequence of processes to attain pure wholesome water. The options available for disinfecting, i.e. making the water bacteriologically sterile by destroying bacteria, viruses and all other forms of microbiological life, include the use of chlorine, ozone and bromine chloride.

Disinfection is discussed in more detail later in this chapter.

2. The Chemical Composition of Sewage and the Transformation of the Constituents during Treatment

Definition: Sewage may be defined as the wastewater from a community and in South Africa this consists basically of discharges from kitchens, toilets, urinals, lavatories and all forms of ablution, domestic cleansing and laundering together with permitted industrial effluent discharges.

In South Africa separate sewerage and stormwater reticulation systems are used whilst other countries with a different rainfall system (e.g. Great Britain) operate on a combined system of drainage for sewage and stormwater.

It is well to remember this fact when comparing sewage "strengths" and the capability of sewage treatment plants in, say, Great Britain and the United States in relation to performance capabilities of plants in South Africa.

Constituents of Sewage

The definition given of sewage directs attention to the chemical constituents to be dealt with at a sewage purification works. For domestic sewage these will include the chemical compounds present in the following:

I. Fats and oils from kitchens, meat handling and food purveying establishments.
II. Urine.

III. Faeces.
IV. Soap and synthetic detergents from household ablution and laundering.
V. Proteins.
VI. Polysaccharides.
VII. Industrial effluent, where allowed, including commercial laundry effluent.

I. *Fats and oils*

Oils, fats and waxes may be grouped as follows:

A. Products of animals and plants: In this category we have
   (i) Fixed oils, fats and waxes;
   (ii) Volatile or essential oils.
B. Products from minerals: In this category we have
   (i) Petroleum oils and waxes;
   (ii) Ozokerite (earth wax) – a naturally occurring crude mixture of solid hydrocarbons;
   (iii) Brown coal, bitumen and peat oil and waxes;
   (iv) Shale oil and waxes;
   (v) Coal tar oils.

The fats and oils discharged by householders, meat and food purveyors come within the category of fixed oils and fats. Essential oils are the concern of the perfumery industry.

The oil products of minerals are not allowed to be discharged into sewerage systems. For this reason garages are required to provide efficient oil traps to prevent discharge of waste oils and other petroleum products into the sewerage system. The trapped material must be satisfactorily disposed of.

Fats and oils may be defined as a class of lipoidal materials consisting of glycerol esters of the fatty acids (and their associated phosphatides, sterols, alcohols, hydrocarbons, pigments, etc.) which are obtained from plants and animals by industrial processes such as pressing, cooking with steam and water, solvent extraction or combinations of such processes.

Fatty Acids: These consist of an even number of carbon atoms arranged in a straight chain with an alkyl group, CH_3 – at one end of the chain and a carboxyl group, – COOH at the other, thus, –

$$CH_3{-}(CH_2)_n{-}COOH$$

In the case of stearic acid n = 16, giving the formula $C_{17}H_{35}COOH$. Other common saturated fatty acids include lauric: $C_{11}H_{23}COOH$, palmitic: $C_{15}H_{31}COOH$, margaric: $C_{16}H_{33}COOH$. These acids, of course, have systematic names, e.g. stearic acid is designated as n-octadecanoic acid.

Naturally occurring fatty acids may be divided according to whether double bonds are present or absent in their hydrocarbon chains, into unsaturated or saturated acids.

The fats (which are glyceryl esters) are neutral in reaction and on saponification yield glycerol and soap, the latter being dependent on the type of alkali (KOH or NaOH) used in the hydrolysis (KOH providing "Soft Soap").

It will be apparent from the above cursory account that fats and oils discharged into the sewers contribute matter made up, *inter alia*, of compounds containing carbon (C), hydrogen (H) and to a lesser extent oxygen (O) atoms.

The fate of these compounds together with their associated dirt is to become emulsified or remain intact. On arrival at the sewage purification works (if it is a conventional one) the oils and fats will rise to form scum on the surface of the sewage in a sedimentation tank(s) and the emulsified portion will remain suspended in the settled sewage overflow.

II. *Urine*

The first person to isolate individual constituents of the animal organism was Rouelle who, in 1773, discovered urea in urine.

Urea is an important nitrogenous substance present in urine and it is of particular interest historically to note that urea $CO(NH_2)_2$ which is also referred to as carbamide, being the amide of carbonic acid, was prepared by Wöhler who, in 1828, transformed the salt ammonium cyanate by heat into urea, viz. –

$$NH_4 - O - C \equiv N \xrightarrow{\text{Heat}} NH_2 - \overset{\overset{O}{\|}}{C} - NH_2$$

Ammonium cyanate Urea

In so doing, the barriers that then existed between organic and inorganic chemistry were broken down i.e. an organic compound, urea, had been prepared from an inorganic one!

Urea is a major constituent of urine as will be seen from the following analysis taken from Cecil[22] (Textbook of Medicine).

Analysis of Urine

Acidity, titratable acidity	200 – 500 ml N/10 alkali
Amino nitrogen (N)	0,4 – 1,0 g per 24 hours
Ammonia as NH_3	0,5 – 0,6 g per 24 hours
Calcium	0,1 – 0,7 g per 24 hours
Chloride as NaCl	10 – 15 g per 24 hours
Creatinine	1,0 – 1,6 g per 24 hours
Glucose	0,5 – 1,0 g per 24 hours
Nitrogen, total	12 – 18 g per 24 hours
Phosphates as P_2O_5	2,0 g per 24 hours
Solids, total	55 – 60 g per 24 hours
Sulphates, as SO_3	1,8 – 3,0 g per 24 hours
Urea	20 – 35 g per 24 hours
Uric acid	0,4 – 1,0 g per 24 hours

An adult of average weight and height produces, an average, 1 500 mℓ of urine daily; though many American observers regard 1 250 mℓ as a better daily average.

Output in Urine in Grams in 24 Hours

	Adequate dietary			Starvation	
	Ordinary Protein Intake	High Protein Intake	Low Protein Intake	First Day	Fourth Day
NITROGEN					
Total N	13,0	28,0	4,2	7,0	14,0
Urea N	11,0	20,0	2,9	5,8	11,8
Ammonia N	0,4	0,8	0,2	0,2	1,3
Creatinine N	0,6	0,6	0,6	0,6	0,6*
Uric acid N	0,2	0,3	0,1	0,15	0,1
SULPHUR					
Total SO_3	2,6	3,5	0,8	1,2	2,0
Inorganic SO_3	2,1	2,8	0,6	—	—
CHLORIDES (NaCl)	12,0	15,0	10,0	5,2	1,3
PHOSPHATES (P_2O_5)	2,6	4,0	1,0	1,7	1,1
TITRATABLE ACIDITY mℓ N/10	280	650	160	180	720
ACETONE BODIES	—	—	—	—	3,9

*Includes 0,15 g creatine N.

Variations in Composition due to Diet: The effect of diet on the composition of urine is shown in the above table based on the results given by Bodansky and quoted by Thorpe.[23]

It will be noted from the table that apart from the high urea N values indicated, high values for chloride (NaCl) are also shown. At one stage, in the past, it was usual to make use of the chloride value, which is easily determined analytically, to indicate the "strength" of a sewage but this has fallen out of use for good and sufficient reasons.

It will also be noted that phosphate and sulphur (SO_3) are present in urine. Consequently, from urine alone sewage is provided with many nitrogenous compounds, in particular, urea and also phosphorus, sulphur, and carbon-containing compounds [cf. urea $CO(NH_2)_2$ and creatinine etc.].

The reaction of normal urine is acid but varies within the pH range of 5,5 to 7,0.

Certain enzymes, notably urease occurring in micro-organisms, soya beans, jackbeans, etc., bring about the hydrolysis of urea at ordinary temperatures as follows:

$$CO(NH_2)_2 + H_2O = CO_2 + 2NH_3,$$

and this takes place in sewage. In aerobic purification processes NH_3 is converted to NO_3.

Synthesis of Urea: Urea is synthesized by the liver from ammonia and carbon dioxide together with the amino acid ornithine present in the liver with arginase and other enzymes.

The formation of urea in the human system has been explained as follows: The primary reaction is considered to be that of ammonia and carbon dioxide with the amino-acid ornithine present in the liver to give the ureido-acid citrulline: this reacts further with ammonia and the guanidino-acid, arginine is formed. The final step is hydrolysis of arginine to urea and ornithine, viz.

$$HO_2C \cdot CHNH_2 \cdot (CH_2)_3NH_2$$
ornithine

$$\xrightarrow{+NH_3 + CO_2} HO_2C \cdot CHNH_2(CH_2)_3NH \cdot CO \cdot NH_2$$
citrulline

$$\xrightarrow{+NH_3} HO_2C \cdot CHNH_2 \cdot (CH_2)_3NH \cdot C(:NH) \cdot NH_2$$
arginine

$$\xrightarrow[\text{(hydrolysis)}]{+H_2O} HO_2C \cdot CHNH_2 \cdot (CH_2)_3NH_2 + CO(NH_2)_2$$
ornithine *urea*

The formula of urea is usually written $O=C\begin{matrix}NH_2\\NH_2\end{matrix}$

According to Manderscheid[24] both reptiles and amphibia are capable of the same urea synthesis but in the case of reptiles uric acid and not urea is excreted. Mitchell[25] states that "in birds and scaly reptiles uric acid rather than urea is the chief end product of protein metabolism as a whole".

As stated above the structure of urea is most commonly given as follows:

$$\begin{matrix}H_2N\\H_2N\end{matrix}\!\!>C=O$$

though a number of other structures have been proposed to express its behaviour.

Today urea is used as a fertilizer and is produced by two main methods, viz.

(1) By the partial hydrolysis, in weakly acid solution, of cyanamide ($N \equiv C - NH_2$), calcium cyanamide is produced by reacting finely ground calcium carbide (CaC_2) with N_2 (nitrogen) at temperatures of the order of 870 to 980°C. The CaC_2 is produced in an electric furnace from a mixture of lime (CaO) and coke (C):

$$CaO + 3C = CaC_2 + CO.$$

Cyanamide is then obtained as follows:

$$CaN-N\equiv N \xrightarrow[\text{under pressure}]{CO_2} H_2N-C\equiv N \text{ (cyanamide)}$$

$$H_2N-C\equiv N \xrightarrow[H_2SO_4]{H_2O} H_2N-\overset{\overset{O}{\|}}{C}-NH_2$$

cyanamide — *urea*

(2) By direct synthesis from ammonia (NH_3) and carbon dioxide (CO_2) to form ammonium carbamate $NH_2 \cdot CO \cdot ONH_2$.

This can be done by the Bosch and Meiser process wherein the mixed NH_3 and CO_2 gases together with moisture are autoclaved at 130 to 140°C. Ammonium carbamate forms first and transforms into urea. Alternatively the Kraze process can be used. In this case liquid ammonia and liquid carbon dioxide are introduced into an autoclave. The ammonium carbamate so formed is heated to 130 to 150°C (under 35 atmospheres pressure) to produce urea.

$$2\,NH_3 + CO_2 \longrightarrow \underset{\text{ammonium carbamate}}{NH_2 \cdot CO - ONH_2}$$

$$\underset{\text{ammonium carbamate}}{NH_2 \cdot CO \cdot ONH_2} \longrightarrow \underset{\textit{urea}}{NH_2 - CO - NH_2} + H_2O$$

Modifications of the process can include the introduction of phosphoric acid to neutralize excess ammonia thereby increasing the fertilizer value of the final product.

Comment: The extensive use of artificial fertilizers by farmers has an impact on the ecology of rivers by increasing the N and P content from non-point sources draining into rivers and so causing eutrophication of such rivers as well as water impoundments on such rivers.

III. *Faeces*

The amount of faeces excreted by normal adult fed on a mixed diet will vary from day to day but, on average, will be of the order of 100 grams per 24 hours. Adults living on a vegetarian diet will excrete up to 370 grams per day. The greater part of the matter passed is water (c. 65 to 80 per cent). The increased amount of faeces produced on a vegetarian diet is occasioned by the greater amount of indigestible cellulose present in such diet, which, in turn, encourages peristalsis resulting in an increased bulk of faeces.

The dried solids from faeces have the following composition:

Parameter	*Per cent*
Nitrogen	5 – 10
Fat	10 – 20
Ash	10 – 20

The ash contains calcium phosphate together with small amounts of iron and magnesium.

About one-fifth to one-third by weight of dried faeces consists of bacteria. The weight will depend on the diet.

Also present (determined by etherial extract), are cholesterol, lecithin, fatty acids, soaps and a fair amount of neutral fat which is partially derived from the bacteria.

Cellulose is the only important constituent of food which is not digested by the human digestive processes.

Odour: The characteristic odour of faeces is due to the presence of indole and skatole (β-methyl-indole). An adult excretes about 50 mg of indole in faeces every 24 hours, on average.

Mercaptans or thioalcohols (RSH) occur in faeces and together with hydrogen sulphide (H_2S) also contribute to the odour of faeces – particularly in the faeces of persons living on a meat diet.

Mercaptans also occur in petroleum and are associated with "sour petrol". Common mercaptans are methyl mercaptan, CH_3SH and ethyl mercaptan, C_2H_5SH. Methyl mercaptan is a gas, the remainder of the mercaptans are volatile liquids with disagreeable smells.

Where undigested protein is absent in the faeces an adult on a mixed diet excretes 1 gram of faecal nitrogen per day. This nitrogen is prescnt in faeces in unabsorbed nitrogenous substances e.g. secreted mucus, excreted bile pigment, bacteria and unabsorbed food derivatives such as indole and skatole.

IV. *Soaps and Synthetic Detergents*

Detergency may be defined as any procedure for the removal of dirt from the surface of a solid by means of a liquid.

This being so both soaps and synthetic detergents act as detergents since, when present in water they effect such purpose.

As noted under "Fats and oils" (cf.) soaps include the sodium or potassium salts of higher molecular weight fatty acids. It may be noted that, by extension, any salt of the fatty acids and a metal ion other than sodium or potassium is referred to as a metallic soap.

Soaps: Probably the first cleansing agent used by man was clay: a notable use in this connexion was fullers earth which is able to absorb oils and grease as well as any associated colouring matter – hence the term 'fuller' for one who fulls or cleans/bleaches cloth.

Soapmaking has been practised for over 2 000 years. In industry the oils and fats used include palm, olive, coconut, cotton-seed oils, rendered tallow and waste fat from abattoirs. These raw materials are boiled in 'lye' solutions containing sodium hydroxide or potassium hydroxide of selected strengths. Saponification (or hydrolysis) takes place – the fats and oils being converted into their respective fatty acids (e.g. oleic, stearic, palmitic, etc.) and glycerine. The fatty acids, in turn, combine with the cation of the alkali present to give soap.

Variations of the process are the use of black ash (impure sodium carbonate, Na_2CO_3) to produce mottled soap; the addition of fillers such as kaolinite and bentonite clays; resin; sodium silicate, etc. The waste lyes after separation of the soap and glycerine is shown, as follows:

$$\begin{array}{l} CH_2O_2CR_1 \\ | \\ CHO_2CR_2 \\ | \\ CH_2O_2CR_3 \end{array} \xrightarrow{NaOH} \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} + 3RCOONa$$

triglyceride glycerine *soap*

R_1, R_2, R_3 of the triglyceride which may all be the same, are straight-chain aliphatic groups which may be unsaturated and/or have hydroxyl groups.

Soap, therefore, is essentially the sodium or potassium salt of a long-chain fatty acid: and glycerine is an important by-product in the manufacture of soap.

Soaps, synthetic (organic) detergents and dyes are common colloidal electrolytes, i.e. the molecules possess both hydrophobic and hydrophilic portions.

Synthetic Detergents ("Syndets"): A notable development in chemical technology during the past 30 years or so has been the production of synthetic detergents which have displaced soaps to a considerable extent today. Synthetic detergents may be regarded as soapless washing or cleansing agents derived from synthetic organic chemicals.

Soap suffers from a number of drawbacks (e.g. reduced efficiency in "hard" waters) in its use as a detergent and, added to this, after World War II there was a shortage of fats and oils suitable for soapmaking. At one stage developments were directed towards incorporating water-softening agents in soap. However, it was found that synthetic detergents could be made from more readily available petroleum products than fats and oils required for soapmaking and also synthetic detergents overcame the drawbacks of soap in hard waters.

As previously noted a typical soap has a molecule consisting of a long hydrocarbon chain and a sodium carboxylate group. One of the early synthetic detergents was sodium dodecyl sulphate which bears relation to a soap in that the sodium carboxylate group is replaced by a group containing sulphur, oxygen and sodium. Its cleansing efficiency matches that of soap but it has the added advantage of satisfactory application in acid and hard water.

Classes of Synthetic Detergents: Three classes of synthetic detergents are manufactured, viz.

(1) Anionic;
(2) Cationic;
(3) Non-ionic.

These three classifications are based on their ionizing properties in water. Of the three classes anionics are the most commonly used and, as a result, contribute more to wastewater treatment and pollution control problems than the cationic and non-ionic detergents.

The cationic detergents have germicidal properties but are more expensive than anionics. Non-ionics suffer from the disadvantage of being usually viscous liquids which are more difficult to market. They are used in "controlled suds" detergents.

(1) *Anionic Detergents*

Anionic detergents ionize in water giving an anion which causes detergency. Examples are: (i) alkyl sulphates; and (ii) alkyl benzene sulphonates, viz.

(i) Alkyl sulphates

$R-CH_2-OSO_3^-$ ------ Na^+ primary alkyl sulphate

$\begin{matrix} R_1 \\ R_2 \end{matrix}\!>\!CH-OSO_3^-$ ------ Na^+ secondary alkyl sulphate

(ii) Alkyl benzene sulphonates

These have the general formula:

$R-C_6H_4-SO_3^-$ ------ Na^+

R – the alkyl group has 9 to 15 carbon atoms.

At one stage (c. 1972) the sodium alkyl benzene sulphonates were considered to be the most important class of synthetic detergents.[26] They were much used before 1965.*

A number of acronyms are used to more concisely designate these synthetic detergents, viz.

ABS – alkyl benzene sulphonate;
LAS – linear alkylate sulphonate;
MBAS – those that can be determined analytically by methylene blue.

(2) *Cationic Detergents*

These are mainly quaternary ammonium or

*e.g. Sodium tetrapropylene benzene sulphonate, $C_{12}H_{25}-C_6H_4-SO_5Na$.

pyridinium salts which derive from pyridine, e.g.

$R - N(C_{15}H_5) - SO_4H$ or $R - N(CH_3)_3Cl$

They have bactericidal properties and find a certain degree of application in the washing of utensils, etc. in hospitals, restaurants and food industries on account of their sterilizing effect but they are expensive.

(3) *Non-ionic Detergents*

These substances do not ionize in water. In general, they are complex compounds of fatty acids with ethylene oxide.

The most generally used non-ionic detergents in industry are ethylene oxylated alkyl phenol with the general formula:

$R \cdot C_6H_4 \cdot (OCH_2 \cdot CH_2)_nOH$

where R is an alkyl group with 8 or more carbon atoms and n has a value between 8 and 11.[27]

The non-ionic detergents are difficultly biodegradable both by percolating filters and activated sludge plants.

Due to their wetting, emulsifying and cleansing properties synthetic detergents are used by a variety of industries e.g. the textile industry (e.g. wool scouring), dyeing, synthetic fibre manufacturers, plastics and rubber industries, food industries (e.g. dairies, breweries, etc.).

When non-ionics are present together with anionics there is a tendency for more foam to be produced.

Most of the detergents used (at one stage estimated at over 90 per cent) were of the anionic type with much less of the non-ionic type and still less those of the cationic type.

Up to about 1964 alkyl benzene sulphonate (ABS) detergents were used mainly for domestic purposes.

However, this type and, in particular, sodium tetra propylene benzene sulphonate, $C_{12}H_{25} - C_6H_4 - SO_3Na$, affected sewage purification works adversely giving rise to considerable foaming particularly in diffused air activated sludge plants.

The performance of plant units was reduced. Further, much foam was present in rivers into which the sewage effluents were discharged. The foam was a health hazard by virtue of the micro-organisms present in the foam and had a deleterious effect on vegetation it came in contact with on a continuing basis (e.g. at sewage purification works and on river banks).

Hammerton[28] concluded that the non-biodegradability of anionic detergents was due to the type of alkyl group present in the molecule and did not depend upon whether the compound was an ester-sulphate (e.g. "Teepol" and "Drene") or a benzene sulphonate. For instance, anionics with a straight chain alkyl group are easily biodegraded aerobically, but with increasing complexity of the alkyl group such as the presence of a number of substituted groups on the main chain (i.e. a branched chain alkyl group) are resistant to aerobic bio-degradation.

Manufacturers have now switched from ABS (so-called "hard" detergents) to LAS ("soft" detergents) thereby leading to amelioration of foaming and biodegradability problems at sewage purification works. But efforts are being made to produce still softer detergents.

As far as sludge digestion is concerned the anaerobic digestion process is not affected unduly if the concentration of detergent does not exceed 1,5 per cent based on the dried solids or 750 mg/ℓ in the wet sludge. Concentrations above this affect gas production and inhibit the digestion process.

Results of experiments on the biological decomposition of hard and soft detergents as reported by the Water Pollution Research Laboratories at Stevenage (Herts, England) are listed in the table below.

Builders: A builder has been described[29] by its function "as affording peak surfactancy at lower surfactant concentrations and, with certain inorganic salts such as polyphosphates actually increasing a surfactants' peak performance at reduced concentrations".

Hammerton[28] gives the following list of builders added to the anionic surfactant materials:

(a) Phosphates (usually sodium tripolyphosphate), which will help to suspend more dirt, and also form complexes with stray metallic ions and thus prevent staining,

(b) Sodium silicate, which prevents metals from being attacked,

Decomposition of hard and soft detergents

Original concentration 13 mg/ℓ

Concentration in effluent	Biological filtration		Activated sludge treatment (6 hrs aeration)	
	Concentration	% Decomposition	Concentration	% Decomposition
(1) Hard detergent	4,30	67,0	4,05	68,7
(2) Mixture of hard and soft	2,20	84,0	1,25	90,9
(3) Soft detergent	0,87	93,7	0,89	93,5

Concentration expressed as mg/ℓ Manoxol

(c) Sodium carboxymethyl cellulose, which aids the phosphate to prevent re-deposition of removed dirt,
(d) Fatty amides, which help to form a denser foam and thus to indicate the amount of detergent present,
(e) Sodium sulphate, formed in the process of manufacture, and a useful electrolyte.

A typical approximate composition of a detergent product is given by Hammerton[28] as follows:

Component	*Per cent*
Sodium alkylaryl sulphonate	20
Sodium phosphates	38*
Sodium sulphate	23
Sodium silicate	8
Sodium carboxymethyl cellulose	1
Fatty alcohol amide	3
Balance mainly H_2O	7
	100

Baars[30] quotes the following per cent removal by unit sewage processes of ABS (alkyl benzene sulphonate), LABS (linear alkyl benzene sulphonate) and SAS (sodium alkyl sulphate):

Process	**Average per cent removal**		
	ABS	**LABS**	**SAS (alkyl sulphate)**
Primary sedimentation	2 – 3	2 – 3	—
Septic tank	9,3	11,8	62,1
Septic tank + percolation field (normal)	73,9	97,4	99,6
Septic tank + percolation field (ponded)	54,5	97,1	99,7
Standard rate oxidation pond	<40	93,1	98,0
High rate oxidation pond	<15	56,2	95,2
Standard rate trickling filter	35,0	84,7	—
High rate trickling filter	19,1	71,0	—
Activated sludge	45 – 60	95	100

Gaillard,[31] early in 1950 before synthetic detergents became generally used in South Africa for domestic purposes, carried out a number of laboratory investigations to ascertain the likely consequences of certain detergents at sewage purification works by determining their effect on aeration tests. He selected the following synthetic detergents: "Teepol", "Teepodol", "Lissapol N", "Santomerse" and reported the results as tabulated on page 48 (Effect of synthetic detergents on aeration tests).

He concluded from experiments 1, 2 and 3 that the addition of 10 p.p.h.t. of "Teepol", "Teepodol" and "Lissapol N" that, with the exception of a small drop in the nitrate (NO_3) content of the effluent, the effluents were of good quality and 100 per cent stable.

However, in experiments 4, 5 and 6 where "Santomerse" was used it was evident that there was a deterioration in the quality of the effluent and of the sludge.

Oldham[32] experimented with sewage containing "Lissapol N" fed to percolating filters at Macclesfield Sewage Works. The concentrations of "Lissapol N" (non-ionic detergent) were 50 and 100 mg/ℓ, i.e. 13 and 26,5 mg/ℓ active agent.

He concluded that, "About 70 per cent of 'Lissapol N' in settled sewage passed through the filters into the outfall. The remainder was adsorbed on the bacterial slime. There was no evidence that 'Lissapol N' could be oxidized biochemically".

Hurley[33] found in large-scale experiments at Wolverhampton that "Teepol" (anionic detergent) in sewage caused no difficulties in treatment of sewage and was "to all intents and purposes" completely removed during purification.

Spargo[34] reported on the degradation of synthetic detergents on Johannesburg Sewage Works and neighbouring streams. From his experiments and observations he has stated, *inter alia*, that:

(1) About 5 per cent of synthetic detergent present in Johannesburg sewage is removed during sedimentation and about 50 per cent of the remainder during biological filtration;
(2) The activated sludge process, as in use in Johannesburg removes approximately 66 per cent of the detergent in tank effluent entering the plant;
(3) A small amount of detergent in humus tank effluent is removed during its passage through a sand filter (the amount is dependant on the age of the filter);
(4) Not all the detergent entering a digester is broken down;
(5) The concentration of detergents in Johannesburg sewage is approximately 4,6 mg/ℓ;
(6) Witwatersrand streams are now showing appreciable pollution by synthetic detergents.

Lumb[35] carried out investigations at Halifax on the effects of synthetic detergents on sewage purification processes. He pointed out that at the time (1956) of his investigations the synthetic detergents in major use were the following:

*Note the high phosphate content (which will influence the eutrophication of rivers and water impoundments).

Effect of synthetic detergents on aeration tests

Exp. detergent	Days	Fillings	4 hr. O/A of Det.	Analysis of effluent				
				4 hr. O/A	NO_2	NO_3	BOD	Relative stability
(1) Teepol	11	18	0,05	0,83		2,5	0,74	100
Control				0,87		3,8	0,71	100
(2) Teepodol	18	26	0,17	0,72		2,8	0,45	100
Control				0,70		3,8	0,61	100
(3) Lissapol N	12	18	0,76	1,51		2,3	0,41	100
Control				0,92		3,5	0,48	100
(4) Santomerse	10	12	0,20	3,07	0,68	2,6		
Control				1,04	0,1	4,7		
(5) Santomerse	5	9	0,20	3,20	0,98	1,4		
Control				1,15	0,41	3,3		
(6) Santomerse	12	18	0,20	2,52	0,52	0,3	1,68	100
Control				1,11	0,27	3,7	0,39	100

(Concentration of detergent in each 10 p.p.h.t.: Control, Nil)

(1) Sodium alkyl sulphates, $R-O-SO_3Na$ (where R denotes a long-alkyl chain, straight or branched) e.g. "Teepol".
(2) Sodium alkyl aryl sulphonates, $R-C_6H_4-SO_3Na$, e.g. "Santomerse No. 1".
(3) Non-ionic ethylene oxide condensates, $R-C_6H_4-(OC_2H_4)_n-OH$, e.g. "Lissapol N".

He indicated that whilst Hurley[33] had found that "Teepol" did not affect biological oxidation, Degens[36] and associates had shown that in the case of alkyl aryl sulphonate biochemical oxidation was retarded at detergent concentrations of 25 mg/ℓ and over. He also drew attention to the results reported by Gaillard (*vide ante*) on the adverse effects of the alkyl aryl sulphonate, "Santomerse".

Lumb[35] has concluded from experiments with small-scale percolating filters and activated sludge systems that the performance of both these processes is adversely influenced by small concentrations of detergents of the alkyl-aryl sulphonate and non-ionic (poly-glycol ether of alkylated phenol) types.

He also concluded that both these types of detergents give rise to foaming of purified effluents and the deterioration caused by these detergents becomes significant when their proportion, as active matter, reaches about 10 mg/ℓ in settled sewage and increases sharply above this level. This amounts to 20 mg/ℓ total concentration of all detergents, as active matter in sewage.

Following the investigations of Hurley at Wolverhampton in 1949 (*vide ante*), Raybould[37] and Thompson reported on "some large-scale investigations on the influence of alkyl benzene sulphonate detergents on sewage purification". They concluded that, apart from a tendency to foam production, synthetic detergents should not cause undue trouble on works employing percolating filters or Howarth-type activated sludge installations provided that the works are in good condition and have sufficient capacity. Overloaded sewage works treating strong sewages may suffer great difficulties. Activated sludge plants which subject the sewage to much greater turbulence than the Howarth-type may encounter more serious foaming troubles. They further conclude that, in all cases, there is still the problem of residual detergent and its effect on natural watercourses.

Comment: It will be realized from the investigations which were carried out at different centres in England and Johannesburg at a time when synthetic detergents were becoming a threat to sewage purification processes and rivers that the only acceptable detergents were of the anionic – alkyl sulphate type. Subsequently, however, manufacturers have "tailored" their products to accommodate the drawbacks which early "Syndet" mixtures possessed in regard to their adverse influence on sewage purification, including foaming.

Notwithstanding, the presence of phosphates (cf. "Builders") in synthetic detergent mixtures is an aggravating factor as far as eutrophication of streams and water impoundments is concerned. Further attention needs to be directed towards the substitution of alternative chemicals for phosphates.

V. *Proteins*

Proteins are important dietary constituents which replace nitrogen lost by the animal organism by the excretion of urea. Some also supply assimilable sulphur to the digestive system.

Proteins contain carbon, hydrogen, oxygen and nitrogen (C, H, O, N) and some to a lesser degree contain sulphur and phosphorus.

Proteins, on average, have the following composition:

Element	*Per cent*
Carbon	50
Nitrogen	16
Oxygen	22
Hydrogen	7
Sulphur	trace – 4
Phosphorus	trace – 4

Haemoglobin also contains iron (Fe)

A protein is a high molecular weight substance made up of some 23 amino-acids held together by peptide linkages, i.e. the α-amino group of an amino-acid molecule is linked with the carboxyl group of the next amino-acid. Polymers with peptide linkages other than the naturally occurring proteins are referred to as polypeptides. Although many of the amino and carboxyl groups of the constituent amino-acids are neutralized in the formation of peptide linkages, there are always some free groups, thereby imparting amphoteric properties to proteins.

Over 30 amino-acids have been identified as constituents of proteins.

The properties and characteristics of proteins include the following:

(1) Formation of fibres;
(2) Display colloidal behaviour;
(3) Ability to orient themselves at a water surface/interface.

Denaturation by such agencies as heat, exposure to ultraviolet light, addition of acid, alkali, acetone, urea, alcohol, detergents, etc. Denaturation diminishes the solubility of a protein particularly at the isoelectric point.

Hydrolysis of proteins by acids, alkalis or enzymes yields, ultimately, a mixture of amino-acids which, in fact, are the building blocks of proteins. Hydrolysis can take place through particular linkages which are attacked by specific enzymes collectively referred to as hydrolases which catalyse the transformations to, mainly, α-amino acids.

Transformation of Proteins in Sewage Purification: The significant transformation of proteins in sewage is their hydrolysis to α-amino acids by the agency of enzymes as indicated previously. Then follows, under aerobic conditions, dissimilation of these into ammonia (NH_3) and CO_2.

The NH_3 under aerobic conditions is transformed by nitrosifying bacteria (e.g. *Nitrosomonas*) to NO_2 (nitrite) and then by nitrifying bacteria (e.g. *Nitrobacter*) to NO_3 (nitrate) viz:

$$\underset{\text{Ammonia}}{NH_3} \xrightarrow{\textit{Nitrosomonas}} \underset{\text{Nitrite}}{NO_2} \xrightarrow{\textit{Nitrobacter}} \underset{\text{Nitrate}}{NO_3}$$

Should anaerobic conditions set in, the process will reverse when denitrification will take place. The nitrate (NO_3) will, in fact, be reduced stepwise to N_2 by micro-organisms such as *Bacillus maraxella*, *Pseudomonas*, etc.

Where, initially, protein decomposition takes place under anaerobic conditions amines as well as ammonia will be formed. The amines will then be decomposed to NH_3 by other bacterial species.

Therefore, in sewage, whether conditions are aerobic or anaerobic, initially, NH_3 and CO_2 will be formed; the conversion then of NH_3 to NO_3 can be easily accomplished by aerobic treatment processes, e.g. the activated sludge process or by means of percolating or other type biofilters.

VI. *Polysaccharides*

Polysaccharides are carbohydrates formed by the condensation of large numbers of monosaccharide molecules.

Carbohydrates may be classified as follows:

(1) Monosaccharides, or simple sugars such as glucose and fructose, $C_6H_{12}O_6$.
(2) Sugar-like polysaccharides or oligosaccharides consisting of,
   (i) Disaccharides, $C_{12}H_{22}O_{11}$, which, on hydrolysis, yield two monosaccharide molecules, e.g. sucrose (cane sugar), maltose (malt sugar), lactose (milk sugar).
   (ii) Trisaccharides, $C_{18}H_{32}O_{16}$, which, on hydrolysis, yield three monosaccharide molecules, e.g. raffinose.
   (iii) Tetrasaccharides, $C_{24}H_{42}O_{21}$, which, on hydrolysis, yield four monosaccharide molecules, e.g. stachyose.
(3) Polysaccharides which do not resemble sugars. They are condensation products of monosaccharides (simple sugars). A formula common to most is $(C_6H_{10}O_5)_n$. Examples are starch, glycogen, cellulose.

Carbohydrate Dissimilation: Sugars (carbohydrates) are degraded by the following pathways, viz:

(i) fermentation;
(ii) oxidation.

For instance, disaccharides may be hydrolysed to monosaccharides. However, cellulose shows greater resistance to biodegradation than many other polysaccharides. The hydrolysis proceeds at a slow rate due to the high molecular weight making it insoluble.

Starch: Starch and oil occur in flowering plants. Tilden[38] states that from the green algae up through the flowering plants true starch and oil remain as characteristic reserve foods. Pentosan also occurs, but as a secondary reserve of far less importance. Commercial sources of starch include maize, wheat, barley, rice, potatoes, sorghum. There are very few of the higher green plants which do not accumulate

starch, notably the onion, leek, snowdrop and dahlia.

Raw starch grains are insoluble in cold water and are hydrophilic. The insolubility is due to the resistance of the outer cellulose layer on the granules. If this outer layer is ruptured by boiling in water the starch becomes soluble. Also, if the starch is very finely ground it will show limited solubility. Starch brought into solution by boiling in water will gelatinize on cooling the solution.

Starch contains amylose, a straight chain polymeric molecule with 200 to 300 glucose units and amylopectin, a branched polyglucose containing phosphate.

Starch is hydrolysed in dilute acid solution to give glucose which, under certain conditions, can be quantitative. It is also readily converted by enzymes (diastase and amylase) into glucose.

Pectin functions as the inter-cellular cementing material of plant tissue. A number of pectins are known. They are the polymers of galacturonic acid, arabinose, and methylated galacturonic acid. The "soft rot" of vegetables and fruit is considered to be due to the pectin-decomposing enzymes of micro-organisms. Pectin substances are incorporated in many foods and pharmaceutical products. Pectin has been defined as a purified carbohydrate product obtained from the dilute acid extract of the inner portion of the rind of citrus fruits or from apple pomace – consisting chiefly of partially methoxylated polygalacturonic acid.[39]

The ability to form jellies and gels is the most important property of pectin isolated from plant sources.

Glycogen: Glycogen bears analogy to starch in that it is the reserve carbohydrate of the animal body, hence the term "animal starch". It is found in the liver and muscles where it is synthesized from glucose stored in the body. Glycogen is also found in plants which are lacking in a chlorophyll system, e.g. fungi and yeasts but not green plants.

Glycogen shows chemical behaviour similar to starch. In acid solution and in the presence of enzymes (e.g. diastase) it is converted to glucose. However, unlike starch, it is readily soluble in water. Glycogen has the formula $(C_6H_{10}O_5)_n$.

Cellulose: Cellulose, $(C_6H_{10}O_5)_n$, is the main constituent of the cell wall of plants and is the most widely distributed organic compound. Cotton is pure cellulose and wood contains cellulose and a certain amount of lignin which is not a polysaccharide. Cellulose is insoluble in water. It forms part of the human food intake but is not digested and passes out, chemically unchanged, in human ejecta.

From the preceeding short notes on polysaccharides it will be evident that as far as sewage purification is concerned, starch will be present in suspension and will be unaffected by gravity techniques unless adsorbed on to settleable particles and will remain in the feed to aerobic treatment units. However, starch adsorbed on settling particles will end up as part of the sludge in sedimentation tanks in a conventional plant.

Glycogen, being soluble in water, will be biodegraded in the usual aerobic process.

Cellulose and cellulosic material e.g. paper, cotton, etc., unless removed by screens and sedimentation, will eventually be somewhat degraded by anaerobic treatment.

VII. *Industrial Effluents*

In a purely residential community there will be no industrial effluents discharged into the sewerage system but with smaller local authorities – as time progresses – decisions have to be made in regard to applications by industrialists to establish industries in the municipal area. Where "dry industries" manufacturing articles which do not require water in their manufacture, except for so-called consumptive use, no effluent problem exists. However, where an industry wishes to dispose of effluent via a sewer then it becomes necessary, in many cases, for pretreatment of such effluent to be prescribed and such prescribed pretreatment to be satisfactorily carried out at all times. However, industries of this nature would require to be established in an industrial township set aside by the local authority for this purpose. An abattoir, for instance, would require to be placed in a noxious trades area of an industrial township.

At one time many small local authorities in South Africa had abattoirs. Today, however, the tendency is for these to be closed down and larger and more modern regional abattoirs to be established throughout the country under the control of the Abattoir Corporation of South Africa.

Thus, with a small municipality, the only industrial discharges would be from laundry and dry-cleaning establishments. The effluents from such establishments will contain large amounts of detergents. A fire hazard might exist in the case of a dry-cleaning works depending on whether the cleaning liquids are flammable. Flammable liquid wastes should not be allowed to gain access to the sewerage system – unless readily miscible in water.

Composition of Sewage

From the foregoing it is plain that sewage will contain, *inter alia*, fats and oils, proteins, amino-acids, ammonium carbonate and ammonia, creatinine, glucose, urea, uric acid, phosphate, sulphate, sulphide, chloride, calcium, magnesium, sodium, iron, a variety of bacteria (mainly coliforms), cholesterol, lecithin, cellulose, indole, scatole, mercaptans, soaps.

However, Albritton[40] has given a large list of substances excreted in urine, faeces and sweat on the

basis of mg/kg body weight/day for urine and faeces and mg/100 mℓ for sweat. This includes – in addition to those indicated above – the following:

Alanine, arginine, aspartic acid, citrulline, cystine, glutamic acid, glycine, histidine, hydroxyproline, isoleucine, leucine, lycine, methionine, ornithine, phenylalanine, proline, serine, threanine, tryptophan, tyrosine, valine. The amounts present are small and vary from as low as 0,02 mg/kg body weight/day for hydroxyproline to 10,1 mg/kg body weight/day for glycine.

Values are also given for lipids (present in sebum); vitamins, hormones, miscellaneous organic compounds as well as minor minerals.

This vast array of constituents focuses attention on the nitrogen and carbon content of sewage.

Jenkins[41] has quoted the following results (due to Painter, *et al*, 1960)

Organic Carbon Distribution in Domestic Sewage
(from the results of Painter *et al*, J. and Proc. Inst. Sewage Purif., 1961, (4), 302-314)

Constituent	% Organic Carbon	mg C/ℓ
Fatty acids	22,8	71,0
Carbohydrates	17,7	55,0
Proteins	10,0	31,0
Fatty acid esters	9,1	28,2
Soluble acids	6,8	21,0
Anionic surface active agents	4,5	14,0
Amino-acids	1,6	5,0
Creatinine	1,1	3,5
Amino-sugars	0,6	1,8
Amides	0,5	1,5
TOTAL	74,7	232,0

Organic carbon: By analysis 311 mg/ℓ
By addition 323 mg/ℓ
Per cent identified = 75

From the above results the three major constituents are seen to be fatty acids, carbohydrates and proteins.

Bacterial Enzymes and Sewage Purification

Wooldridge and Standfast[42] concluded from experiments carried out by them at the London School of Hygiene and Tropical Medicine that the purification of sewage is essentially a matter of bacterial enzymes – whether associated with living or dead bacterial cells being immaterial – and mainly of oxidation-reduction enzymes. However, they do not exclude as part of the process such agencies as colloidal flocculation, sedimentation and adsorption, or rule out the possibility of some step in the purification being due to the agency of other enzymes such as proteases, lipases and carbohydrases.

Notwithstanding, the thesis propounded by them is to the effect that the most important factor in sewage purification is a series of catalysed oxidation-reduction reactions determined by bacterial enzymes present in either living or dead bacterial cells, or liberated by them into the fluid of the reacting system.

There seems little doubt that organic catalysts (enzymes) play a part in the purification of sewage when cognizance is taken of the short time of contact of settled sewage in a percolating filter to achieve purification. In fact, it is a very striking and fascinating transformation of organic impurities by catalytic reaction.

Ingols[43] investigated the hydrolytic enzymes in activated sludge. He concluded, *inter alia*, that there is a marked increase in pepsin during the development of activated sludge from sewage. Lipase, diastase and trypsin increase slightly.

Lipase, pepsin and diastase are found only on the surface of the sludge floc.

A specific enzyme, diastase, of the sludge organisms may be increased to the extent of 500 per cent by feeding the sludge organisms with starch at 5°C.

Purification is correlated with the biochemical property, enzyme activity, of the sludge floc.

Clarification of the sewage is correlated with the biophysical property of the activated sludge floc.

Anaerobic Digestion

Boruff and Buswell[44] have shown that polysaccharides such as starch, cellulose, the pentosans and cellulosic materials decompose during sludge digestion to give a gas composed of equal volumes of CO_2 and CH_4 (methane). Cellulose was found to decompose quantitatively as follows:

$$C_6H_{10}O_5 + H_2O = 3CO_2 + 3CH_4$$

Neave and Buswell[45] studied the anaerobic decomposition of the various nitrogenous constituents of sewage as well as the fatty acids.

The main constituents were found to be urea, nucleoproteins and simple proteins and other degradation products. Rapid hydrolysis of urea to ammonium carbonate was demonstrated.

They have shown that fatty acids decompose to give CO_2 to CH_4 ratios which increase with the molecular weight of the acid, e.g.

n-Butyric acid $2C_4H_8O_2 + 2H_2O = 3CO_2 + 5CH_4$
Stearic acid $C_{18}H_{36}O_2 + 8H_2O = 5CO_2 + 13CH_4$

They have put forward the following fatty acid formula:

$$C_nH_{2n}O_2 + \frac{(n-2)}{2} H_2O = \frac{n+2}{4} CO_2 + \frac{(3n-2)}{4} CH_4$$

Symons and Buswell[46] studied the anaerobic

fermentation of carbohydrates, ketones, aldehydes, alcohols, glycols, acids, esters and other related compounds. All these substances investigated were found to hydrolyse anaerobically to give definite volumes and ratios of CO_2 and CH_4.

Buswell and Buroff[47] reported results for the anaerobic decomposition of pure substances as follows:

Anaerobic Fermentation of Pure Substances, 25 – 35°C
gas recovered S.T.P[2]

Substance fed	Grams fed	CH_4 as drawn[1]	Vol litres	Weight[4] grams	Ratio CO_2:CH_4	Theoretical Ratio[3] CO_2:CH_4	Per cent of material fed measured as $CO_2 + CH_4$[2]	
							Found	Theoretical[3]
Cellulose[a]	180,0	48 – 55	152,30	197,99	1:1,03	1:1,00	111	111
Starch[a]	68,5	48 – 55	56,71	74,86	1:1,0	1:1,00	109	111
Glycerol[b]	10,0	56 – 60	7,11	8,81	5:7,07	5:7,00	88	90
Acetic acid[c]	114,18	48 – 55	80,80	107,41	1:0,97	1:1,00	94	100
Propionic acid[c]	130,06	56 – 60	119,70	145,15	5:6,93	5:7,00	112	112
Butyric acid[d]	150,0	60 – 65	158,46	184,82	1:1,70	1:1,67	123	120
Benzoic acid[d]	91,38	55 – 60	103,27	144,0	1:1,20	1:1,16	158	166
Casein[a]	47,5	65 – 72	44,50	57,8	1:1,08	1:1,07	—	171[5]
					1:2,30[1]	1:2,26[1]	76[1]	82[1]
Peptone[e]	27,5	62 – 72	25,56	26,21	1:0,60	1:0,8	—	166[5]
					1:2,6[1]	1:3,2[1]	48[1]	46[1]
Carbon (theoretical)	1,0		1,87	2,5		1:1		250

1. Gas as drawn, N_2 free basis but not corrected for retained CO_2.
2. Corrected for dissolved CO_2.
3. Based on equations given in body of article.
4. Does not include small volume of N_2 [Ind. Eng. Chem. 18, 407, (1926)].
5. Includes $NH_4HCO_3 + H_2S$.
a. Boruff.
b. Symons.
c. Neave. All with Buswell.
d. Tarvin.
e. Thrush.

The same authors (Buswell and Boruff) give results for gas production from various sewage constituents (fats, scum, grease, crude fibre, protein).

Gas Production from Various Sewage Constituents
(Gas as drawn – not corrected for retained CO_2) 760 mm and 0°C

Material	CH_4 %	Volume per g decomposed c.c.	Weight per g decomposed g	Volume per lb decomposed cubic ft
Fats	62 – 72	1112 – 1433	1,33 – 1,54	18 – 23
Scum	70 – 75	900 – 1 000***	—	14 – 16
Grease*	68	1 050	1,13	17
Crude fibre	45 – 50	892	1,11	13
Protein**	73	720	0,76	12

*Petroleum ether extract, fats, lime soaps, etc.
**Average composition, Mathew's "Physiological Chemistry", 4th Ed. page 116.
***Per gram scum added.

Buswell and Boruff[48] have inferred from their results and those of their collaborators that the methane (CH_4) content as well as the total gas produced in the anaerobic decomposition of organic matter depends on the ratio of C:H:O:N in the material being decomposed and that the water acts as the oxidizing-reducing agent.

They have concluded that greases, fats and soaps furnish the best quality (62 to 75 per cent CH_4) and the greatest quantity of gas. Protein materials, they state, furnish a similar high grade of gas but in lesser amounts per unit weight digested. The small amount of cellulose and cellulosic materials when fermented anaerobically gives more than 0,454 kilograms of gas for the same weight of volatile matter digested.

3. Matters of Bacteriological Importance – the Significance of Waterborne Diseases

The bacteriological aspects of sewage and sewage purification can be reasonably considered under the following headings:

(1) Micro-organisms present in sewage.
(2) Biological changes brought about by aerobic fermentation.
(3) Anaerobic decomposition.
(4) Waterborne disease organisms and their fate during sewage purification.

(1) *Micro-organisms Present in Sewage*

Bacteria in sewage

Prescott and Winslow[49] have quoted enumerations from different sources, viz:
1 000 000 to 5 000 000 bacteria per millilitre in the sewages of Essen, Berlin, Charlottenburg, Leeds, Exeter, Chorley and Oxford; 2 000 000 to 10 000 000 in the sewages of London, Walton and West Derby, and, over 10 000 000 per millilitre in the sewages of Paris, Ballater and Belfast. Levine[50] considers that the number can exceed 60 000 000 per millilitre but points out that ordinary plate counts rarely exceed several million per millilitre.

Prescott and Winslow[49] state that the number of colon bacilli in English sewages varies between 50 000 and 75 000 per millilitre. Currie[51] places the number as high as 100 000 per millilitre and states that summer counts are highest.

The World Health Organization[52] has indicated that raw domestic sewage can contain up to 10^9 coliforms per 100 millilitres, 10^8 *Escherichia coli* per 100 millilitres, and 10^7 faecal streptococci per 100 millilitres and more than 10^4 *Salmonellae* per 100 millilitres. During epidemics it is considered that several thousand cholera vibrios can be present in 100 millilitre of raw sewage.

Points to note, however, are that the above numerical evaluations of Prescott, Winslow and Currie are probably on the high side since they may represent counts done on samples taken during the day; the number of bacteria in samples taken at night are lower.

This was borne out by the results of Winslow and Phelps[49] on Boston sewage as far back as 1905, e.g. during the night period 03h30 to 07h30 the count was only 400 000 per millilitre whereas during the day period 15h30 to 19h30 the number of bacteria per millilitre was 4 600 000.

The bacterial population in sewage will vary from place to place depending on the industrial effluents present together with the domestic sewage. In this connexion it should be noted that the soakage water from laundering clothes contains a large number of bacteria and this is also the case with certain industrial effluents e.g. abattoir effluent. On the other hand, certain industrial effluents destroy a portion of the bacterial population of sewage. It has been found that during workdays the count is much lower than on Sundays – pointing to the overall depressing effect of industrial effluents.

The bacteria in sewage are mainly of faecal origin and, in certain instances, pathogens such as typhoid and paratyphoid as well as dysentery bacilli will be present.

In addition to the bacteria present in sewage, viruses, protozoa and helminths may be present.

Broadly considered, the bacteria in sewage fall into two groups viz:

(i) Saprophytes which use dead matter as substrate and do not cause disease, and,
(ii) Pathogens which may cause disease.

Saprophytic bacteria: The saprophytic bacteria are of two types, viz:

(a) Autotrophic bacteria which use carbon dioxide as their sole carbon source for growth and,
(b) Heterotrophic bacteria which make use of carbon in organic material.

From a sewage purification point of view the problem of biological treatment is quite different from that of industrial fermentation where a substrate of carefully arranged composition is inoculated with a pure culture of organisms, e.g. bacteria, yeasts. In the case of sewage, however, a large, uncontrolled number and variety of organisms are present and the composition of the substrate also cannot be controlled.

Therefore, the problem of sewage purification is to maintain conditions such as environment and temperature which are best suited to the activities of desirable bacteria whilst at the same time ensuring that the activities of undesirable bacteria are suppressed or eliminated.

Gaseous Requirements: Micro-organisms can be classified according to their gaseous requirements as follows:
An *aerobic* organism is one which requires free oxygen, whilst an *anaerobic* organism is one whose growth is inhibited by free oxygen; and one that can

grow under aerobic or anaerobic conditions is termed *facultative*. Yet again, there are organisms which do not grow in contact with oxygen at atmospheric pressure nor in conditions totally devoid of oxygen, these are referred to as *micro-aerophilic* organisms.

The classification of organisms according to oxygen requirements is as follows:

Obligate (strict) aerobes:	These require the presence of oxygen.
Facultative aerobes:	These grow better in the presence of oxygen but can grow under anaerobic conditions.
Micro-aerophilic organisms:	Organisms which can live in the absence of oxygen or in the presence of very low tensions of oxygen (less than 0,2 Atmospheres). Higher oxygen tensions are inhibitory.
Facultative anaerobes:	Organisms which can live equally well in the presence or absence of oxygen.
Obligate (strict) anaerobes:	Organisms which multiply only in the complete absence of oxygen.

Bacteria in Sewage: Saprophytic bacteria found in sewage include the following:

Pseudomonas fluorescens, Pseudomonas aeruginosa, Proteus vulgaris, Bacillus subtilis, Bacillus cereus, Acrobacter cloacae, Zooglea ramigera.

Most bacteria are saprohytic and most bacteria in sewage are aerobic or facultative anaerobes.

Categorization of Bacteria in Sewage: The following is a brief categorization of bacteria in regard to aerobic and anaerobic respiration:

Obligate Aerobes:

Included in this category are the following: *Bacillus subtilis*; the nitrifying bacteria *Nitrosomonas* and *Nitrobacter*; the sulphur oxidizing bacteria, *Thiobacillus* and *Desulpho vibrio*.

Obligate Anaerobes:

Clostridium sporogenes (This organism has been used as an indicator of pollution of water by sewage as well as *E. coli* which is the commonly used indicator in South Africa).

Facultative Anaerobes:

These include, *Escherichia coli*, *Klebsiella* and other genera of the family *Enterobacteriaciae*, *Pseudomonas aeruginosa*, *Thermothrix*, *Thiobacilli* (e.g. *T. ferro-oxidans*) and methane-producing bacteria (e.g. *Methanobacterium*).

Viruses in sewage

These are dealt with in sub-section (4) in connexion with waterborne diseases (q.v.).

Protozoa in sewage

A protozoon consists of a single cell which is morphologically and functionally complete. All parasite forms are not pathogens, e.g. *Entamoeba coli* is a harmless commensal whereas the amoeba, *Entamoeba histolytica* is the causative organism of amoebiasis (or amoebic dysentery).

Entamoeba histolytica (size 20 μ to 30 μ) has as its normal habitat the large intestine of man where it causes ulceration. The disease may manifest itself in the form of a mild diarrhoea or chronic dysentery. Secondary lesions can take place by migration of the organism to the liver or brain when abscesses are set up.

Another amoeba, *Naegleria grubii*, has been shown to cause a fatal meningoencephalitis in persons swimming in certain lakes and ponds. However, only a few cases of the disease have been notified – mainly in the USA, Czechoslovakia and Australia. Its connexion with sewage, however, has not been reported.

Helminths in sewage

Helminths are metazoan parasites (or parasitic worms) which infest man and animals. They may be classified in three main categories viz:

(1) Nematodes (roundworms, threadworms, whipworms, etc.).
(2) Cestodes (tapeworms).
(3) Trematodes (flukes).

The classification of the above three divisions is as follows:

Family	**Species**
NEMATODES (Class: Nematoda)	
Ascaridae	*Ascaris lumbricoides* (Roundworm)
Oxyuridae	*Enterobius vermicularis* (Pinworm)
Trichinellidae	*Trichenella spiralis* (Muscleworm)
Ancylostomatidae	*Ancylostoma duodenale* (Hookworm)
	Necator americanus
Rhabditidae	*Strongyloides stereoralis* (Threadworm)
Trichuridae	*Trichuris trichiura* (Whipworm)
Filaridae	*Wuchereria bancrofti* (Bloodworm)
	Loa loa
Dracunculidae	*Dracunculus medinensis* (Guineaworm)

CESTODES (Class: Cestoda) – Tapeworms	
Taeniidae	*Taenia solium* (Pork tapeworm)
	Taenia saginata (Beef tapeworm)
	Echinococcus granulosus (infests the dog, wolf and other carnivores – transmitted to man, causes hydatid cysts).
Diphyllobothridae	*Diphyllobothrium latum* (Broad tapeworm or fish tapeworm)
Hymenolepedidae	*Hymenolepis nana* (Dwarf tapeworm)
TREMATODES (Class: Trematoda) – Flukes	
Schistosomatidae	*Schistosoma haematobium* (Blood fluke)
	Schistosoma mansoni (rectal fluke)
	Schistosoma japonicum (Intestinal fluke)
Fasciolidae	*Fasciola hepatica* (Liver fluke)
	Fasciolopsis buski (Intestinal fluke in man and pig)
Troglotrematidae	*Paragonimus westermani* (Lung fluke)
Opisthorchidae	*Clonorchis sinensis* (Asian/Chinese fluke)

Nematodes and cestodes are found in faeces together with their ova. Helminths cannot reproduce within a human host and have to distribute their ova into the outside environment. Helminths are relatively long-lived – from a few months up to 30 years.

From the point of view of sewage disposal in South Africa the roundworm (*Ascaris lumbricoides*) is of interest. The eggs/ova are resistant to low temperatures and a high degree of desiccation as well as to certain chemicals, but are killed by a temperature of 60°C. This being so, they are able to survive mesophilic digestion.

At one stage, dried digested sludge was used by householders as a fertilizer for their gardens and lawns. But this practice is not allowed for a number of reasons, one of which, is the likely infection of children by the roundworm (*Ascaris lumbricoides*).

Keller[53] reviewed the literature pertaining to the occurrence and viability of parasitic ova and cysts in sewage with special reference to *Ascaris lumbricoides*. A significant reference quoted by him concerned the extraordinary power of resistance of *Ascaris* ova to changes in temperature and moisture concentration, to chemical influences and to sewage treatment which was considered to be due mainly to the complicated structure of the egg's shell. The eggshell consists of five layers, namely, an outer proteinaceous epithelial membrane, three layers of chitinous material, and an inner fibrillary lipoidal membrane.

This, perhaps, is no less significant than the survival of tomato seeds, watermelon and pumpkin pips which are viable after passing through the sludge digestion process.

Keller[54] subsequently investigated the influence of heat treatment on the ova of *Ascaris lumbricoides* in sewage. He noted that in controlled laboratory scale experiments, thermophilic digestion at 53 to 54°C for a minimum period of 24 hours destroys all parasitic ova and cysts and that prolonged (impracticable) exposure of sewage sludge to a temperature of 37°C inactivation of the ova of *Ascaris lumbricoides* occurs. However, he established that the important factor was the temperature of 54 to 55°C which alone destroyed the viability of the ova.

This being so, it can be concluded that in both the "Porteous" and "Zimpro" processes of sludge treatment the ova of *Ascaris lumbricoides* and, probably the ova of other parasite helminths, will be inactivated since Keller found that increase of temperature of exposure above 55°C reduces the time necessary to destroy the viability of the ova, since at boiling point complete inactivation is achieved in a few minutes.

In a conventional activated sludge plant involving sedimentation of raw sludge and digestion of surplus activated sludge together with the raw sludge *Ascaris lumbricoides* ova, if present originally in the raw sewage entering the sewage purification works will be present, finally, in the digested sludge. This will be the case, also, for a conventional plant using biofiltration of settled sewage and anaerobic digestion of raw sludge.

In the case of sewage purification works employing the 'extended aeration' activated sludge method without digestion or heat treatment of the surplus activated sludge, the ova of *Ascaris lumbricoides* will be present in the sludge disposed of and will be a matter of concern.

Osborn,[55] in referring to Johannesburg's newer sewage purification works operating on the extended aeration principle, has stated that the main concern in the disposal of sludge is the large number of roundworm ova of *Ascaris lumbricoides* present in South African sludges. He points out that Melmed and Comninos[56] found concentrations of *Ascaris* ova in Johannesburg's Olifantsvlei extended aeration activated sludge works of the order of 3 000 per gram. However, Osborn[57] noted that Melmed has shown that irradiation at a dose of 1 000 Gray (Gy) is as effective as heat treatment in reducing the viability of helminth ova (99 per cent reduction being obtained).

(2) *Biological Changes brought about by Aerobic Fermentation*

As has been indicated in the previous sub-section, sewage is literally teeming with bacteria and the problem of sewage purification is to create and maintain

environmental conditions such that the different types of bacteria essential to the treatment processes will be active to the best advantage.

In a sub-section (2) of this Chapter (3) the chemical constituents of sewage and their dissimilation products have been dealt with. The transformation of these hydrolysed products by nitrifying bacteria now require consideration.

Nitrification

(a) *Biological oxidation of ammonia to nitrate:* An insight into the process of nitrification whereby ammonia (NH_3) is converted to nitrate (NO_3) has been arrived at by investigation of the transformations in the soil.

Pasteur and Müller were the first to suggest that the oxidation of ammonia to nitrate was due to micro-organisms. However, the first investigators to prove this were Schloesing and Muntz in 1877. But elucidation of the organisms concerned came later through the investigations of Winogradsky.

Winogradsky, Munro and Warington, separately, worked out the conditions which were essential for nitrification. They noted, *inter alia*, that phosphate and oxygen were essential to the activity of nitrifying bacteria.

Warington found that nitrifying organisms have an optimum temperature of 37°C and that they are fairly active at 12°C and effects are produced at a temperature of 3 to 4°C.

Later, Boullanger and Massol, and Chick* were able to conclude that the nitrifying organisms found in percolating filters treating sewage were the same as those found in the soil.

Nitrification, i.e. the conversion of NH_3 to NO_3, has been found to take place in two steps. The first step is one of nitrosification whereby NH_3 is converted to NO_2 (nitrite). This is then followed by oxidation of the NO_2 to NO_3 which is the final nitrification step. Thus,

$$NH_3 \xrightarrow[\text{(oxidation)}]{\text{Nitrosification}} NO_2$$

$$NO_2 \xrightarrow[\text{(oxidation)}]{\text{Nitrification}} NO_3$$

The optimum pH value for the oxidation of ammonia to nitrite and nitrite to nitrate have been given by various authors as follows:

			pH value
Stephenson[58]	$NH_3 \longrightarrow$	NO_2	8,5 – 8,8
	$NO_2 \longrightarrow$	NO_3	8,3 – 9,3
Anderson[59]	$NH_3 \longrightarrow$	NO_2	8,3 – 8,8
	$NO_2 \longrightarrow$	NO_3	8,3 – 9,3
Mitchell[60]	$NH_3 \longrightarrow$	NO_2	Active under alkaline conditions but inhibited at pH values less than 6,0.
	$NO_2 \longrightarrow$	NO_3	Inhibited at pH values above 9,5 in presence of NH_4^+.

Mitchell considers the optimum temperature for nitrification to be 30°C, limits of activity, upper 40°C, lower 5°C.

The pH values given by Stephenson (above) are, in fact, those found by Meyerhof, Pflügers Arch. 1916, 164, 390; and Pflügers Arch. 1917, 166, 245, where the "rate of oxidation curves" are actually given.

Winogradsky, S and Winogradsky, H[61] (Ann. Inst. Pasteur 1933, 50, 350 – 432) give the overall pH limits for the complete conversion of $NH_3 \longrightarrow NO_3$ as 6,0 to 9,2.

However, all strains of nitrifying bacteria do not conform with these high pH values since we have the case of nitrifying bacteria being active in acid peat soils at a pH value of 4,6.

Nitrifying bacteria are autotrophic and belong to the family *Nitrobacteraceae*. Those responsible for nitrosification (i.e. the first oxidation step) are *Nitrosomonas*, *Nitrosococcus*, *Nitrosolobus* and *Nitrospira* whilst *Nitrobacter* and *Nitrospina* cause nitrification (i.e. the second oxidation step).

(b) *Denitrification: Biological reduction of nitrate to nitrite:*

($NO_3 \longrightarrow NO_2$)

Bacteria which catalyse the reduction of nitrate to nitrite are mainly facultative anaerobic and include *Escherischia coli*, *Klebsiella pneumoniae*, *Clostridium welchii*, *Pseudomonas denitrificans* as well as other *Pseudomonas* species.

When oxygen is unavailable, during so-called "anoxic" conditions, heterotrophic bacteria, such as the above, are able to use nitrate as a source of oxygen to produce nitrite ($NO_3 \longrightarrow NO_2$).

(c) *Denitrification: Reduction of nitrite to nitrogen (gas):*

($NO_2 \longrightarrow N_2$)

As the denitrification process continues and the availability of oxygen lessens, N_2(gas) can be produced. The whole denitrification process is thus as follows:

$$NO_3 \longrightarrow NO_2 \longrightarrow N_2O \longrightarrow N_2$$

If this denitrification process is allowed to proceed in an activated sludge settlement tank the

*Harriette Chick, "A Study of the Process of Nitrification with Reference to the Purification of Sewage", Proc. Roy. Soc. 1905, April 1, pp. 241-266.

settled sludge may be caused to rise to the surface by the nitrogen bubbles[62(a),(b)] and so report in the final effluent – thereby resulting in a poor effluent.

(3) *Anaerobic Decomposition*

Anaerobic decomposition is brought about by the activities of micro-organisms operating under anaerobic conditions whereby organic matter is converted to methane (CH_4), carbon dioxide and non-biodegradable solids, which in sludge digestion is referred to as "digested sludge".

The production of an inflammable gas in swamps ("Marsh gas"), coal mines ("fire damp") has been known for centuries. But it was not until 1776 that this gas was characterized as methane (CH_4).

In 1906 Söhngen made a study of methane-producing bacteria in mixed impure culture and showed that the calcium salts of certain simple fatty acids could be quantitatively converted to methane and carbon dioxide.

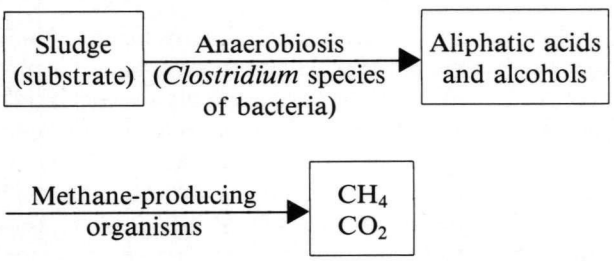
A significant discovery of Söhngen was that the cultures which decomposed formate also synthesized methane from carbon dioxide and hydrogen.

It later became apparent that many organic compounds and, in particular, those present in sewage could be anaerobically fermented to produce methane.

The anaerobic decomposition of sewage sludge takes place in two stages, viz:

(1) Conversion of polysaccharides, proteins, carbohydrates, fats, etc. to their corresponding fatty acids (e.g. acetic, propionic, butyric acids) and alcohols. This results in a pH value for the reacting mixture of about 6,0 or lower.

(2) This is followed by the conversion of the fatty acids and alcohols by methane-producing bacteria to methane (CH_4) and carbon dioxide (CO_2). This two-stage conversion may be represented as follows:



A large number of reactions are possible under anaerobic conditions involving methane-producing organisms, viz.

$$CH_3COOH + CO_2 \longrightarrow 2CO_2 + CH_4$$
$$2CH_3CH_2COOH + CO_2 \longrightarrow CH_4 + 2CH_3COOH$$
$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$
$$4\ HCOOH \longrightarrow CH_4 + 3CO_2 + 2H_2O$$
$$HCOOH + 3H_2 \longrightarrow CH_4 + 2H_2O$$
$$CH_3OH + H_2 \longrightarrow CH_4 + H_2O$$

Methane-producing bacteria (or *Methanobacteriaceae*) are obligatory anaerobes. Four genera of these anaerobes are known to produce methane, viz:
Methanobacterium (non-spore-forming rod)
Methanobacillus (spore-forming rod)
Methanococcus (coccus – non-spore-forming)

Methanosarcina (packets of eight cocci – non-spore-forming)

These so-called "methane fermenters" collectively have two optimum temperatures of activity, viz: – mesophilic group (32 to 37°C); thermophilic group (55°C).

The optimum pH value for the growth of the methane-producing bacteria lies between the limits pH 6,4 to 7,2. Below pH 6,0 and above pH 8,0 the growth is severely inhibited.

Sludge digestion: Anaerobic digestion of sludge is therefore seen as a two-stage process, viz: an acid-forming stage which is orchestrated by a variety of fairly environmentally adaptable bacteria followed by methane fermentation caused by *Methanobacteriaceae* with more sensitive requirements in regard to pH value and temperature.

In starting-up of a new sludge digester it is best to supply it first with a large volume of digesting sludge from a satisfactorily operating digester to ensure a sufficient concentration of methane-producing anaerobes as well as adequate buffering to maintain an optimum operating pH value (7,0 to 7,2 has been found satisfactory).

Alternatively, if a source of digested sludge for "seeding" purposes is not available, lime should be added in controlled amounts to ensure that the mixed digester contents do not stray below neutrality (pH 7,0) or exceed pH 7,2 in the new digester.

Also, it is well to note that the addition of lime has to be resorted to when digester capacity is inadequate (e.g. in an overloaded sewage purification works) to ensure a stable final digested sludge which is free from odour and does not give rise to fly-breeding.

(4) *Waterborne Disease Organisms and their Fate during Sewage Purification*

There are three major portals of entry by disease organisms to the animal body, viz:

(i) *Respiratory tract:* By the inhalation of droplets containing micro-organisms. This mode of infection is evidenced in the case of infectious diseases such as pneumonia, tuberculosis and measles.

(ii) *Gastrointestinal tract:* By consumption of food (which includes water) where the contamination is due to micro-organisms giving rise to dysentery, cholera, poliomyelitis, botulism, typhoid fever, hepatitis.

(iii) *Skin and mucuous membranes:* By direct con-

tact and through wounds, animal and insect bites (e.g. by fleas, lice, mites, ticks, rabid animals). Diseases in this category include tetanus, gangrene, plague, rabies, typhus, malaria, gonorrhea, syphilis, schistosomiasis (bilharzia), Congo fever.

Disease-producing organisms that require consideration are those that are water-related, a classification of which is given as follows:

Classification of Water-related Diseases

According to Feacham (*et al*)[63] the classification of water-related disease depends on four separate mechanisms as tabulated below:

Classification of Water-related Diseases

Category	*Examples*
(1) Faecal – oral (waterborne or water-washed)	Cholera Hepatitis
(2) Water-washed	
(a) Skin and eye infections	Trachoma, scabies
(b) Other	Louse-borne fever
(3) Water-based	
(a) Penetrating skin	Schistosomiasis
(b) Ingested	Guinea worm
(4) Water-related insect vectors	
(a) Biting near water	Sleeping sickness
(b) Breeding in water	Malaria

Pathogenicity

The term "pathogenic" implies the power of producing disease. Organisms that are present on the skin and other parts of the body such as the mouth, throat, bowel and do not exert any harmful effects, are described as "commensals" in contradistinction to the "pathogens" which cause disease.

However, certain commensals are potential pathogens and also, in the case of "carriers" pathogens can play the role of commensal in such carriers.

The pathogenic and commensal micro-organisms of interest in sewage disposal include bacteria, viruses and protozoa. These three pathogenic categories may be defined and described as follows:

Bacteria

Bacteria are unicellular living organisms, belonging to the plant kingdom, distinguished from the majority of other plants by the absence of a definite nucleus, the green pigment chlorophyll and the supporting substance, cellulose.

A bacterium is enclosed by a membrane composed of condensed protoplasm, referred to as ectoplasm. This encloses the endoplasm, in which granules may be distinguished. In some cases, the surrounding membrane is sufficiently stiff to keep the cell rigid, in others, it may be somewhat flexible but does not permit of rapid change of shape, as occurs in certain protozoa.

Bacteria are non-motile unless suspended in a fluid. They may be wafted about by air and eventually settle as is the case with fine particles such as fine dust, fog, etc.

Bacteria possess an asexual method of reproduction. Under suitable conditions of food and temperature a bacterium usually elongates, forming a septum in the middle which divides the bacterium into two; these two segments separate to become two independent bacteria.

Certain species of bacteria are spore-forming. A spore is a round or oval body which forms within a bacterium: when the spore is mature, the bacterium disintegrates leaving the spore free. This affords a means of protecting the bacterium against adverse conditions since when conditions become favourable the vegetative form of the bacterium emerges by rupture of the spore.

Spore formation constitutes a means of keeping the species alive in conditions of adversity and is not to be regarded as a method of reproduction.

Morphology: Bacteria display a limited number of shapes, e.g. spheres, rods, spirals.

Cocci: These are relatively uniformly spherical in size (c. 1 μ being the average size). Apart from the single state of coccus we have diplococci where the cocci are arranged in pairs; staphylococci, arranged in clusters; streptococci, in chains; tetracocci, plates or multiples of four; sarcina, packets or multiples of eight cocci.

Bacilli: These are rod-like and reproduce by division. Some bacilli have flagella and are motile and some are able to produce spores.

Vibrios, spirilla, spirochaetes: These are mobile, non-sporing organisms. In the case of vibrios, the view presented is a short curved organism, the longer spiral form being spirilla or spirochaetes.

Most aquatic bacteria are heterotropic (i.e. they live on organic matter). Heterotrophic bacteria obtain their carbon mainly from organic sources, their nitrogen from either or both inorganic and organic sources. Autotrophic organisms are able to multiply in a purely inorganic environment, synthesizing their carbon substances from CO_2 or HCO_3 and their nitrogenous material from ammonia or nitrate.

Waterborne Diseases

Feacham *et al*[64] consider a "waterborne disease" as one which is transmitted when the pathogen is in water which is drunk by an animal or a human being resulting in the drinker becoming infected. The term waterborne disease they state, has been indiscriminately used to the extent that the term "waterborne disease" has become synonymous with "water-

related disease".

Another misconception is that waterborne implies the usual or only means of transmission. However, all waterborne diseases can also be transmitted by any route which allows faecal contaminated material to be ingested. For instance, cholera can be spread by contaminated food as well as by faecal contaminated drinking water. Thus it is axiomatic that transmission of disease by the waterborne route can also result from any other faecal-oral route.

In the following tabulation a variety of water-related pathogenic diseases are given together with the type of causative organism in each case and the specific pathogenic agent responsible for the disease/s.

It will be noted that four types of causative organisms, viz: bacteria, viruses, protozoa and helminths are given.

Pathogenic Bacteria in Sewage

Intestinal organisms present in sewage are many and varied. A considerable number of the *B. coli (Escherichia)* type are present. These are present in the large intestine of human beings and animals.

The presence of *E. coli* organisms in water is taken as an indicator that pollution from a faecal source has taken place. However, *B. coli* organisms are merely indicators of faecal pollution and not, *per se*, to be regarded as disease organisms.

Indicator Organisms: Escherichia coli constitute the most important indicator organisms. Nonetheless other organisms e.g. faecal streptococci have received favour in many quarters. But, their disadvantage in relation to *E. coli* is that they are not as abundant as *E. coli* in faeces and may grow on vegetation and insects.

Indicator organisms should comply with the following criteria:

(1) They should be present in greater numbers than any pathogen;
(2) Be unable to proliferate in water to any great extent;
(3) Be more resistant than any pathogen to the water environment and disinfection processes;
(4) Give simple and characteristic reactions enabling unambiquous identification in culture.

Intestinal bacterial indicators of pollution include the following:

E. coli, coliforms (*Citrobacter*, *Enterobacter*, *Klebsiella*), *Streptococcus faecalis*, *Streptococcus faescium* (man and animals), *Clostridium perfringens*, *Pseudomonas aeruginosa*.

Waterborne bacteria and their associated diseases are listed according to Hutchinson and Ridgway[65] as follows:

Bacterium	Disease
Vibrio cholerae	Cholera
Salmonella typhi	Typhoid fever
Salmonella paratyphi A and B	Paratyphoid fever
Salmonella montevideo B	Salmonellosis

Causative Agents of the Faecal-oral Category of Water-related Pathogenic Diseases

Water-related disease	Type of causative organism	Specific pathogenic agent
Amoebic dysentery	Protozoa	*Entamoeba histolytica*
Ascariasis	Helminth	*Ascaris lumbricoides* (roundworm)
Bacillary dysentery	Bacteria	*Shigella dysenteriae,* *Shigella paradysenteriae*
Balantidiasis	Protozoa	*Balantidium coli (ciliate)*
Cholera	Bacteria	*Vibrio cholerae*
Diarrhoeal diseases	Miscellaneous	*Giardia intestinalis* *B. faecalis alkaligenes* *Morgan's bacillus*
Enterobiasis	Helminth	*Enterobius vermicularis* *(Oxyuris vermicularis)* i.e. pinworm
Enteroviruses (some)	Virus	Poliovirus
Gastro-enteritis	Miscellaneous	*Salmonella paratyphi* *Salmonella enteritides*
Giardiasis	Protozoa	*Giardia intestinalis*
Hepatitis (infective)	Virus	Hepatitis virus
Leptospirosis	Spirochaete	Strains of leptospira
Paratyphoid	Bacteria	*Salmonella paratyphi A, B, C,* etc.
Trichuriasis	Helminth	*Trichuris trichiura* (whipworm)
Tularaemia	Bacteria	*Pasteurella tularensis*
Typhoid	Bacteria	*Salmonella typhi*

Bacterium	Disease
Salmonella typhimurium	Salmonellosis
Shigella sonnei *Shigella dysenteriae* *Shigella flaxneri*	Bacillary dysentery
Escherichia coli serotypes	Enteritis
Leptospira icterohaemorrhagia	Leptospirosis

Cholera and Typhoid

The following statement by Joseph W Bigger* is significant:

"No community which has not satisfactory methods of sewage disposal and of water treatment and protection will escape indefinitely an outbreak of cholera or enteric fever".

Cholera

Robert Koch, the famous German bacteriologist, isolated the vibrio *cholerae* in 1883 although, earlier, in 1854 the name *Vibrio cholerae* had been given in honour of Filippo Pacini, Professor of Anatomy at Florence (who had used the name). A great deal of work in elucidating the aetiology of cholera in the context of outbreaks of the disease in the water supplies of London was carried out by John Snow, an anaesthetist (in 1854).

Morphology: Cholera has been described by Mackie and McCartney[66] as "curved or 'comma-shaped' rods (vibrios) with rounded or slightly pointed ends about 1,5 to 3 μ by 0,5 μ. They are actively motile, and the movement is of a 'darting' or 'scintillating' type. Mobility is due to a single long terminal flagellum. The vibrios occur singly, in pairs, or in chains, end to end with the curves alternating – i.e. presenting a somewhat spiral arrangement. 'S' forms and spirals representing elongated undivided single cells may be noted – no spores are produced . . .".

Culture: the *Vibrio cholerae* is strictly aerobic and grows readily on ordinary culture media. The optimum pH range for growth is 8,0 to 9,0. Even in moderately acid conditions growth is inhibited but growth occurs in conditions of alkalinity sufficient to inhibit other species of bacteria.

Epidemics: Since the 19th century seven pandemics of cholera have been recorded. The focus of the 7th pandemic was in the Celebes in 1961 and the causal organism was the *El Tor* vibrio.

Kamal,[67] dealing with the "Seventh Pandemic of Cholera", regarded the global spread of cholera during the 1961 to 1971 period as taking place sequentially in three geo-chronological stages, viz:

First period, 1961 to 1962: The period taken by the pandemic to invade the states of South East Asia.

Second period, 1963 to 1969: The stage of pandemic involvement of the mainland states of Asia.

Third period, 1970 onwards: The period of Middle East-Afro-European phase of the pandemic.

Gallut[68] has drawn attention to the fact that two "neo-types", *Vibrio cholerae* and *Vibrio eltor*, had to be considered. He points out that in 1971 it was considered that the genus *Vibrio* should be regarded as containing a single species *V. cholerae*, subdivided into four biotypes:

- *V. cholerae* biotype cholerae: the classic cholera vibrio
- *V. cholerae* biotype eltor: the El Tor vibrio
- *V. cholerae* biotype proteus: common (banal) vibrios
- *V. cholerae* biotype albensis: common (banal) vibrios

Severity of the Disease: Pierce and Mondal,[69] in dealing with the clinical course of the disease of severe cholera, have quoted the following statement,

"Cholera, in its most severe form, is a dramatic and terrifying illness. The acute onset of vomiting and voluminous watery diarrhoea may lead to hypovolemic shock and death in less than 24 hours if untreated. If appropriate water and electrolyte replacement are provided, the disease may last 4 – 6 days, during which the patient may pass a total volume of liquid stool equal to twice his body weight."

Effective antibiotics shorten the duration of the illness but do not substitute for adequate fluid therapy.

The cholera vibrios are sensitive to tetracycline. A total dose of 3 or 4 grams for adults given by mouth over a period of 48 to 72 hours is sufficient to halve the average duration and volume of diarrhoea.

In recent years there have been outbreaks of cholera in South Africa – in Zululand and the Lowveld of the Eastern Transvaal.

On September 30, 1980 the first confirmed case of cholera was reported in the Transvaal Lowveld and by the end of November 1980 some 546 confirmed cases had been reported.

At the Shongwe Hospital, 269 patients were admitted between October 1, 1980 and January 7, 1981. Of these, 193 were confirmed cholera cases. Of these only two deaths took place.

A solution of "Ringers Lactate" to each litre of which 25 mℓ of 8,5 per cent Na_2CO_3 was added, was used for rehydrating the patients. The overall average imbibation of the solution was of the order of 15 ℓ per patient per 36 h. Tetracycline was given orally.

Typhoid Fever (Enteric fever)

Typhoid fever (enteric fever) is an acute infective disease of human beings caused by the bacterium,

*Joseph W. Bigger, late Professor of Bacteriology and Preventive Medicine, Trinity College, University of Dublin in "Man against Microbe".

Salmonella typhi (Bacillus typhosus, Eberthella typhi).

Paratyphoid fever resembles typhoid but is caused by such micro-organisms as *Salmonella paratyphi* giving rise to paratyphoid A; *Salmonella schottmülleri* (paratyphoid B) and the paratyphoid C group.

The typhoid bacillus was recognized by C J Eberth in 1880. There are a large number of recognized species of Salmonella – named after D E Salmon.

Course of the Disease: Typhoid bacilli, when ingested multiply in the intestines and the biliary tract and invade the bloodstream via the lymphatic system. The liver, kidneys, spleen and gallbladder also suffer their inroads.

Most typhoid fever patients are bacteria-free after approximately 3 months. However, about 2 to 5 per cent develop into chronic carriers and may remain carriers for many years. Most of the carriers harbour the organisms in the gallbladder, some in the intestinal tract and others in the urinary passages.

Dissemination of the bacilli by carriers perpetuates the disease. An illustration of this is given by Bigger[70] as follows:

"In 1937, in Croydon, a gang of workmen was employed in a well to increase its capacity. At night, when work had ceased, water was pumped from the well and distributed to the inhabitants without adequate treatment. Sanitary arrangements were made for the workers, but it seems likely that some of these avoided the unpleasant journey to the surface by relieving themselves close to where they worked. One of these was a typhoid carrier: the water was contaminated by the excreta. 311 Persons suffered from typhoid fever: 42 died".

The concentration of pathogens (e.g. cholera and typhoid) in sewage is a function of the number of carriers and cases of a community utilizing a particular sewage reticulation or other sanitary system. It is necessary, by the use of adequate sewage purification and waterworks facilities to provide a community with pure, wholesome water.

In the United States no water filtration plants existed prior to 1870. However, with the progressive installation of community water supplies deaths due to typhoid fever were reduced and finally eliminated except for certain minor occurrences. This is illustrated by the fact that in 1900 the number of deaths per 100 000 was 35,8 and this reduced to 2,5 in 1936 and, today, to all intents and purposes it is zero.

This surely is a lesson for developing countries – to place a high priority on the exercise of high standards of sanitation and hygiene to give protection to their people against the inroads of waterborne diseases.

Viruses

At one stage viruses were referred to as "filterable viruses" due to the fact that they filtered through a filter membrane which retained bacteria.

They are self-reproducing agents smaller than the microscopically visible bacteria and only multiply within living susceptible cells. They are responsible for a wide range of infectious diseases.

Various diseases affect human beings, animals, insects, plants and bacteria. In many situations viruses are present as harmless minor parasites. Bacterial viruses are referred to as "bacteriophages" or simply "phages".

Viruses function as parasites within cells of their host but, unlike bacteria which compete for nutrient, the parasitic *modus operandi* of the virus takes place at the genetic level.

In general, viruses are composed of distinctive particles (called virions) which contain two main substances, viz: a nucleic acid genome and a protein coat (capsid). Nucleic acids, in combination with protein, are important in reproduction, heredity and evolution.

Two types of nucleic acid are known, viz: ribonucleic acid and deoxyribonucleic acid. These are referred to, respectively, as RNA and DNA. Ribonucleic acid (RNA) was formerly called the yeast nucleic acid or plant nucleic acid. Deoxyribonucleic acid (DNA) (also referred to as desoxyribonucleic acid) was formerly known as thymo or animal nucleic acid. Some viruses may contain enzymes, carbohydrates and lipids within the virions.

Viruses differ from micro-organisms in that they only contain one type of nucleic acid. Thus we have DNA and RNA types of viruses, as follows:

Virus	*Type*
Tobacco mosaic	RNA
Influenza	RNA
Newcastle disease virus	RNA
Reovirus	RNA
Adenovirus	DNA
Herpes virus	DNA

The application of X-ray crystallography has led to the elucidation of the structure of virion-aggregates and their morphology has been revealed by electron microscopy.Most virions are roughly spherical – some fairly rigid cylinders – and yet others with more complex shapes. Pleomorphism (change of shape) is also displayed in some cases.

The size range of viruses lies between that of the largest molecules and bacteria, e.g.

E. coli	10 000 – 30 000 Å	bacterium
Herpes	1 200 – 2 000 Å	virus
Influenza	800 – 1 200 Å	virus
Reovirus	600 Å	virus
Poliovirus	270 Å	virus

Cooper and MacCallum[71] state that "few of the treatments applied to sewage are wholly effective in removing viruses and in fact cyanophages and bacteriophages are commonplace during and after treat-

ment. Similarly, the amounts of enteroviruses (largely of the vaccine-derived poliomyelitis viruses) recovered in the primary effluent routinely range between 10 and 100 per cent of that of the influent sewage".

Viruses in Sewage: Shuval[72] drew attention to a report of the US Department of Health and Welfare, 1962, wherein it was stated, "More than 70 viruses have been detected in human faeces. All may be present in sewage. Viruses pass through sewage treatment plants, persist in contaminated waters, and may penetrate the water treatment plants. Numerous outbreaks of infectious hepatitis have been traced to contaminated drinking water . . ."

Nupen[73] has stated that the viruses found in sewage are mainly of human origin, excreted in large numbers in the faeces and lists these as enteroviruses in six main groups. (See table below.)

The World Health Organization (Geneva, 1972) reporting in its publication "Health Hazards of the Human Environment"[75] states, "The viruses most commonly present in polluted waters are the enteroviruses (poliovirus, coxsackie viruses and echoviruses), adenoviruses, reoviruses and the virus (not yet identified) of infectious hepatitis." This accords with the listing of Nupen (*vide ante*) although they are not all regarded as enteroviruses.

Polio, coxsackie and ECHO viruses are collectively termed enteroviruses. Reovirus (Respiratory Entero Orphan) virus, as the name implies is associated with the respiratory system and alimentary tract giving rise to respiratory infection and diarrhoea. It has been isolated from abattoir wastes.

The WHO publication[75] further states, "Of the enteroviruses, the spread of poliovirus by water has rarely, if ever, been demonstrated, because of the extremely high dilution of the virus and the consequent difficulty of isolating it, whilst the more direct faecal-oral route is the most likely mode of spread of the ECHO viruses and coxsackie viruses; adenoviruses and reoviruses are usually transmitted to other persons from the oropharynx (respiratory route)."

Shuval[72] has given the following enterovirus concentrations (in PFU per litre) in raw sewage from different neighbourhoods in Israel, viz: Katamon (Jerusalem), 1 677; Rassco (Jerusalem), 480; Reading Pumping Station (Tel Aviv), 663,5; Kiryat Smoneh (Upper Galilee), 1 572; City of Tiberias, 1 135.

These concentrations are averages for a reasonably extended sampling period during the years 1967 to 1969.

Virus Removal Efficiency of Wastewater Treatment Plants: Shuval[76] evaluated the virus-removal-efficiency of two wastewater treatment plants:

(1) The Mefachim stabilization pond in North-Eastern Jerusalem which provided a 20-day detention period and gave a BOD removal of c. 80 per cent and coliform reductions of c. 90 per cent removed only 67,5 per cent of the enteroviruses.
(2) The second plant, that of the Tiberias Municipality, consisted of an Imhoff tank, the settled sewage from which was fed to two biological filters in parallel and thence through a final sedimentation tank. The BOD removal efficiency of the plant as a whole, was c. 85 per cent with c. 92 per cent removal of coliforms. The virus removal by the Imhoff tank was found to be negative in eight (8) out of ten (10) series of tests while the total plant efficiency for virus removal was negative in five (5) out of ten (10) tests. The virus removal efficiency was considered to be only 24 per cent.

Shuval concluded that these two series of tests confirmed the findings of other investigators that certain types of standard wastewater treatment plants have very low efficiencies in removing enteroviruses from

Enteric Viruses

Virus	Number of types	Disease
Poliovirus	3	Paralytic poliomyelitis, aseptic meningitis
Coxsackie virus:		
Group A	24	Herpangia, aseptic meningitis
Group B	6	Pleurodynia (Bornholm's disease), aseptic meningitis, acute infantile myocarditis
ECHO virus	32	Aseptic meningitis, rash and fever, diarrhoeal diseases, respiratory illness
Infectious hepatitis*		
(H. virus)	1(?)	Infectious hepatitis
Reovirus	3	Fever, respiratory infections and diarrhoea
Adenovirus	30	Respiratory and eye infections

*Grabow and Prozesky[74] later, isolated and identified Hepatitis A and B types in water.

sewage.

Rao, Lakhe, Waghmare and Raman[77] have investigated the removal of viruses in the primary sedimentation of raw sewage. The study was undertaken to reassess the effectiveness of enteric virus removal in the primary sedimentation of raw sewage both in full-scale and on the pilot plant level.

They found that the average per cent removal of naturally occurring viruses from raw sewage in the full-scale primary settling tank at Dadar, Bombay during 1972 to 1974 was 55 and in the pilot plant in the Institute of Nagpur during 1974 to 1975 and 1976 to 1977 the virus removals were 47 and 67 per cent respectively.

They concluded that primary sedimentation of raw sewage followed by lime coagulation and settling can eliminate viruses to a high degree and that the two unit processes together require field evaluation. Their reasoning was based on the finding of Nupen, Bateman and McKenny,[78] for excess lime treatment and sedimentation.

However, sight must not be lost of the fact that the sludge has to be satisfactorily disposed of.

Gear and Measrock[79] have shown that adequately-digested sludge is free of polioviruses when such viruses are present in the raw sludge.

Rao *et al.*[77] state that out of twenty (20) populous cities in India, only six (6) have provision for sewage treatment and only two (2) of these carry out secondary treatment. They point out that primary sedimentation of raw sewage could be afforded by small towns and cities where sewers already exist.

Nupen *et al.*[78] investigated virus reduction by various unit processes used in the reclamation of sewage to potable water. They found, *inter alia*, that at least a one to two log unit reduction of viruses can be expected during conventional secondary sewage purification, and, if maturation pond systems are used a further three log unit reduction can be expected.

Treatment of a humus tank effluent by excess lime sedimentation, they state, will remove five log units of poliovirus, and the carbon-contacting-stabilization process greater than five log units.

They concluded that, theoretically, with treatment by a combination of sewage purification, excess lime sedimentation and carbon-contacting-stabilization a minimal reduction of eleven (11) log units of poliovirus is possible, prior to disinfection. By chlorination a further seven (7) log units is stated to be achievable.

Hepatitis: Attention was drawn to this waterborne virus disease by an epidemic of infectious hepatitis which occurred in Delhi in 1955 to 1956 when more than 28 000 cases were identified and the fatality rate was 0,9 per 1 000. The estimated total case incidence was put at 97 000.

Shellfish can become infected with the virus as a result of contamination with sewage effluents.

According to Grabow,[80] viral hepatitis is pre-eminently a disease of low hygiene such as prevails during wartime e.g. during World War II (5×10^6 cases occurred in Germany) and, also, during the conflicts in Korea and Vietnam.

However, he states that viral hepatitis has a low mortality but due to liver damage patients are hospitalized for six weeks. However, its high incidence makes it one of the world's significant health hazards. Fortunately, no waterborne epidemic of viral hepatitis has been recorded in South Africa – so far.

Grabow[80] states that Type A (infectious) hepatitis virus is transmitted generally by the faecal-oral route and is characterized by epidemic outbreaks; it has a relatively short incubation period of 15 to 150 days. Type B (serum) hepatitis virus is transmitted by inoculation of blood which contains the virus. This type rarely occurs in epidemics and has a much longer incubation period – 160 to 180 days.

Grabow reports success in the use of *Galago senegalensis* (Bushbabies/Nagapies) as clinical means in identifying hepatitis A virus by observation of body fluids and by surgical examination of the liver to determine necrosis of liver cells.

This method may not have universal application as Bushbabies are an endangered species and it would involve intensive breeding of this quaint and interesting little nocturnal animal.

Grabow and Prozesky[74] have concluded as a result of elaborate instrumented and other laboratory techniques that the hepatitis B virus is rarely present in polluted water.

Irving and Smith[81] carried out a one year survey of enteroviruses, adenoviruses and reoviruses isolated from the effluent of an activated sludge plant at Fairfield, Victoria, Australia.

Samples of raw sewage, primary effluent and secondary effluent from a large activated sludge plant near Melbourne were collected systematically for one year. Viruses were detected in all secondary effluent samples and in 6 of 7 samples obtained after chlorination.

Reductions in virus content were as follows: Adenovirus – 85 per cent reduction; Reoviruses – 28 per cent reduction; and Enteroviruses were removed more efficiently – 93 per cent reduction.

Fifty-seven of 171 effluent samples were positive for either adenoviruses or reoviruses or both when enteroviruses were not isolated.

They conclude, therefore, that the use of enteroviruses as sole indicators of viruses in water may miss up to one-third of instances of viral contamination.

REFERENCES

1. Smoluchowski, M. v. Phys. Zeit, 1916, **17**, p. 557-571, 585-599; Wiegner, G. J. Soc. Chem. Ind., 1931, **50**, 55 T.
2. Mills, E.V. J. and Proc. Inst. Sewage Purif., 1936(11), p. 301-323.
3. Mills, E.V. Loc. cit.

4. Ridenour, G.M. Sew. Wks. J., 1930, **2**, 245.
5. Murray, K.A. J. Soc. Chem. Ind., 1936, **55**, pp. 302-307 T.
6. Lumb, C. J. and Proc. Inst. Sewage Purif., 1936(1), P. 121-136.
7. McBain J.W. J. Chem. Soc., 1912, **101**, 2042; 1914, **105**, 417, 957; 1918, **113**, 825.
8. Durham D. "*Surface Activity and Detergency*", Macmillan and Co. Ltd., New York, St. Martin's Place, 1961, p. 1.
9. Hartley, G.S. "*Progress Reports in the Chemistry of Fats and other Lipids*", 1955, **3**, 20.
10. Dean, R.B. "*Modern Colloids*", D van Nostrand Co. Inc., Toronto, New York, London, 1948, p 223.
11. Stander, G.J., van Vuuren, L.R.J. and Dalton, G.L. J. Inst. Water Poll. Control, 1971, **70**(11), pp. 213-221.
12. Middleton, F.M. J. Inst. Water Poll. Control, 1971, **70**(11), pp. 201-211.
13. Truesdale, G.A. "*Chemistry of Effluent Treatment*", edited by Kakabadse G., Applied Science Publishers, London, 1979, p. 44 "Tertiary Treatment".
14. Truesdale, G.A. Loc. cit.
15. Middleton, F.M. J. Inst. Water Poll. Control, 1971, 70(11), p. 205.
16. Black, G.M. "*Chemistry of Effluent Treatment*" edited by Kakabadse G., Applied Science Publishers, London, 1979, p. 50 "Recent Advances in Chemical Treatment".
17. Middleton, F.M. J. Inst. Water Poll. Control, 1971, 70(11), p. 206.
18. Black, G.M. Ibid.
19. Osborn, D.W. MSc. Thesis, University of the Witwatersrand, Johannesburg.
20. Osborn, D.W. J. Water Poll. Control, 1979, 51(3), 481.
21. Giampietri, A. and Voysey, J.A. J. Water Poll. Control, 1979, **51**(3), 519.
22. Cecil, R.L. (Editor) and Kennedy (Ass. Editor) "*A Textbook of Medicine*" by American Authors, W.B. Saunders Company, 6th Ed., Philadelphia and London, 1900, p. 1530.
23. Thorpe, W.V. "*Biochemistry for Medical Students*", 2nd Ed., J. and H. Churchill Ltd., London, 1941, p. 419.
24. Manderscheid, H. Biochem. Z, 1933, **263**, 245.
25. Mitchell, A.H. "*A Textbook of Biochemistry*", McGraw Hill Book Co. Inc., New York, London, 1946, p 464.
26. Wiseman, P. "*An Introduction to Industrial Organic Chemistry*", Applied Science Publishers, Ltd., London, 1972, p. 163.
27. Ministry of Housing and Local Government, Progress Report of the Standing Committee on Synthetic Detergents, 1959-1967, London, H M Stationery Office.
28. Hammerton, C. J. Appl, Chem., 1957(3), p. 293.
29. Kirk-Othmer "*Encyclopaedia of Chemical Technology*", 3rd Ed., J. Wiley and Sons, 1981, Vol 7, p. 837.
30. Baars, J.K. "*Chapters on Chemistry and Microbiology of Water and Sewage*", Lectures delivered at the University of the Witwatersrand, Johannesburg, Nov. 24-28, 1969.
31. Gaillard, J.R. J. and Proc. Inst. Sewage Purif., 1950(3), 276.
32. Oldham, L.W. J. and Proc. Inst. Sewage Purif., 1958(2), 130 *et seq.*
33. Hurley, J. J. and Proc. Inst. Sewage Purif., 1950(3), 249.
34. Spargo, P.E. J. and Proc. Inst. Sewage Purif., 1959(2), 236.
35. Lumb, C. J. and Proc. Inst. Sewage Purif., 1953(4), 269-279.
36. Degens, P.N., van der Zee, H., Kommer, J.D. and Kamphuis, A.H. J. and Proc. Inst. Sewage Purif., 1951(1), 63-68.
37. Raybould, R.D. and Thompson, L.H. J. and Proc. Inst. Sewage Purif., 1956(1), 12.
38. Tilden, J.E. "*The Algae and their life Relations*", The University of Minnesota Press, Mineapolis, London, Oxford, 2nd Ed., 1937, p. 36.
39. Kertesz, Z.I. "*The Pectic Substances*", Interscience Publishers Inc., New York, London, 1951, p. 478.
40. Albritton, E.C. (Editor), "*Standard Values in Nutrition and Metabolism*", Wright Air Development Center, Technical Report 52-301, 1952, p. 380.
41. Jenkins, D. "*Biochemistry of Industrial Microorganisms*", Editors: Rainbow, C. and Rose, H.H. "Sewage Treatment", Academic Press, London and New York, 1963, p. 510.
42. Wooldridge, W.R. and Standfast, A.F.B. Nature, 1932, **130**, 664.
43. Ingols, R.S. "*A Study of Hydrolytic Enzymes in Activated Sludge*", New Jersey Agricultural Experiment Station, New Brunswick, New Jersey, Bulletin 669, September 1939.
44. Boruff, C.S. and Buswell, A.M. Ind. Eng. Chem., 1930, **22**, 931.
45. Neave, S.L. and Buswell, A.M. "*Chemical Studies in Sludge Digestion*", Illinois State Water Survey, Bulletin 30, 1931.
46. Symons, G.E. and Buswell, A.M. PhD Thesis, University of Illinois, 1932 (Buswell and Boruff), Sewage Works J., 1932(IV)(3), 455.
47. Buswell, A.M. and Boruff, C.S. Sewage Works J., 1932(IV)(3), 456.
48. Buswell, A.M. and Boruff, C.S. Loc. cit. p. 457.
49. Prescott, S.C. and Winslow, C.A. "*Elements of Water Bacteriology*", John Wiley and Sons Inc., New York and London, 1924, pp. 148-149.
50. Levine, M. "*Modern Sewage Disposal*", Anniversary Book of the Fed. Sewage Wks. Assoc., 1938.
51. Currie, J.R. "*Laboratory Practice*", E. and S. Livingstone, Edinburgh, 1936, p. 104.
52. World Health Organization, "*Health effects relating to direct and indirect re-use of wastewater for human consumption*", Internat. Reference Centre for Community Water Supply, Technical Paper No. 7, p. 73.
53. Keller, P. J. and Proc. Inst. Sewage Purif., 1951(1), 93-99.
54. Keller, P. Loc. cit. p. 100.
55. Osborn, D.W. J. Water Poll. Control Fed., March 1979, p. 481.
56. Melmed, L.N. and Comninos, D.K. "*Disinfection of Sewage Sludge with gamma radiation*", NIWR Symposium, Pretoria, 26-27 Oct 1977.
57. Osborn, D.W. Ibid.
58. Stephenson, M. (citing Meyerhof, O. Pflügers Arch., 1917, **166**, 255) "*Bacterial Metabolism*", Longmans Green and Co., London, New York, Toronto, 1949, pp. 247-248.
59. Anderson, C.G. "*An Introduction to Bacteriological Chemistry*", E and S Livingston Ltd., Edinburgh, 1946, p. 70.
60. Mitchell, R. "*Introduction to Environmental Microbiology*", Prentice Hall International Inc., London, p. 175.
61. Winogradsky, S. and Winogradsky, H. Ann. Inst. Pasteur, 1933, **50**, 350-432.
62. (a) O'Shaughnessy, R.F. and Hewitt, C.H. J. Soc. Chem. Ind., Trans, 1935, 167; J. and Proc. Inst. Sewage Purif., 1935(1), 221.
    (b) McLachlan, J.A. J. and Proc. Inst. Sewage Purif., 1936(1), 49 *et seq.*
63. Feacham, R. *et al*, "*Water, Health and Development*", Tri-Med Books Ltd., London, 1978, p. 142.
64. Feacham, R. *et al*, Ibid p. 139.
65. Hutchinson, W. and Ridgway, J.W. "*Microbiological Aspects of Drinking Water Supplies*" in "Aquatic Microbiology" edited by Skinner, F.A. and Shewan, J.M. published by Soc. Appl. Bact., Academic Press Ltd., London, New York, San Francisco, 1977, p. 102.
66. Mackie, T.J. and McCartney, J.E. "*An introduction to Practical Bacteriology*", E and S Livingstone, 4th Ed., 1934, p. 359.
67. Kamal, A.M. "*Cholera*", edited by Barua, D. and Burrows, W. W B Saunders Co., Philadelphia, London, Toronto, 1974, pp. 1-13.
68. Gallut, J. "*Cholera*", edited by Barua, D; and Burrows, W. W.B. Saunders Co., Philadelphia, London, Toronto, 1974, pp. 17-40.
69. Pierce, N.F. and Mondal, A. "*Cholera*", edited by Barua, D. and Burrows, W. W.B. Saunders Company, Philadelphia, London, Toronto, 1974, p. 212.
70. Bigger, J.W. "*Man Against Microbe*", The Book Club, 121 Charing Cross Road, London WC2, 1941, pp. 192-193.
71. Cooper, J.I. and MacCallum, F.O. "*Viruses and the Environment*", Chapman Hall, London and New York, 1984, pp. 121-123.
72. Shuval, H.I. "*Detection and Control of Enteroviruses in the Water Environment*", Proc. Internat. Conf. on Water Quality and Pollution Research, Jerusalem, June 1969, pub. in "Developments in Water Quality Research", Ann Arbor Science Publishers Inc., 1971, pp. 47-71.
73. Nupen, E.M. Water Poll. Control, 1970, p. 430.
74. Grabow, W.O.K. and Prozesky, O.W. "*Studies on the isolation and identification of Hepatitis viruses in Water*", Internat. Conf. on Advanced Treatment and Reclamation of Wastewater, Johannesburg, June 1977, pp. 13-17.
75. World Health Organization, "*Health Hazards of the Human Environment*", Geneva, 1972, pp. 52-53.
76. Shuval, H.I. Ibid, p. 54 *et seq.*

77. Rao, V.C., Lakhe, S.B., Waghmare, S.V. and Raman, V. J. Environmental Eng. Div., Feb 1981, p. 57.
78. Nupen, E.M., Bateman, B.W. and McKenny, N.C. Conference on Viruses, Austin, Texas, April 1-3 1974.
79. Gear, J. and Measrock, V. J and Proc. Inst. Sewage Purif., 1949 (1), 82.
80. Grabow, W.O.K. "*Progress in studies on the Type A (infectious) Hepatitis in Water*", Symposium NIWR, 16 Oct. 1975.
81. Irving, L.G. and Smith, F.A. Appl. Environ. Microbiol., 1981, 41(1), pp. 51-59.

Chapter 4 SOUTH AFRICAN ORGANIZATIONS DEALING WITH WASTEWATER TREATMENT PROBLEMS

South African organizations dealing with wastewater treatment problems include the following:

(1) The Department of Water Affairs;
(2) The Institute of Water Pollution Control (Southern African Branch);
(3) The National Institute for Water Research (NIWR);
(4) The Water Research Commission;
(5) The Department of National Health and Population Development;
(6) The South African Bureau of Standards (SABS);
(7) Provincial and Local Authorities;
(8) Industries.

(1) The Work of the Department of Water Affairs

Water Pollution Control

The work of the Department is concerned with the control, conservation and use of water for domestic, agricultural, urban and industrial purposes.

The authority and *modus operandi* of the Department is vested in the principal Act, the Water Act (Act No. 54 of 1956). A number of amendments have been promulgated since 1956. However, the most significant and comprehensive amendment is the Water Amendment Act, No. 96 of 1984.

Naturally, in concerning itself with the work outlined above the Department has to take appropriate steps to ensure the quality of water used for particular purposes and in doing so has to pay particular attention to pollution prevention.

For this reason the Division of Pollution Control was established and its Director and staff of water pollution control officers deal with applications for the use of water for industrial purposes mainly in terms of Section 12 of the Water Act. The Division also elaborates conditions in regard to the quality and method of disposal of effluents resulting from such uses. This is done in terms of Sections 21 and 22. Section 23 is concerned with the prevention of pollution – both wilful and negligent – of water and together with Sections 11, 12, 21, 22 and regulations promulgated under Section 26 constitute a legislative armoury against water pollution when administered adequately.

Use of Water for Industrial Purposes

It should be noted that "use for industrial purposes", in relation to water, means use of water (including effluent supplied by a person other than the user) for or in connexion with –

(a) the manufacture, alteration, processing, treatment, repair, decoration, painting, spraypainting, electroplating, corrosion prevention, cooling, dyeing, washing, polishing, cleaning, finishing or breaking up of any article or part thereof, whether that article or part is a solid, liquid, vapour or gas or a combination thereof;
(b) the generation of power;
(c) railway purposes;
(d) mining or the winning or washing of sand, ground or stone;
(e) an intensive animal feeding system or the breeding of fish or any mollusc;
(f) the slaughtering of livestock;
(g) any sewerage system or work or any water care work;
(h) the conveyance of any substance; or
(i) printing or photographic work,

and including use for domestic purposes or for the watering of stock or of streets and gardens in so far as such use may be incidental to use for industrial purposes.

Section 12 permits

No user, utilizing a quantity of water for industrial purposes in excess of 150 m^3 during any one day shall do so except under the authority of a permit issued by the Minister.

Where the usage of water exceeds 150 m^3 on any one day application for a permit in terms of Section 12 of the Water Act must be made to the Director-General, Department of Water Affairs, Private Bag X313, Pretoria, 0001.

It must be pointed out that this provision applies to all users operating within the jurisdiction of a local authority as well as elsewhere.

An application for a permit must conform with the Departmental requirements provided for in terms of

Section 21 in regard to the quality and point of discharge, regulations promulgated under Section 26, and in the case of local authorities Section 22 also.

Applicants are required to reply adequately to official questionnaires which have been drawn up to assist the Mining Industry, Local Authorities and other Industries with the administrative procedures arising. Questionnaire forms are available on application to the Director-General in Pretoria via the Pollution Control Division or from the Department's regional offices in Cape Town, Port Elizabeth and Durban, viz.

M – questionnaire forms for Mining applications (gold, coal, etc. mining);
WA1 forms for local authority applications, and,
WA2 forms for industrial (non-mining) applications.

Section 21 permits

Section 21 of the Water Act is concerned with the purification and disposal of water used for industrial purposes. This includes the purification of sewage and disposal of the resulting effluent. Water used for industrial purposes includes water from inland sources, sea water and effluent.

Where water is derived from a public stream or river, the purified effluent must be returned to such public stream or river from where it was abstracted unless otherwise directed by the Minister.

Non-proven Processes: The Department is reluctant to issue permits for processes and plant which have not been in successful operation for a reasonable period of time. However, there is no intention to stifle new ideas and where a process unit proposed for installation is at the time of application non-proven over a period of five years, the Minister may grant a permit for an initial period of three years or until the efficiency of such process unit has been proven whichever is the lesser period.

Such caution on the part of the Department is considered to be in the best interest of:

(1) pollution prevention;
(2) ratepayers and others involved in the capital expenditure arising to be faced by them.

Renewal of Permits: The onus for the renewal of a permit rests with the permit holder who is enjoined to renew such permit timeously.

Regional Standards

"Regional Standards for Industrial Effluents" have been promulgated in terms of Government Notice 991 of 18 May, 1984, as follows:

(1) Special Standard;
(2) General Standard.

The Special Standard

This standard is applicable to wastewater or effluents produced or resulting from the use of water for industrial purposes in catchment areas draining into a number of scheduled rivers or their tributaries, at any point source between the source of the river or tributary and the place specified in the schedule. (The schedule contains 66 listings).

The General Standard

In all areas of the Republic of South Africa other than the catchment areas draining into rivers or portions of rivers listed in the Special Standard Schedule the General Standard applies.

The Special Standard is a rigorous one aimed at preventing the pollution of clear mountain streams, trout streams and the like. The General Standard constitutes relaxed requirements which can be reasonably and must necessitously be conformed with.

Regional standards have been amended and added to from time-to-time. The most significant amplification of the requirements is to the effect that in a number of so-called "sensitive areas" the orthophosphate content of an effluent shall not exceed 1,0 mg/ℓ expressed as P.

The introduction of a phosphorus limitation was necessitated by the severe eutrophication of a number of water impoundments, notably the Bon Accord and Hartebeespoort dams.

Algae and water hyacinth (*Eichhornia crassipes*) flourish in an aquatic environment which is endowed with nutrients such as nitrogen-containing salts and phosphate – the latter acting as a "trigger mechanism".

South African Bureau of Standards: The Department is guided by the SABS in respect of quality criteria for effluents. Government Notice 991 of 18 May 1984, prescribes the quality requirements for wastewater or effluent, produced or resulting from the use of water for industrial purposes, which after purification are discharged into catchment areas throughout the Republic.

These include colour, odour, taste, pH value, dissolved oxygen content, typical (faecal) coli, temperature, chemical oxygen demand, oxygen absorbed, total dissolved solids, suspended solids, sodium content, soap, oil or grease, residual chlorine, free and saline ammonia, boron, hexavalent chromium, total chromium, copper, phenolic compounds, lead, cyanides and related compounds, sulphides, fluoride, zinc.

Industries Established within Municipal Areas

Where an industry wishes to establish within a municipal area it is required to conform with the industrial effluent by-laws of the respective local authority. Each local authority draws up its own effluents acceptance by-laws which require ratification by the respective Provincial Administration. These by-laws normally contain a charge formula which

varies from one local authority to another. This is usually based on the ability of the sewage purification works of the local authority to deal adequately with a particular industrial effluent which is the subject of an application. The charge formula usually contains a volume and a "strength" factor.

It is necessary for a local authority to enforce its effluent acceptance requirements both in respect of daily volume and rate of discharge and also the quality of an industry's discharge since such local authority, in turn, has to conform with the requirements of the Water Act as far as the final discharge of its sewage purification works effluent to the aquatic environment is concerned.

A local authority which is unable to accept a particular industrial effluent to its sewers and knowing full-well that by doing so, will lead to its inability to conform with the requirements of the Regional Standards laid down in terms of paragraph (a) of subsection (1) of Section 21 of the Water Act (Act 54 of 1956), will be working against its own best interests and may render its Council guilty of an offence unless adequate steps are promptly taken to cope with this extra commitment.

Many industries are forced to install adequate plant for the pretreatment of their effluents prior to discharge into a municipal sewerage system. In a number of cases large industrial undertakings are forced to provide their own treatment plants to enable direct discharge of the treated effluent to a watercourse or for irrigation where this is permitted. In such cases these industrialists deal directly with the Pollution Control Division of the Department of Water Affairs and the necessary permit is issued by the Minister.

Malpractices and Effluent Violations by Industries

Apart from the effluent an industry produces as a result of the use of water in processing, polluted water can arise and be allowed to leave the property due to a number of causes, viz:

(1) Surreptitious discharge of industrial effluent to a stormwater drain during rainstorms or under dry weather conditions;
(2) Scouring of water from open yard surfaces, stored waste accumulations and deposits on roofs during heavy rains;
(3) Inadvertent discharges due to breakdowns or accidents;
(4) Flow diversions during factory alterations;
(5) Insufficient surveillance of pollution-prevention equipment such as oil traps at garages and other oil handling and distribution depots and, also, oil recovery plants;
(6) Changing the *modus operandi* and the chemicals and products used and produced without notifying the Department and/or local authority;
(7) Illegal use of a sewer by adding waste at a municipal manhole;
(8) Surreptitious discharge of slugs of highly polluted, toxic or inflammable matter into the sewerage system or stormwater drains;
(9) Deliberate breaching of evaporation dam walls during river flood conditions;
(10) Failure of walls of residue dams due to unsatisfactory construction and operation;
(11) Runoff of effluent due to inadequate freeboard provided on residue dams.

None of these violations and malpractices are condoned by the Department. Where such violations are deliberate or due to negligence prosecutions can follow.

Where an industry discharges effluent of a quality not conforming with the requirements and gains financially as a result, then in terms of Section 68 of the Water Amendment Act (Act No. 96 of 1984) a fine may be imposed by a Court for an amount equal to the assessed financial advantage gained. This is in addition to any other fines imposed by such Court.

Industrialists are advised to fully aquaint themselves with the provisions of the principal Act (Act No. 54 of 1956), and the Water Amendment Act (Act No. 96 of 1984); Government Notice No. 991 of 18 May 1984, and current SABS methods of analyses (copies of which may be had from the South African Bureau of Standards).

NB: The issue of a Section 12 permit for the use of a daily quantity of water in excess of 150 m^3 is contigent upon adherence by the user to conditions stipulated in the permit for the disposal of the effluent.

Should these conditions not be complied with the Minister may direct that the supply of water to such user be suspended.

Part of the duties of the Pollution Control staff of the Department is to examine records and inspect premises and sites to ensure conformance by a user with the conditions of the permit issued to such user by the Minister.

Procrastination, Indicision and Lack of Enforcement of By-Laws by Local Authorities

It has to be emphasized that when constructing a sewage purification works for a community, an adequate degree of forward planning should take place to cater for future developments and exigencies, otherwise a stage is allowed to be reached where the sewage works is unable to produce an effluent conforming with the permit conditions. Its sewage purification works having reached such a stage, a local authority, in continuing to operate such works does so to the prejudice of the quality of the aquatic environment and its Council lays itself open to censure and actions at law.

A local authority prejudices the adequate functioning of its sewage purification works and the well-being of the community it serves due, *inter alia*, to

the following causes:

(1) Procrastination and indicision by not timeously providing extensions to an existing sewage purification works. (In any case a safety factor of 25 per cent should be provided for with all operating plants);
(2) Poor control of infiltration of water and entrance of stormwater to the sewerage system;
(3) Lack of enforcement of approved sewerage and effluent acceptance by-laws, which, *inter alia*, should provide for even rates of discharge to the sewerage system.

It is not the concern of a government department to prescribe what methods of purification should be used by a local authority since its ratepayers have to shoulder the financial burden of a sewerage system and the sewage purification works – but methods which are proposed should be satisfactory when judged by methods acceptable in practice.

For small communities oxidation pond systems for treating sewage are allowed up to a limiting daily flow of 700 m^3. When this daily limit is exceeded alteration of this process becomes necessary and concerned local authorities should provide for this eventuality without delay.

Surveillance Network

Pollution control is centred in Pretoria and surveillance is exercised on a regional basis.

The work of pollution control has been dichotomized into non-mining and mining sectional activities and is exercised by the two sections on separate regional bases, viz:

Non-Mining Section (Head Office in Pretoria)

(1) Eastern Transvaal and Natal with regional and sub-regional offices in Durban, Dundee and Nelspruit;
(2) Western Transvaal, Western Free State and Cape with regional and sub-regional offices in Cape Town, Port Elizabeth, East London and Bloemfontein;
(3) Witwatersrand and Eastern Free State with sub-regional office in Bloemfontein.

Mining Section

Pollution control personnel concerned with the mining industry are based in Germiston (– linked to the Head Office in Pretoria) with regional offices and sub-offices in Cape Town, Dundee, Vryheid and Kimberley.

The mining section is concerned, *inter alia*, with enforcing regulations made in terms of Section 26(c) and (d) of the Water Act (Act No. 54 of 1956) and promulgated under Government Notice R287 of 20 February 1976.

All Mine Managers and Consulting Engineers in the mining industry should be *au fait* with these regulations which have particular reference to the construction and operation of slimes dams as well as other matters of concern (Refer to Chapter 15 – Mining Industry).

The mining section has given particular attention to supplying vegetative cover to mine dumps of defunct mines. Work on shrouding of dumps and slimes dams has been done in association with the Chamber of Mines of South Africa.

Prior Consultation with the Department

An industrialist wishing to establish an industry in a particular situation and requiring water in excess of 150 m^3 on any one day is advised to approach the Department for advice to ascertain the following information:

(1) Availability of water for the intended use;
(2) The impact of the resulting effluent on the aquatic environment.

In regard to (1) the Department can readily supply an answer.

Water Court Authority: It must be noted that in terms of Section 11 of the Principal Act as amended by Section 6 of the Water Amendment Act (Act No. 96 of 1984) ". . . no person shall use public water for industrial purposes except with the permission of a water court: provided that the permission of a water court shall not be required in the case of –

(i) a local authority or any other body constituted under any law which has the right to control and supply public or private water within its area of jurisdiction;
(ii) any person to whom such water is supplied by the Minister from a Government water work or by such a local authority or other body."

. . . there are a number of other exceptions.

If the proposed situation is in a municipal area, the ability and willingness of the local authority concerned to supply the quantity of water sought and accept the effluent into its sewerage system, should be obtained in writing. In other situations the authority of the Department must be obtained.

In respect of (2) the situation is sometimes not considered suitable for a number of reasons which may be advanced by:

(a) The Department of Water Affairs,
(b) The Department of Planning.

As far as (a) is concerned the Department, for example, would not give its consent to the discharge of a highly saline effluent into a river which feeds a drinking water impoundment; the operation of an industry detrimental to the aquatic environment – both on surface and underground; aggravation of an already latent pollution problem in the area contemplated.

Monitoring of Rivers

The Department's Division of Hydrology continuously records the flow in rivers at established gauging stations and its Hydrological Research Institute carries out mineral analyses of river waters at these points. The results are kept in a computer data bank.

The Pollution Control Division samples water in rivers and streams on a systematic basis and has both mineral and sanitary analyses of the samples carried out by the South African Bureau of Standards at the Bureau's Head Office Laboratories in Pretoria and its regional laboratories in Durban, Port Elizabeth and Cape Town.

The regional laboratories of the National Institute for Water Research in Durban have carried out chemical and biological surveys of the beaches and sea water along the Natal coast and their reports have been submitted from time to time to indicate the *status quo* from a pollution point of view.

The Pollution Control Division has installed a number of water quality monitoring devices based on electrical conductivity measurements: temperature is also monitored. So far, there are 7 monitoring stations in the Hartebeespoort Dam catchment. These give valuable information in regard to the quality of the watercourses feeding this impoundment – mainly in regard to the overall mineral load placed on the dam.

Three monitoring stations, one each in the Waterval, Trichardt and Groot Spruits have been installed in the SASOL II area. Further stations have been installed in the Klein Olifants River (Middelburg, Transvaal); Olifants River (below the Witbank dam); Brug Spruit (Witbank); Moses River* (Groblersdal/ Marble Hall area): Elands River* (Groblersdal/ Marble Hall area) Elands River (Ngodwana). Four monitoring stations have been installed in the City Deep area near Johannesburg.†

Pollution monitoring ("Polmon"): Results of analyses and other important criteria contained in the Pollution Control Division's records relevant to water use and effluent discharge are being fed, on a regular and systematic basis, into the Department's computer system to be available for ready retrieval of information when required.

The information is being stored for all the drainage areas in the Republic to enable quick retrieval of information in regard to a particular drainage area and, more specifically, to keep a watchful eye on the quality of specific effluents and the pollution impact in a drainage area(s).

*Tributaries of the Olifants River.
†Sponsored by the Water Research Commission to monitor mine dump pollution.

Water Pollution Control – a Multidisciplinary Approach

The present Department has evolved from the original Department of Irrigation which, as the name implies, was concerned with the supply of water for irrigation. In order to effect its purpose the Department had to make use of engineers – mainly civil engineers, together with mechanical and electrical engineers, hydrologists and hydrogeologists.

However, as time progressed and the demands of water for industry increased and the complexity of the problems which arose from industrial discharges became apparent, it was necessary to employ professional incumbents of varied disciplines. It is necessary that the staff dealing with pollution control should include employees, mainly chemists and chemical engineers as well as microbiologists and water biologists.

In dealing with pollution, the Pollution Control Division has availed itself of the services of the National Institute for Water Research of the Council for Scientific and Industrial Research, the South African Bureau of Standards and maintains a close relationship with the Southern African Branch of the Institute of Water Pollution Control, to the extent that it is guided by the recommendations contained in its publications.

Infraction

It has been found from experience that most of the larger industries adopt a reasonably co-operative attitude and operate responsibly in regard to their permit conditions.

This is also the case with a number of local authorities but, unfortunately, some city and town engineers have not always placed the emphasis on sewage purification which it demands, either due to lack of funding or diversion of interests into other necessitous municipal avenues of endeavour. However, there have been a number of un-co-operative industrialists who have forced upon the Department – after frustration from policing activities and numerous injunctions to take cases to court. This being so provision has been made in terms of Section 68 of the Water Amendment Act (Act No. 96 of 1984) to cover violators, viz:

68(2) "Any person who is convicted of an offence under Section 9C, 12, 12A, 20, 21, 22, 23, 24 or 166A shall be liable, in the case of a first conviction, to a fine not exceeding R10 000 or to imprisonment not exceeding 12 months or to both such fine and such imprisonment, and, in the case of a second or subsequent conviction, to a fine not exceeding R20 000 or to imprisonment for a period not exceeding 12 months or to both such fine and such imprisonment."

A large company might regard such fines as insignificant and a worthwhile debit when compared

with the financial gain to the company by disregarding its permit commitments. However, when the charge is coupled to certain sections of the Criminal Procedure Act it becomes a personal matter directed at a senior official/executive of the company such as the Managing Director and prosecution of such executive may redound to his/her discredit as well as that of the company.

Reuse of Effluent

The reuse of effluent depends on its acceptability for the purpose intended. For example, local authorities are allowed to use purified sewage effluent for irrigation of specified crops, provided there is no detriment to the owners of land riparian to the river from which the water was originally abstracted. This involves giving up a portion of their water rights as a *quid pro quo* for the effluent not returned to the river.

It must be pointed out that the purified sewage effluent discharged from a sewage purification works should be returned to the river of origin. Furthermore, such effluent does not belong to the local authority and so cannot be sold for reuse to a second user.

Municipal farming with sewage effluent is not favoured by the Department and farming with settled sewage is not allowed (by direction of the Department of Health). However, in the case of small local authorites (daily flow of sewage less than 700 m^3), the irrigation of fodder crops which are dried before being fed to animals and timber trees may be used as a method of disposal of sub-standard effluent in order to protect a watercourse from the discharge of such sub-standard effluent.

The reuse of effluent by an industry is encouraged provided this does not result in a final effluent after reuse which is highly saline or otherwise unacceptable.

Water Renovation and Reclamation: Of interest in this connexion is the publication of the CSIR (Technical Guide K42, U.D.C. 628.315) entitled *"Manual for Water Renovation and Reclamation"* which is concerned with the reclamation of water from municipal wastewaters. It is based mainly on the results obtained by the National Institute for Water Research in the large-scale operation of the "Stander"* water reclamation plant as well as laboratory and pilot plant investigations.

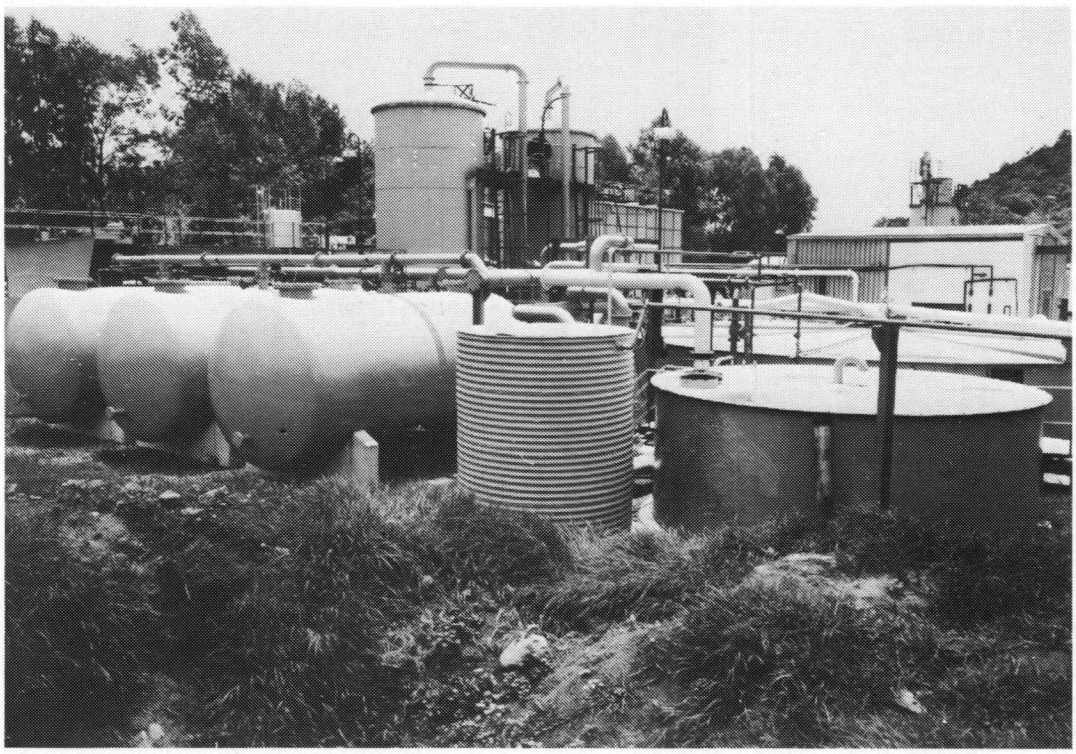
Treatment processes proffered are for secondary purified sewage effluent (with phosphate removed) and include the following:

High lime treatment, ammonia stripping, filtration, adsorption by activated carbon, disinfection with chlorine and ozone.

The processes are applicable to industrial wastewaters as well as municipal wastewaters.

Restraints on the use of Pure Wholesome Water: The Department favours the use of dry-cooling

*Refer to Chapter 3-1 under "Chemical, Physico-chemical and Biological Treatment".



Part of the Stander Reclamation Plant at Daspoort, Pretoria.

systems in place of the historical use of water for cooling. This has particular significance in relation to large electric power generating stations.

In a number of municipal power stations purified sewage effluent has been used with success for cooling purposes. This is an acceptable method of reuse.*

The use of good quality water for such purposes as ash quenching and solids conveying is considered inconsonant with the correct hierarchical use of water.†

The discharge of sewage or purified sewage effluent into the sea by local authorities at the coast constitutes a wastage of water, which may require examination in due course.

Pollution from Diffuse Sources

The Water Act legislates against pollution mainly from point sources where effluent discharges into watercourses. However, the farming methods used by agriculturists can give rise to pollution from non-point or diffuse sources. This is exemplified in the following cases:

(i) Farming too near the banks of a river. This is sometimes the case with sugar-cane growing in Natal where secondary pollution by runoff and seepage takes place from canefields over which mud/filter cake, milo, etc. have been broadcast (cf. Chapter 15).‡

(ii) Allowing heaps of fertilizer containing nitrogen and phosphate to be subject to the vagaries of the weather before ploughing in and general seepage from such fertilized land. (This, of course, will depend on the nature of the soil and will vary from place to place).

Contributory Legislation

Contributory legislation to control pollution is contained in the following Acts:

- The Health Act (Act No. 63 of 1977)
- The Sea Shore Act (No. 21 of 1935)
- The Sea Fisheries Act (No. 58 of 1973)
- The Lake Areas Development Act (No. 39 of 1975)
- The Prevention and Combating of Pollution of the Sea by Oil Act (No. 67 of 1971)

The Health Act is concerned with pollution by substances and organisms which are inimical to health and constitute a health hazard when present in the aquatic environment.

The remaining Acts are more specific with respect to pollution of the sea, sea shore or estuaries.

When dealing with permit applications, the Pollution Control Division refers such applications for comments and recommendations to the South African Bureau of Standards, the Department of Health and any other relevant department/s or bodies.

Permit conditions are then laid down in terms of these recommendations and the requirements of the Department of Water Affairs.

*cf. Osborn, D.W., Chapter 6, Ref. 43.
†cf. Chapter 14.
‡cf. Chapter 15: *"Progress in the Control of Pollution in the Sugar Industry in South Africa"*.

(2) The Institute of Water Pollution Control (Southern African Branch)



Original Cydna Laboratories, where the founding meeting took place.

The South African Branch* of the Institute of Sewage Purification† was founded on May 4, 1937, on a petition to the Council of the Institute of Sewage Purification, London duly signed by the requisite number‡ of people.

Two members of the Institute who were largely instrumental in launching the local branch were Dr Harold Wilson and Dr E J Hamlin.

Meetings have been held regularly since its inception. A review of the history of the branch during its first twenty-one (21) years of existence has been given by McLachlan.[1] During this period the Corporate Membership of the Institute rose from 21 in 1942 to 85 in 1957, with a total membership of corporate plus non-corporate members of 129. The corresponding membership figures for 1984 were Corporate Members 269 and total membership, 581. The Branch, therefore, has shown steady growth since its inception.

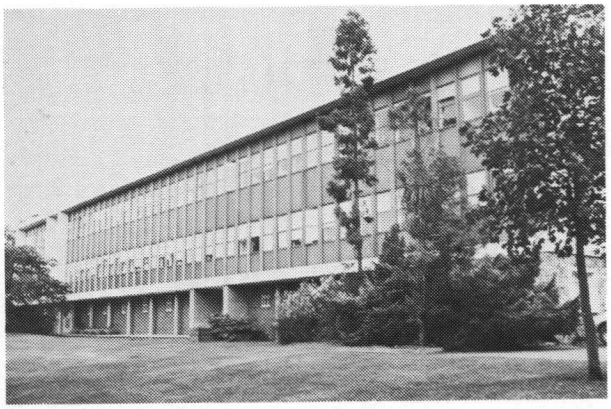
Initially, and for many years, the monthly meetings of the Branch were held in a lecture room of the Johannesburg Public Library and later in a lec-

*Later changed to Southern African Branch
†Later changed to The Institute of Water Pollution Control
‡The signatories were as follows:
Alison, W.R., Clausen, H.T., McLachlan, J.A., Murray, K.A., Pollock, J., Richardson, J., O'Reilly, P., Samson, J., Spencer, B.R., de Vaal, H.M., Vosloo, P.B.B., Wilson, H.

Note: The Institute of Water Pollution Control is to amalgamate with The Institution of Public Health Engineers and The Institution of Water Engineers and Scientists to form The Institution of Water and Environmental Management.

ture room at the Civic Centre in Braamfontein, Johannesburg. However, due to the institution of special security precautions by the City Council a new vanue had to be sought and, for a while, meetings were held at the Paterson Park Sports Club.

At present meetings are held at the Portland Cement Institute at Halfway House (Midrand) which is a generally more convenient venue for members (commuting by car) to meetings from Pretoria, Johannesburg and the Reef.



Present Cydna Laboratories where the IWPC (SA Branch) was inaugurated.

The secretarial work is carried out by the Branch Secretary, Mrs E S Blanchard from the Cydna Laboratories of the Johannesburg City Council. The postal address of the Secretary is:

P O Box 81249
Parkhurst
2120
Tel: (011) 728 7373

The Branch has interested itself in practically every aspect of sewage purification and disposal of effluents and holds conferences every two years at different centres in the Republic.

Interest in the Branch has developed to the extent that viable sections exist in Natal (Durban); Eastern Province (Port Elizabeth) and Western Cape (Cape Town).

Publications: The Southern African Branch publishes, and has available for sale, the following publications of particular interest to persons in Southern Africa who are concerned with sewage purification, viz:

(1) *A Guide to the Design of Sewage Purification Works;*
(2) *Operators Handbook.*

The Department of Water Affairs regards the provisions of the "Guide", (1), as acceptable when applied in applications for permits to construct and operate new sewage facilities as well as alterations and extensions thereof.

Selected papers presented at Branch meetings are published in *"Water Pollution Control"*, the Journal of the Institute of Water Pollution Control which is published quarterly. During the early years of its existence, papers and information were published in *"Public Health"*, a monthly publication of the South African Health Officials Association, but this avenue of publication has been discontinued. At present, a working arrangement exists whereby an "Institute of Water Pollution Control Newsletter" and sundry submissions of members of the Institute appear in the monthly issue of *"Imiesa"*, the official organ of the Institute of Municipal Engineers of Southern Africa.

Wilson Award



Dr. Harold Wilson.

Dr Harold Wilson (1887 to 1974) was the originator of a plan to create a South African Branch of the Institute (then entitled "The Institute of Sewage Purification"). He arranged a meeting of interested persons in the office of Mr H T Clausen, then Johannesburg's Superintendent of Sewage Disposal at the original Cydna Laboratories in Abbotsford, Johannesburg, on May 4, 1937. Thereat, twelve (12) signatories gave formal consent to a petition requesting the Institute to form a South African Branch.

Immediately thereafter Dr Wilson, with the assistance of Dr E J Hamlin, at that time City Engineer of Johannesburg, submitted a motivation to the Institute in England for its consent to the establishment of a local branch. Both Wilson and Hamlin were Corporate Members of the Institute at that time.

At the foundation meeting of the Branch in Johannesburg, Harold Wilson was appointed Chairman. In 1953 Harold Wilson became President of the Parent Body.



Dr. E.J. Hamlin.

As the Biochemist to the City of Johannesburg and from his previous experiences in Manchester, Wolverhampton and Reading, he was able to inspire those around him with verve and enthusiasm for what was somewhat of a new science to South Africa.

His attitude at all times was frank – and to an extent outspoken on many sewage purification problems – and his pronouncements were accepted as sound.

He stressed such matters as the importance of efficient process operation, an original approach to process problems and, together with Dr Hamlin, the landscaping and beautification of sewage purification works as well as the maintenance of the grounds and surroundings in an attractive condition. He was courageous, at all times, in his advocacy of pollution prevention and creatively imaginative.

The Wilson Award was instituted to commemorate the late Dr Harold Wilson's dedicated approach to his work and his efforts in developing the Southern African Branch, and is presented by the Southern African Branch to acknowledge the combined competence and initiative of the Owner and Works Manager of a Wastewater Treatment Works having a design capacity of not more than 25 000 m^3 per day average dry weather flow.

Works which have received the award include – Umhlanga (Natal), Milnerton (Cape) and Cape Recife (Port Elizabeth, Cape).

Nomination forms may be obtained from the Branch Secretary.

Fulfilled Objectives

The South African Council for Scientific and Industrial Research (CSIR) was established in 1945 and at an early stage representations were made by the Branch to Dr B F J Schonland, the then newly appointed President of the CSIR, to use his influence in the following directions:

(1) To influence Government Departments in the formation of a Central Authority;
(2) To set up a Water Pollution Research Organization under the CSIR.

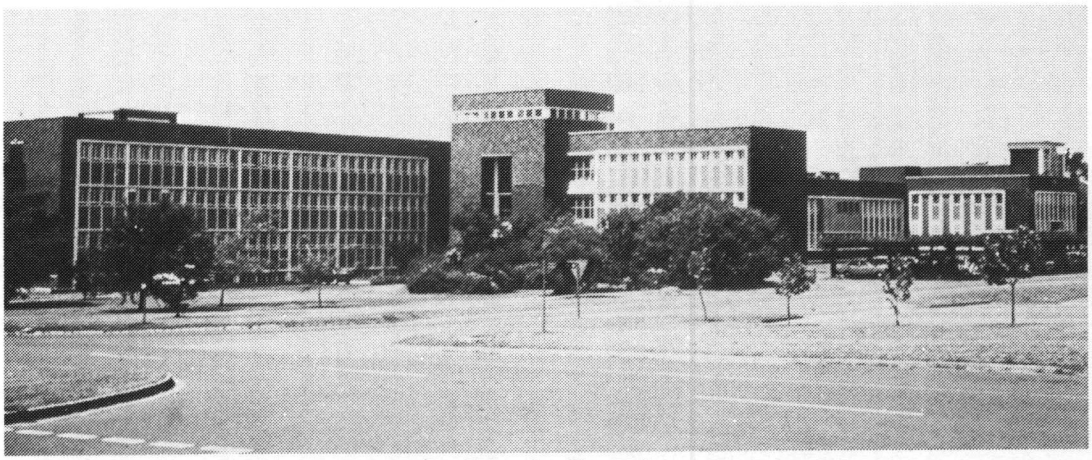
It took some time for objective (1) to be attained as it is today through the powers vested in the Minister of Water Affairs acting on the authority of the Water Act (Act No. 54 of 1956) as amended by Water Amendment Act (Act No. 96 of 1984) and on the advice of the Department of Water Affairs.

Objective (2) was initially achieved by the establishment in Johannesburg of the Water Treatment Research Unit of the CSIR's National Chemical Research Laboratory (Director: Dr W S Rapson).

The first Head of the Water Treatment Research Laboratory was Dr H Wilson. Later, under the control of Dr G H Stander, the unit became transformed into the National Institute for Water Research when it was established on the CSIR campus at Scientia, Pretoria.

(3) National Institute for Water Research (NIWR)

In 1944 Dr B F J Schonland was called on by the



National Institute for Water Research: Scientia, Pretoria.

Prime Minister, General J C Smuts, to draft legislation for the promotion of scientific research in South Africa.[2]

Arising out of this the South African Council for Scientific and Industrial Research (CSIR) was established in 1945.[3]

Initially, only four (4) CSIR research laboratories were created, viz:

- National Physical Research Laboratory (NPRL);
- National Chemical Research Laboratory (NCRL);
- National Building Research Institute and,
- National Personnel Research Institute.

The National Chemical Research Laboratory, originally directed by Dr W S Rapson, formed, as part of its set-up, a Water Treatment Research Unit which was temporarily accommodated at the University of the Witwatersrand, Johannesburg. This unit was later transferred to a permanent building on the CSIR's property at Scientia, Pretoria. The unit became a separate institute of the CSIR under the style and title of the National Institute for Water Research. Dr G J Stander was the first Director. Dr Stander had previously taken over control of the temporary establishment on the campus of the University of the Witwatersrand from Dr Harold Wilson, who headed this unit for a contract period of four years.

When first established, the CSIR was accommodated in the old Mint Building in Visagie Street, Pretoria. However, with expansion it moved to Scientia and is now accommodated in a large complex of buildings housing extensive research facilities and competent staff.

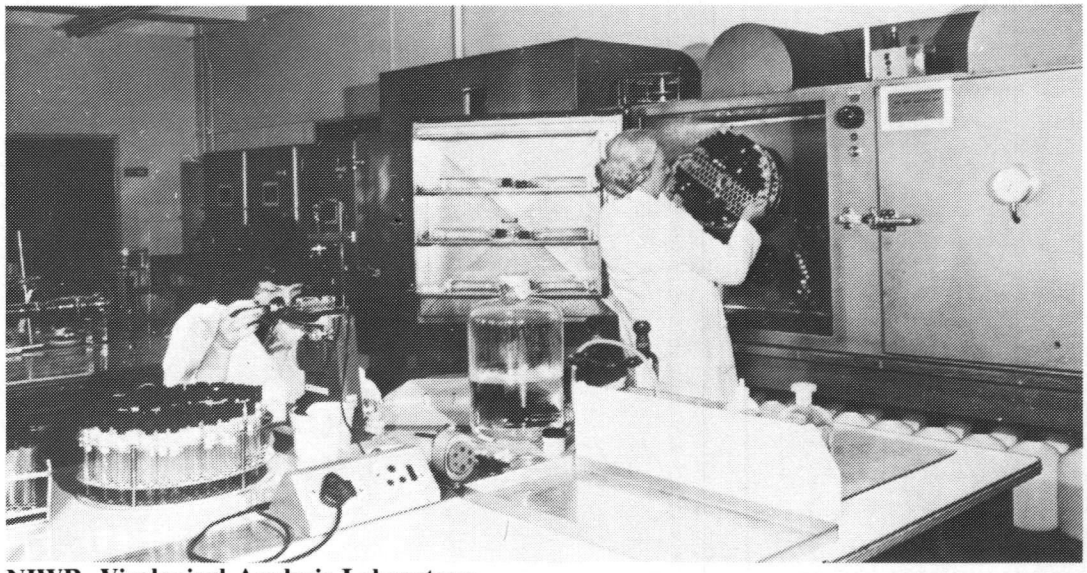
Laboratories, Institutes, Units and Groups presently established forming part of the CSIR establishment are as follows:[4]

Institutes, Laboratories, Units and Groups:

NCRL – Nat. Chemical Research Laboratory
NPRL – Nat. Physical Research Laboratory
NAC – Nat. Accelerator Centre
NRIMS – Nat. Research Institute for Mathematical Sciences
SAAO – South African Astronomical Observatory
MO – Magnetic Observatory
NRIO – Nat. Research Institute for Oceanology
NMERI – Nat. Mechanical Engineering Research Institute
NEERI – Nat. Electrical Engineering Research Institute
CERG – Chemical Engineering Research Group
NBRI – Nat. Building Research Institute
NIWR – Nat. Institute for Water Research
NITRR – Nat. Institute for Transport and Road Research
NITR – Nat. Institute for Telecommunication Research
NIAST – Nat. Institute for Aeronautics and Systems Technology
NIPR – Nat. Institute for Personnel Research
NFRI – Nat. Food Research Institute
SAWTRI – South African Wool and Textile Research Institute
NTRI – Nat. Timber Research Institute
NIMR – Nat. Institute for Materials Research
NICR – Nat. Institute for Coal Research
ACU – Applied Chemistry Unit
CCS – Centre for Computing Services
CSTI – Centre for Scientific and Technical Information

The National Institute for Water Research, from its inception in 1957 under the direction of Dr G J Stander, later followed by Dr G G Cillié and now Dr D F Toerien, has applied itself to the task of investigating and developing methods which will lead to the more efficient use of water and the conservation of available water supplies and resources.

The activities of the NIWR include investigations into:



NIWR, Virological Analysis Laboratory.

(1) water purification;
(2) the treatment of effluent and,
(3) various types of pollution encountered in dams, rivers, estuaries and the sea.

The Institute comprises a number of research groups and regional laboratories. The research groups are stationed in Pretoria and undertake basic and applied research in the fields concerned with the optimum utilization of water. Regional laboratories have been established at Durban, Belville and Bloemfontein and are concerned with local water problems: a Limnological Research Group operates at Rhodes University, Grahamstown. Research groups have been established for investigating problems in the following contexts:
Limnology, water quality, biological treatment processes, physico-chemical treatment processes, desalination and the practical technological development of processes investigated by the Institute.

Achievements: During its period of existence the NIWR has been responsible for a number of advances in the science of wastewater treatment among which may be mentioned:

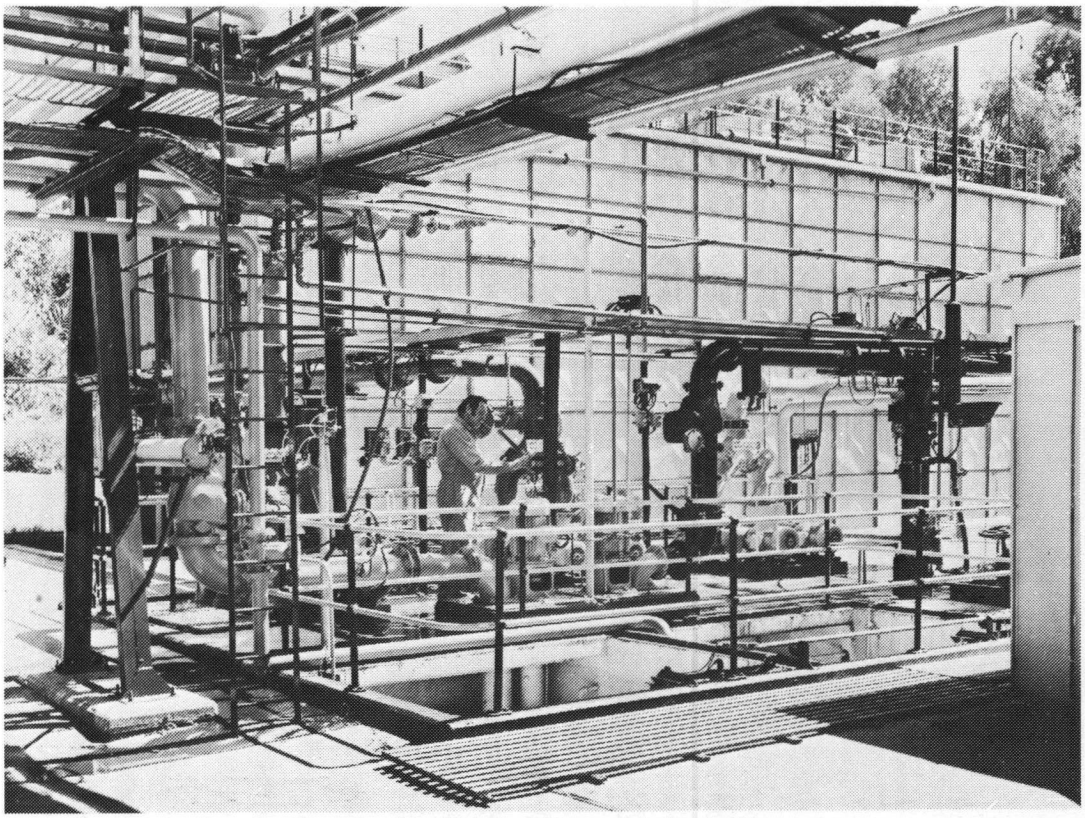
- the treatment of wine distillery wastes;
- the reclamation of pure wholesome water from sewage as evidenced by the results of an experimental Stander Plant at the Daspoort Sewage Purification Works of the Pretoria City Council and a prototype at Windhoek (South West Africa);
- the work on oxidation pond systems;
- maturation ponds;
- bio-disc filtration;
- orbal activated sludge units;
- eutrophication of impoundments;
- the composting of municipal wastes, removal of nutrients from sewage effluents;
- continuous automatic effluent quality monitoring using fish – the movements of which are electronically recorded under standardized conditions.

Publications: The results of research carried out by the NIWR have been published locally and overseas. "A.15 List of Publications – NIWR" is available on request. All publications are free of charge unless otherwise indicated in "A.15". The address of the NIWR is:

P O Box 395
Pretoria
0001

Other Organizations

Apart from the National Institute for Water Research (NIWR) other CSIR organizations which have featured, from time to time in connexion with wastewater treatment and pollution control have been the following:
(1) National Research Institute for Oceanology (NRIO) at Stellenbosch, Cape, where marine



A section of the Stander Reclamation Plant at Daspoort, Pretoria.

disposal of sewage, sludge and industrial effluents have been concerned;

(2) Co-operative Scientific Programmes (CSP) – CSIR, Pretoria, has participated in certain aspects of pollution with respect to ecosystems and marine disposal of effluents;

(3) South African Inventions Development Corporation (Pretoria) – patenting of new wastewater treatment developments.

The National Research Institute for Oceanology (NRIO) based at Stellenbosch is a multidisciplinary organization using the disciplines of marine and coastal engineering sciences.

NRIO has been studying (on a long-term basis) the behaviour of the constituents of raw sewage discharged into the sea off Green Point in Table Bay. It has also co-operated with the NIWR (Durban Regional Laboratory) in investigations concerned with the marine disposal of sewage and industrial effluents at Richards Bay.

Co-operative Scientific Programmes (CSP) aim at identifying problems of national and international importance which lend themselves to solution through co-operative, inter-disciplinary, multi-disciplinary and multi-institutional research. CSP then develops research programmes around these problems.

Some of the CSP programmes serve as contributions to international programmes in which the Republic is an agreed participant. Present national programmes relevant to water include oceanography, embracing coastal processes, estuaries and marine pollution.

Over a period of at least ten (10) years the CSP of the CSIR has carried out an extensive Marine Pollution Monitoring and Survey Programme of the South African coastline, supported by the Department of Water Affairs.

Further organizations: Though more directly concerned with other matters yet maintaining a "watching brief" on pollution in so far as it concerns rivers, inland waters, or the sea, there are the following:

(1) Oceanographic Research Institute (ORI),* Durban;

(2) The Department of Nature Conservation of the Transvaal, Cape, OFS and the Natal Parks, Game and Fish Preservation Board;

(3) Sea Fisheries Research Institute† (Division of Sea Fisheries) Sea Point, Cape;

(4) Natal Town and Regional Planning Commission, Pietermaritzburg;

(5) Council for the Habitat (set up by the Department of Planning in 1974 to co-ordinate representations to government departments on environmental matters).

Statutory Bodies: The three statutory bodies concerned are:

(1) The Department of Water Affairs (all aspects of wastewater treatment and water pollution control);

(2) The Department of National Health and Population Development (health matters concerned with water).

(3) The South African Bureau of Standards (effluent quality criteria).

All three deliberate on permit applications for the discharge of effluents.

(4) The Water Research Commission

The Water Research Commission was founded in 1971. Its first Chairman was Dr J P Kriel, at that time Secretary for Water Affairs.

Dr G J Stander became Vice-Chairman and Chief Executive Officer after terminating his service as Director of the National Institute for Water Research (NIWR) on September 30, 1971. Later Dr Stander succeeded to the post of Chairman and Chief Executive Officer of the Commission. On the retirement of Dr Stander, Dr M R Henzen, the subsequent encumbent, took over as Chairman and Chief Executive Officer of the Water Research Commission. Mr J F Otto became Vice-Chairman in 1980. The present Chairman is Dr J P Kriel and Mr P E Odendaal, Executive Director.

For some time prior to 1970 it had become apparent that a co-ordinated effort at National level should be made to optimize the Republic's water resources.

Following on the *"Report of the Commission of Enquiry into Water Matters"* submitted to Parliament in 1970 by the Minister of Water Affairs, the Honorable Mr S P Botha, Parliament passed the "Water Research Act" (Act No. 34 of 1971) ". . . to provide for the promotion of research in connection with water affairs; for that purpose to establish a Water Research Commission and a Water Research Fund; and to provide for matters incidental thereto . . .".

Objects of the Water Research Commission: According to Section 2(3) of the Water Research Act the

*The Oceanographic Research Institute in Durban was founded over thirty (30) years ago by Dr George Campbell when Chairman of the University of Natal. Its present Director is Professor A P Bowmaker who reports to the South African National Committee for Oceanographic Research and the South African Association of Marine Biological Research. The Institute is concerned, *inter alia*, with marine pollution along the Natal Coast.

ORI has carried out work on the estuaries of Natal to update the Natal Town and Regional Planning Commission's publication *"The Estuaries of Natal"*.

ORI is naturally interested in the condition of the estuaries of Natal since the estuaries fulfil a vital role as nursery and feeding grounds of a large number of marine organisms, many of which are of commercial significance.

The Institute has been monitoring the sea discharge area of the Richards Bay marine pipeline system.

†The Marine Fisheries Act (No. 10 of 1940) transferred control of sea fisheries and intertidal life to the Division of Sea Fisheries of the Department of Commerce and Industries. However, the Natal coastline and Cape estuaries are not within this Division's jurisdiction.

objects of the Water Research Commission are to co-ordinate, to promote, to encourage, or to cause to be undertaken, as determined by the Minister specifically or in broad outline, research in respect of:

(a) The occurrence, preservation, conservation, utilization, control, supply, distribution, purification, pollution or reclamation of water supplies and water;
(b) The use of water for:
    (i) agricultural purposes;
    (ii) industrial purposes, and,
    (iii) urban purposes.

Functions of the Water Research Commission: In terms of Section 3(1) of the Water Research Act (Act No. 34 of 1971) the functions of the Water Research Commission are clearly delineated and consist of the following:

"(a) to cause by itself or in collaboration with the Council for Scientific and Industrial Research established by section 2 of the Scientific Research Council Act, 1945 (Act No. 33 of 1945), any State department, university or other institution, research to be undertaken in respect of matters relating to water;
(b) to promote the research referred to in section 2(3), and in connection therewith to establish research programmes or to alter research programmes so established;
(c) to make grants, with the approval of the Minister, and on such conditions as the Minister may approve (including conditions relating to rights regarding inventions and discoveries arising therefrom) from the fund to individuals, universities and other institutions for the benefit of such research, the development work for the application of the results of such research and the establishment of facilities for such research;
(d) to receive and to examine progress reports on such research and the development work for the application of the results of such research;
(e) to obtain information relating to such research and to development work for the application of the results of such research;
(f) to accumulate, to assimilate and to disseminate knowledge in regard to the results of such research and the application thereof, and to promote development work for the purposes of such application;
(g) to co-operate with institutions undertaking such research in other countries, with a view to the accumulation or dissemination of knowledge of such research and the results thereof;
(h) to advise the Minister in respect of the levying of rates or charges under section 11;
(i) with the approval of the Minister, to purchase, hire or otherwise acquire and to hold such immovable property as the Commission may consider necessary for the performance of its functions, and to alienate or let any immovable property held by it; and
(j) to take such other measures as the Commission may consider conducive to the attainment of its objects."

Constitution of the Commission: The Water Research Act, 1971, provides for the appointment of a Secretary and seven (7) other members appointed by the State President on grounds of their special knowledge or experience in regard to any aspect of the Commission's functions. Of these seven members provision is made for the designation by the Minister of a Chairman and a Vice-Chairman of the Commission.

Provision is also made for the appointment of officers and employees to assist the Commission in its functions in terms of the Water Research Act, 1971.

Water Research Fund: Provision is made in terms of section 12 of the Water Research Act, 1971, for the establishment of a Water Research Fund to consist of:

(a) Moneys appropriated by Parliament for the benefit of the fund;
(b) Rates and charges levied under Section 11 of the Act;
(c) Donations, bequests or contributions which the Commission may receive from any other sources.

Section 11 provides that the Minister may, in consultation with the Minister of Finance, from time to time by notice in the Government Gazette:

(a) levy rates on land which may be irrigated by means of water supplied or made available by the State, an irrigation board or a water board;
(b) levy charges on water supplied or made available for use for agricultural purposes, urban purposes, industrial purposes or any other purposes by the State, an irrigation board, a water board, a local authority, the Rand Water Board or any other body; or,
(c) levy both such rates and such charges.

In terms of Section 11 of the Water Research Act, 1971, and by Government Notice No. 214 of the 18th February, 1974, the following rates and charges were levied:

"(1) Forty (40) cents in respect of each hectare of land scheduled in terms of section 63(7) or, where applicable, section 88 of the Water Act, 1956 (Act No. 54 of 1956), to be irrigated at any time during the (calendar year)* with water supplied or made available from a Government dam and distributed by means of a canal, irrespective of whether or not such canal belongs to or is controlled by the Government, an irrigation board or other statutory body . . .
(2) Twenty (20) cents in respect of each hectare of land scheduled as in paragraph (1) but where

*Year requires to be specified.

the water supplied or made available is not distributed by means of a canal . . .

(3) Twenty (20) cents in respect of each hectare of land scheduled in terms of section 88 of the Water Act, 1956 (Act No. 54 of 1956) . . .

(4) Two-tenths (0,2 c) of a cent per cubic metre in respect of metered water supplied or made available (during a calendar year) from a Government waterworks for purposes other than the irrigation of land . . .

(5) Two-tenths (0,2 c) of a cent per cubic metre in respect of the quantity of water used, supplied or made available for use for urban, industrial or domestic purposes (during a calendar year) . . ."

Note: The omissions from the above schedule are concerned with the mode of recovery of the rates and charges indicated.

Up to 30 June 1981 the tariffs were 0,2 c/m³ for water supplied for urban, industrial or domestic use and an amount varying between 20 c and 40 c/ha of land scheduled for irrigation.

On 1 July 1981 the tariffs were fixed at 0,25 c/m³ for water supplied for urban, industrial or domestic use and 40 c/ha for all land scheduled for irrigation.

Subsequent tariffs for recent financial years were as follows:

1982 Financial year – 0,25 c/m³ for water supplied for urban or domestic use; and 40 c/ha for land scheduled for irrigation.

1983 Financial year – the corresponding tariffs were 0,35 c/m³ and 60 c/ha.

Growth in the Commission's Expenditure

(i) *Research and Advisory Services:* From April 1972 to the end of 1977 expenditure on research and consultation services was as follows:

1973 ... R 121 300
1974 ... R 591 700
1975 ... R1 011 700
1976 ... R1 599 600
1977 ... R3 403 500

(ii) *Specific research Areas:* Expenditure on specific research areas for the total inclusive period of 11 years from 1972 to 1982 was as follows:

	Amount R	*% of Total*
(1) Water reclamation	6 958 000	26
(2) Ground water	2 774 000	11
(3) Water environment (incl. eutrophication)	2 411 000	9
(4) Municipal wastewater	1 880 000	7
(5) Industrial effluents	2 891 000	11
(6) Desalination	1 932 000	7
(7) Water consumption (incl. dry cooling and water economy)	1 142 000	4
(8) Irrigation	1 518 000	6
(9) Surface hydrology	2 834 000	11
(10) Rainfall stimulation	2 243 000	8
TOTAL	R26 583 000	100%

(iii) *Total Annual Expenditure:* Total yearly expenditure was as follows: (To nearest Rand)

1971/72 ... R 19 865
1972/73 ... R2 204 635
1973/74 ... R2 257 731
1974 ... R1 751 937
1975 ... R3 189 389
1976 ... R3 885 862
1977 ... R3 825 292
1978 ... R3 987 890
1979 ... R4 057 212
1980 ... R4 321 404
1981 ... R5 069 523
1982 ... R6 498 111
1983 ... R7 405 352

Wastewater Treatment and Pollution Control

The Commission has concerned itself with many aspects of the treatment and disposal of municipal wastewater as well as the treatment of industrial effluents from various industries. The mineralization of the water in rivers and impoundments has given rise to interest in desalination projects.

Relevant research projects have included the following:

- Eutrophication research in the Hartbeespoort Dam (contract with the National Institute for Water Research).
- Evaluation of the impact of phosphate limitation on the trophic status of South African Impoundments (contract with the University of the Orange Free State – the Institute of Environmental Sciences and the Hydrological Research Institute of the Department of Water Affairs).
- Research on a modified activated sludge process for nutrient removal (contracts with the National Institute for Water Research; City Council of Johannesburg; University of Cape Town – Department of Civil Engineering).
- The removal of nitrogen and phosphate from biological filter effluents (contracts with the National Institute for Water Research and the City Council of Pretoria).
- Sludge disposal to sea (contract with the City of Durban).
- Autothermic aerobic digestion of sludge (Contract with the City Council of Johannesburg).
- The composting of sludge by means of forced aeration (contract with the National Institute for Water Research).
- Effluent treatment in the textile and wool-scouring industries (contract with the University of Natal – Pollution Research Group, Depart-

ment of Chemical Engineering).

- The purification and reuse of effluents from tanning and fellmongering industries (contract with the Leather Industries Research Institute, Grahamstown).
- Water and effluent management problems in the fishing, fruit and vegetable processing industries (contract with Binnie & Partners, consulting engineers in South Africa).
- Water management and effluent treatment in the processing of pulp and paper; metals; fermentation products and pharmaceutical products (contracts with the University of Natal – Pollution Research Group, Department of Chemical Engineering). The development of membranes for reverse osmosis and ultrafiltration (contract with the University of Stellenbosch – Institute of Polymer Science).
- Technological development of continuous counter-current ion exchange for the reclamation of water of potable quality from secondary effluents (contract with the University of Cape Town – Department of Chemical Engineering).
- The desalination of mine water (contract with the Chamber of Mines of South Africa).
- Pollution of rivers and streams and water reclamation in the Pretoria-Witwatersrand-Vereeniging-Sasolburg Complex (contracts with the University of the Witwatersrand – Hydrological Research Unit and a firm of (local) consulting engineers).
- Water reclamation from sewage projects include the following:

  Operation of the Stander Water Reclamation Plants at Windhoek and Pretoria;

  Reclamation of water at the Athlone Sewage Purification Works, Cape Town (contract with the City Council of Cape Town and the National Institute for Water Research).

Publication, Communication, Information

The Water Research Commission maintains contact with overseas organizations engaged in water research and obtains the services, from time to time, of overseas persons experienced in relevant fields of investigation. In this connexion, consultants have been brought to South Africa to study and report on specific problems (e.g. the treatment and disposal of industrial wastes from specific industries).

In order to disseminate the results of original scientific research work the Commission publishes quarterly *"Water SA"* – the first issue (Volume I No. 1 was published in April 1975. This is a journal designed to be of high standing.

The Commission also publishes *"SA Waterbulletin"*,* a bimonthly news-letter. The first issue of this publication appeared in August 1975.

The Commission has contracted with the Council for Scientific and Industrial Research whereby the Information and Research Services Division of the CSIR operates a National Information Centre on Water. The main functions of the Centre are to coordinate information and library services in the promotion of an efficient and rapid journal service.

The Centre publishes current awareness bulletin *"Selected Journals on Water"* (SJOW). This publication contains the index pages of a number of the most important journals in the field of water.

Guidelines for Industries

The Commission plans to establish guidelines for industries in regard to methods for complying with the quality standards for effluents. These will be drawn up for each particular type of industry.

The publication of these technical manuals represents part of the Commission's programme of technology transfer. These manuals are to be based on the results of projects which are financed by the Commission and which have been satisfactorily concluded or on the results *per se* obtained during the execution of a project.

The first publication to appear in this technology transfer category was entitled *"Tussentydse riglyne vir die beheer van eutrofikasie"* (*"Interim measures for controlling eutrophication"*).

Subsequently, a guide entitled *"Guide for planning, design and implementation of a water reclamation scheme"* was published in 1982.

Another guide which is being considered is on water management and effluent treatment in the textile industry.

(5) The Department of National Health and Population Development

The Department of National Health and Population Development operates within the framework of the Health Act, (Act No. 63 of 1977). As far as wastewater treatment is concerned it pays particular attention to the pollution of water sources by liquid or solid matter which is or may be directly or indirectly infectious or injurious to man or may cause a nuisance.

However, the control of solid wastes disposal, *per se*, is regulated in terms of Section 12(2)(a) of the Environment Conservation Act, (Act No. 100 of 1982) by Government Notice 1549 of 12 July, 1985. (Refer to Chapter 16).

The Department of National Health and Population Development operates a number of Regional Offices. Each Regional Office comments and makes recommendations in regard to applications referred to it by the Department of Water Affairs for the issue of permits in terms of Section 21 of the Water Act.

* *"SA Waterbulletin"* contains articles, news snippets and items of general interest in many aspects of water locally and overseas. It concentrates especially on introducing the activities of different organizations dealing with water in the Republic.

The comments and recommendations of the Department of National Health and Population Development are particularly pertinent when dealing with the discharge of sewage liquors into the sea where bathing beaches require safeguarding and also in cases relating to the use of end-products (e.g. digested sludge and activated sludge) for agricultural and gardening purposes.

(6) The South African Bureau of Standards (SABS)

Like the Department of National Health and Population Development the South African Bureau of Standards acts as an advisory body in regard to the acceptability of effluents for discharge into water sources. The SABS has laid down limits for the purity of water for domestic supplies (SABS 241 – 1984) and has set out water quality criteria for various uses. (Refer to Chapter 14)

Applications received by the Department of Water Affairs for the discharge of effluents to the water environment are automatically referred to the SABS.

Methods of sampling and analysis can be had on application to the SABS. All analyses reported in applications for permits made to the Department of Water Affairs for the discharge or re-use of effluents must conform with the SABS methods.

(7) Provincial and Local Authorities

As originally constituted the provincial authorities were formed as subordinate regional authorities of the Republic. Their legislative authority is confined to a number of matters which include the use of water and the installation of sewage purification and disposal facilities (for resorts, schools, hospitals and institutions).

The provincial authorities have power to enact ordinances for the control of the activities of local authorities in the four provinces of South Africa. Such ordinances provide for such matters as sanitation, sewerage and drainage works.

Local authorities are required to pass adequate industrial effluent acceptance by-laws for approval by the respective provincial authority and, in turn, by the Department of Water Affairs (Refer to Chapter 10).

A great deal of useful investigational work in the field of wastewater treatment has been carried out and reported by the employees of local authorities. (Refer to Chapter 6).

(8) Industries

A gratifying amount of work has been done in the handling and treatment of wastewater arisings by a number of major water-using industries. The problems and achievements of eight (8) of such industries are described. (Refer to Chapter 15(i) to 15(viii))

REFERENCES

1. McLachlan J.A. J. and Proc. Inst. Sewage Purif., 1959, **3**, pp. 297-307.
2. Naudé Meiring S. *A History of Scientific Endeavour in South Africa*, Royal Society of South Africa, Cape Town, Editor Brown A.C. June, 1977, p. 75.
3. Established by Section 2 of the Scientific Research Council Act, 1945 (Act No. 33 of 1945).
4. CSIR: *"Organisation and functions of the CSIR"*, Annual Report, 1983, p. 39.

Chapter 5 OVERSEAS ORGANIZATIONS

The treatment of wastewater and control of pollution of the aquatic environment involves reconciling the conflicting interests of water supply versus wastewater and waste disposal. This is exemplified by:

(1) the interests of industrialists as opposed to recreational interests of the public,
(2) acceptable standards of hygiene and chemical quality as opposed to financial gain by corporate bodies and other effluent and waste disposers.

In a nutshell, the nub of the problem is the conservation of water resources by ensuring the maximum judicious use of available water resources for the maximum benefit of the community.

It is interesting to discover how different nations have attempted to reconcile these conflicting interests in their particular circumstances.

There is little doubt that as urbanization and industrial development of a country increase a stage is reached, eventually, when legislation is necessary to prevent the pollution of potential water supplies.

The enforcing legislation has taken a number of forms, viz:

(1) The promulgation of uniform emission standards for effluents discharging into rivers and other relevant concomitants of the aquatic environment.
(2) Allowing discharge of effluent such that the load does not exceed the assimilatory capacity of the water body into which it is discharged.

    (This leads to control of pollution by quality objectives and consideration of environmental quality standards to meet particular circumstances).
(3) Establishing water quality criteria for specified uses e.g. agricultural, industrial, recreational, fish and wildlife and domestic use.

The water quality control legislation enacted by a particular country will determine the type of organization considered necessary for the administrative enforcement of legal requirements.

Dealing with the law and its execution, Thayer[1] has concluded that "It is necessary that pollution control be carried out within a sound legal framework but it is often the attitude and competence of the regulatory authority which determines overall effectiveness".

The first country to deal with the problems of pollution control in a systematic manner was Great Britain (United Kingdom).

United Kingdom

The establishment of the Royal Commission on Sewage Disposal in 1898 constituted a significant step forward in creating a colligative organization for the examination of the problems of wastewater purification and disposal. This Royal Commission continued its activities up to 1912 (cf. Chapter 1).

Prior to 1948 the prevention of pollution in the United Kingdom was the responsibility of over 1 700 different types of authority (sanitary authorities, county councils, fishery boards, catchment boards, etc).[2] Today, there are 10 Regional Authorities for England and Wales. Nine Regional Water Authorities cover England and one covers Wales – based on drainage areas. Seven River Purification Boards cover the mainland of Scotland. The areas of the three Island Councils in Scotland (Western Isles, Orkney and Shetland) have no River Purification Board; the duties in these areas are undertaken by the Island Councils.

The Regional Water Authorities in England and Wales control sewage treatment whereas in Scotland control is in the hands of the local authorities.[3]

Moss[3] gives the following listing of statutory bodies controlling liquid effluent:

	England and Wales	Scotland
Discharge to public sewer	Regional Water Authority	Local Authority
Operation of public treatment works	– do –	– do –
Discharge to inland (fresh) water	– do –	Area River Purification Board
Discharge to tidal water (sea) up to the 3-mile limit	– do –	– do –

The UK has subscribed to the philosophy of control of pollution by means of environmental quality objectives and environmental quality standards.

In terms of the Control of Pollution Act 1974[4] a water authority is concerned with examining the effluent standard for each treatment works and adjusting this, where necessary, to keep pace with the quality status of the receiving water. It also has to deal with the revision of standards for industrial discharges as well as setting standards where none previously existed.

The United Kingdom, of course, being a member of the European Economic Community (EEC), is required to subscribe to directives approved of by the EEC Council of Ministers. In this connexion the Paris Convention on the prevention of marine pollution from land-based sources (which includes that from rivers) has particular relevance.

Naturally, statutory bodies controlling pollution, of necessity, have to provide suitable staff and facilities for examination and control within their respective areas of jurisidiction.

Additionally, central research facilities have been established by the Water Research Centre at the following centres:

(1) WRC Processes, Elder Way, Stevenage, Herts.
(2) WRC Environment, Henley Road, Medmenham, Bucks.
(3) WRC Engineering, Frankland Road, Blagrove, Swindon, Wilts.

The registered office and headquarters of the WRC is Henley Road, Medmenham, Bucks, England.

Originally establishments (1) and (2) operated separately – Medmenham being concerned with potable water problems and the environment and the Stevenage laboratory (established in 1954 by the Water Pollution Research Board of the Department of Scientific and Industrial Research) being concerned mainly with problems associated with sewage and industrial waste treatment and disposal. The two establishments have been united with control centred at Medmenham. Prior to 1954 (i.e. from 1927 onwards) the work of the Water Pollution Research Laboratory was carried out, temporarily, at a number of centres where facilities were available for the type of work being carried out.

WRC Engineering buildings at Swindon were opened on July 6, 1982.

The Water Research Centre is incorporated as a private company. It is financed by subscriptions from its members and also receives financial support from the Department of the Environment and from commercial contract work.

USA

At the beginning of the century the main motivating factor for curbing pollution in the United States was contained in a public desire to eliminate waterborne diseases such as typhoid.[5] However, by 1929 there was an awareness that the discharge of sewage and industrial effluents was a matter of public concern though some still adhered to the fallacious idea that the running water of a stream would purify itself in some nine miles (14 to 15 kilometres) of travel.

By 1940 public conviction had reached a stage that a much broader policy on pollution than merely the transmission of diseases should be instituted.

In 1948, Congress passed the Federal Water Pollution Control Act (FWPCA) and, later, amendments to the Act in 1956. Eventually, in 1965 water quality standards for waterways were promulgated by the passage through Congress of the Water Quality Act, 1965 wherein each state was required to establish standards for interstate waters within or on its border.

It should be emphasized that the United States of America is a federal body of 50 states and both state and federal governments are involved in pollution control. This being so an individual state can promulgate any act for controlling pollution provided it is not in conflict with the federal laws.

The Water Improvement Act of 1970 increased federal authority and established state certification procedure. 1970 Saw the establishment of the US Environmental Protection Agency (EPA) to coordinate the attack on environmental problems including water pollution, solid waste management, pesticides, radiation, noise and toxic substances. In 1972 the US Congress passed the comprehensive amendment of the Federal Water Pollution Control Act. This was based on three major considerations, viz:

- uniform national standards,
- enforceable regulations,
- the issuing of permits specifying effluent limits.

Barabas[6] has indicated that, though not legally binding, the goal of the act was to restore water quality by July 1, 1983 to the extent that it would be suitable for public recreation as well as the protection and propagation of fish and wildlife.

Further amendments to the Federal Water Pollution Control Act were enacted in 1977 and 1978. These amendments changed the emphasis from water quality standards to effluent limitations (i.e. regulating the amount of pollutants discharged from point sources).

Research in the field of sewage treatment in the United States has been carried out by federal, state and municipal authorities, industrial companies and higher educational institutions working independently or under sponsorship.

The federal government through the US Public Health Service has been primarily concerned with matters of stream pollution. State governments, mainly through their respective boards of health, have operated research stations and have dealt with a number of matters such as stream surveys, sanitary conditions and the operation of sewage purification

works. Local authorities (municipalities) – cities, sanitary districts and commissions have operated experiment stations as a guide to the design and correct operation of sewage purification plants.

Industries have given attention to the recovery of by-products in ameliorating stream pollution. Institutions of higher education have carried out research principally aimed at enhancing the techniques, improving and elucidating processes involved in sewage purification.

In 1887 the Massachusetts State Board of Health set up an experiment station at Lawrence (cf. Chapter 1).

A sewage testing station was set up at the Massachusetts Institute of Technology in 1902, at the University of Illinois in 1903 and at Iowa State College in 1904.

Between 1908 and 1914 many research laboratories and testing stations were established mainly by universities and colleges.

Apart from the above-mentioned testing stations some of the other research centres of note include the following:

Columbus, Ohio-State University; Urbana, Illinois-State Water Survey; Pennsylvania State College; Milwaukee, Wis., Sewerage Commission; Brooklyn NY, City of New York; Washington DC – US Public Health Service; Cincinnati, Ohio – US Public Health Service; Houston, Texas – City and also State Department of Agriculture; Syracuse, NY – City; Purdue University, Lafayette Mich.; Harvard University, Cambridge, Mass.; New Brunswick NJ, New Jersey Agricultural Experiment Station and Rutgers University; Michigan State College; Columbia University.

The United States has wrested itself from an attitude of benign neglect in its accomodating attitude towards the discharge of effluents into rivers and now – through the EPA – is very much concerned with the quality of water in rivers.

Water quality monitoring has become an essential ingredient of the EPA's programme of water quality management.

Legislative authority for water monitoring is inherent in the following Congressional Acts, viz:

(1) Federal Water Pollution Control Act.
(2) Marine Protection, Research and Sanctuaries Act.
(3) Safe Drinking Water Act.
(4) Federal Insecticides, Fungicides and Rodenticides Act.
(5) Solid Wastes Disposal Act.

According to Robert L Crim of the Monitoring Branch, US Environmental Protection Agency, Washington DC – ". . . most of the monitoring authorized by Congress falls into the category of explicit requirements for EPA and others to achieve certain results that cannot be accomplished without the conducting of monitoring or the developing of monitoring procedures".

The US Geological Survey[7] also operates a federal water quality programme consisting of the following commitments:

(1) Operation of a series of nationwide water-quality monitoring networks;
(2) Collection of data at designated sites to determine compliance with relevant promulgated inter-state requirements or international treaties;
(3) Collection of water-quality data in support of the US energy programme;
(4) Conduction of a pilot river-quality assessment programme designed to develop and demonstrate techniques and methodology for assessing the relative merits of water-quality alternatives;
(5) Conduction of a sub-surface waste storage programme to develop information that can be used by other bodies to formulate regulations that will minimize pollution of ground water.

Water Pollution Control Federation

The Water Pollution Control Federation is composed of 40 member associations in the US and is affiliated with 23 organizations in other countries.

The Federation publishes a monthly *"Journal"*. Prior to 1950 the publication was known as *"Sewage Works Journal"* and from 1950 until 1960 was published under the title of *"Sewage and Industrial Wastes"*. An annual *"Literature Review"* is also published.

Particular attention is paid to the examination and certification of sewage works operators in each state.

Federal Republic of Germany

The Federal Republic of Germany consists of 10 länder (states). According to Wolf[8] "Basic Law" in regard to water resources is enacted by the Federal Government. Such enactments form the Federal Water Resources Law to which each state has to conform. However, the basic requirements enshrined in Federal Law may be supplemented by the State Water Laws.

The Federal Water Resources Law *inter alia*, contains the following provisions:

(1) The use of water requires official permission.
(2) By use is meant (in law) the introduction and discharge of matter into surface water or ground water.
(3) Provision shall be subject to certain conditions pertaining to such use.
(4) Authority to use water for a particular purpose is revocable: permission for such use being defined in regard to the manner and extent of usage.

Effluent threshold values are determined for their respective areas of jurisdiction by the individual states (länder). Threshold values vary from state to state. Attempts have been made to "standardize" threshold values on the basis of feasible technical attainment. These standard values have been set out as

a guide to the authorities.

Where threshold values are stipulated an attitude which has prevailed is that threshold values must not be exceeded, with a probability of c. 85 per cent – in other words the guide values stated in the Requirements must not be exceeded in more than 15 per cent of cases.

The Federal Government has endeavoured to amend Basic Law and the Water Resources Law in order to stipulate quality criteria for effluents consistent with the composition of the wastewater supply.

The following is a formula for calculating the charge made to a user depending on the extent of polluting quality:

$$S = Q(0{,}45A - 0{,}45A_o) + 0{,}55\,\frac{COD - COD_o}{80} + 0{,}1\,\frac{C_B - C_F}{2}$$

Where Q = The quantity of wastewater discharge in m^3/day.
A = Settleable solids in mℓ/ℓ
COD = Chemical Oxygen Demand in mg/ℓ
C = Toxic effect on bacteria and fish

The value $A_o = 0{,}1$ mℓ/ℓ and $COD_o = 15$ mg/ℓ are deducted in each case as basic values.

Professional Institute: Abwassertechnische Vereinigung

River control authorities: Notable river authorities include the following: Rührverband, Emschergenossenschaft, and Lippeverband.

The Netherlands

The Netherlands with a population of over 14 million presents an interesting example of a densely populated country (415 people per square kilometre) with somewhat unique water pollution control problems. It is situated in the deltaic area of the rivers Rhine and Meuse and over half of the country is situated below sea level.

The low-lying northern and western parts of the Netherlands are susceptible to saline infiltration. Apart from the seeping in of salt water from the sea, the position is further aggravated by pollution caused by mineral salts from the River Rhine, since this river supplies about 70 per cent of the total amount of fresh water available for use in the Netherlands. The salinity of the Rhine is influenced considerably by waste discharges from potassium mines in France and mine drainage from coal mines in Germany.

The River Rhine together with its tributaries receives discharges of poor quality water in its passage through highly industrialized areas as it flows from its source in Switzerland through France, Federal Republic of Germany, Luxembourg through to the Netherlands and final discharge into the North Sea.

An International Commission consisting of representatives from Switzerland, France, Federal Republic of Germany, Luxembourg and the Netherlands was set up in 1950 to improve the quality of the water in the Rhine. However, Brouwer[9] has stated that, despite all the efforts made by the Commission the quality of the water in the Rhine is poor. He points out that c. 70 per cent of drinking water in the Netherlands is obtained from ground water and c. 30 per cent from surface water but due to lack of fresh ground water the country will have to rely, increasingly, on surface-derived supplies for potable use in order to cope with the rising demand for potable water.

In 1875 the Public Health Service of the Netherlands issued a directive in regard to water pollution control. Subsequent directives of the medical inspectors followed in later years but none of these ever became law.

However, due to increased urbanization and industrialization in the Netherlands subsequent to World War II the Surface Water Pollution Act was promulgated on December 1, 1970.
Inherent in this act is the principle of decentralization of administrative control of pollution which allows for better use of knowledge of local problems.

The state is responsible for the control of the quality and quantity of discharges into large international rivers, namely, the Rhine, Meuse and the Scheldt; the main canals; great lakes; estuaries and territorial maritime waters. State control is vested in the Ministry of Transport and Water Control.

There are 11 provincial authorities and these are responsible for the management of all other watercourses and water resources. However, they may delegate their authority and management powers to water boards.

Two important requirements were set out in the Surface Water Pollution Act of 1970, viz:

(1) Where wastewater is discharged into a receiving water a permit issued by the authority controlling the receiving water is required and such permit shall specify conditions in regard to quality and quantity of such wastewater to be discharged.
(2) Every discharger of wastewater into an aquatic environment (river, lake, etc.) must pay a pollution charge/effluent fee in accordance with the following payment formula:

$$P = Q\,\frac{(COD + 4{,}57\ N)}{180}$$

Where, P = Pollution load [in population equivalents (p.e.)].
COD = Chemical Oxygen Demand (in mg/ℓ).
N = Organic N + Ammoniacal (NH_4) N-content in mg/ℓ.

The monies received are used for financing pollution control measures.

The standard rate of charge per population equivalent is fixed annually (initially, in 1971 the

charge was fixed by the government at 2 guilders per p.e.).

The rates for effluent discharged into non-state waters vary from region to region and are generally higher than those for discharges into state waters.

Research Institute

In the Netherlands wastewater problems are the concern of the Rijkinstituut voor Zuivering van Afvalwater.

Italy

Italy represents a European country which has been somewhat tardy in dealing with water pollution. Beccari[10] has stated, in regard to the protection of waters from pollution that the situation in Italy was characterized, until a few years ago, by two negative factors, viz:

(1) Inadequacy of pollution control technology, and;
(2) By lack of planning for public intervention and regulation.

He has pointed to the serious conditions of many small and middle-sized lakes and increasingly worsening conditions in some large lakes such as Lakes Maggiore and Como.

Italian coastal waters, Beccari[10] states, are considerably polluted. This conclusion is reached not only from the considerable daily polluting load discharged into the sea (0,3 kg BOD_5/km of coast) but, more particularly, from the distribution of this load.

In the upper Adriatic Sea, the pollution is so considerable as to affect the sea's ecosystem.

Industry is responsible for 60 to 70 per cent of Italy's total coastal pollution.

Prior to the promulgation of Law 319 of May 1976, the problem of protecting the water environment against pollution had been dealt with in a perfunctory manner without the benefit of satisfactory legal backing by appropriate laws.

The main purpose of Law No. 319 is as follows:

(1) Control of the discharge of public and private wastewaters,
(2) Organization of public utilities (water supply systems, sewerage, and wastewater treatment plants),
(3) Drawing up of a general plan for water quality improvement on a regional basis,
(4) Compilation of a qualitative and quantitative inventory of water resources.

The tasks associated with the above legal objectives are assigned to the central offices of the Public Administration and to local authorities such as the regions, provinces and municipalities according to their respective responsibilities.

Acceptable concentrations for certain pollutants set out in Law No. 319 have been specified. However, compliance with the requirements has been called for on an interim and final basis to be reached gradually. This is illustrated by the fact that wastewaters from already existing industries must comply with the following directives:

When discharged into surface waters, the concentrations of pollutants in the wastewaters shall conform with certain values reported in the Law within three (3) years from the law coming into force and with stricter specified values within the subsequent six (6) years.

When discharged into public sewers the concentration of pollutants shall comply with similar initial values to those cited above within three (3) years from the law coming into force and shall comply with the requirements of the local authorities from the date of commissioning of the centralized sewage treatment plant.

In December 1979 Law No. 319 was incorporated into and superseded by Law No. 650. The new law, *inter alia*, modified certain permissible concentration values and slightly postponed the deadlines set by Law No. 319.

Research Institute:

Water Research Institute, Rome.

International Organizations and Research

The International Association of Water Pollution Research (IAWPR) organizes conferences at selected centres throughout the world. The Eleventh Conference took place in Cape Town early in 1983 followed by a CSIR post Conference Seminar at Pretoria: This seminar dealt with *"Mine Water Pollution"*.

International conferences on sanitary engineering have been organized by the Institution of Sanitary Engineers, London, as far back as 1924 when the First International Conference took place in London.

International conferences and symposia have been organized, from time to time, by Harvard University and the American Chemical Society in the United States whilst the Royal Society of Chemistry and the Society of Applied Bacteriology have sponsored symposia at the University of Lancaster in England. Symposia papers are usually issued in book form.

The American Public Health Association Inc. jointly with the American Water Works Association and the Water Pollution Control Federation publish *"Standard Methods for the Examination of Water, Sewage and Industrial Wastes"*: This has been revised, enlarged and up-dated through many editions and is a valuable publication for analytical personnel in the field of wastewater treatment and research.

Pergamon Press (Oxford, New York, London and Paris) publish research papers on water pollution in the publication *"Water Research"* which has gained international standing inasmuch as it contains papers

delivered at IAWPR conferences as well as submitted material.

REFERENCES

1. Thayer, J.M. Proc. Roy. Soc. Chem, Ann. Chem. Congress, Univ. of Lancaster, April 11-13, 1983.
2. White, M.J.D. WHO Water Quality Bulletin, 1982, 7(3), pp. 113-117.
3. Moss, A.A.H. *"Industrial Approach to the Chemistry of Effluent Treatment with Reference to Legal Implications"*, in "Chemistry of Effluent Treatment", Edited by Kakabadse, G. Applied Science Publishers, London, 1978, pp. 1-15.
4. *"Control of Pollution Act 1974"*, Chapter 40, Part II, "Pollution of Water", London, H M Stationery Office.
5. Bunch, R.L. WHO Water Quality Bulletin, 1982, 7(3), pp. 107-112.
6. Barabas, S. WHO Water Quality Bulletin, 1977, 2(1), 2.
7. Pickering, R.J. WHO Water Quality Bulletin, 1977, 2(1), 6.
8. Wolf, P. *"Workshop on New Aspects of Biological Treatment"*, Pretoria 24-26 February 1975.
9. Brouwer, W.A.H. WHO Water Quality Bulletin, 1982, 7(3), 131 *et seq.*
10. Beccari, M. WHO Water Quality Bulletin, 1982, 7(3) 135 *et seq.*

Chapter 6 SOUTH AFRICAN CONTRIBUTION TO THE DEVELOPING FIELD OF WASTEWATER PURIFICATION



DR G J STANDER
First Director of the NIWR and a former Chairman and Chief Executive Officer of the Water Research Commission who has rendered invaluable and meritorious service in the field of water research.

It was pointed out in Chapter 2 that much of the progress in the field of wastewater treatment in South Africa during the period 1936 to 1951 was catalysed by the enthusiasm, energy and dedication of Drs Hamlin and Wilson.

During the period 1934 to 1944 the following papers were published in the Journal and Proceedings of the Institute of Sewage Purification.

These give a picture of some of the investigations that were carried out on the Witwatersrand and Pretoria during this ten year period as well as matters discussed at meetings of the South African Branch in Johannesburg.

Inchoation: The First 10 years 1934 to 1944

Activated Sludge Process

McLachlan J A, *"The Settlement and Rising of Activated Sludge"*, J and Proc Inst. S.P., 1936 (1), 49.

Carbon Dioxide and Sewage Purification

McLachlan J A, *"The Rôle of Carbon Dioxide in Sewage Purification Processes"*, J and Proc Inst. S.P., 1940, 199.

Composting

Walker A R P, *"The Rôle of Humus in Soil Fertility and its Maintenance by the Utilization of Agriculture and Habitation Wastes"*, J and Proc Inst. S.P., 1943, 186.

Disposal of Sewage by Irrigation

Spencer B R, *"Sewage Disposal by Irrigation"*, J and Proc Inst. S.P., 1943, 197.

Double Filtration

Dekema C J and Murray K A, *"Studies in Multiple Filtration by Deep Enclosed Artificially Ventilated Filters"*, J and Proc Inst. S.P., 1942, 318.

Enclosed Artificially Ventilated Filters

Dekema C J and Murray K A, *"Deep Enclosed Artificially Ventilated Filter Beds versus Ordinary Open Filter Beds – a Comparison under Working Conditions"*, J and Proc Inst. S.P., 1942, 311.

Industrial Effluents

Schrader H, *"A Discussion on the Problem of the Admission of Trade Wastes into Sewers"*, J and Proc Inst. S.P., 1939(2), 367.

Percolating Filters

Hamlin E J and Wilson H, *"Some Notes on the Ventilation of Percolating Filters"*, J and Proc Inst. S.P., 1937(2), 178.

Hamlin E J and Wilson H, *"Investigations on Percolating Filters, Part II"*, J and Proc Inst. S.P., 1938(1), 4.

Hamlin E J and Wilson H, *"Investigation on Percolating Filters, Part III"*, J and Proc Inst. S.P., 1939(1), 39.

Relative Stability Test for Sewage Effluent

de Vaal H M and Stander G J, *"The Utility and Limitations of the Methylene Blue Stability Test for Sewage Effluents"*, J and Proc Inst. S.P., 1939(2), 355.

de Vaal H M and Stander G J, *"A Discussion on the Utility and Limitations of the Methylene Blue Stability Test for Sewage Effluents"*, J and Proc Inst. S.P., 1939(2), 355.

Sterilization of Sewage Effluent

White E G, *"Attempted Sterilization of Sewage Works Effluent by Means of Chlorine"*, J and Proc Inst. S.P., 1939(2), 355.

Transmission of Disease

Wilson H, *"Some Risks of Transmission of Disease during Treatment, Disposal and Utilization of Sewage, Sewage Effluent and Sewage Sludge"*, J and Proc Inst. S.P., 1944, 214.

Washing of Watercress

Hogg Elizabeth S, *"The Washing of Watercress Grown in Sewage Effluent"*, J and Proc Inst. S.P., 1944, 214.

Expanding Horizons: The Next 25 Years 1945 to 1970

At the start of this new era commendable work on the production of methanol from sewage sludge digester gas was completed by McLachlan and Gaillard of the Chemical Division of the Public Health Department of the Johannesburg City Council.

Their work is fully reported (1946/1947) in the following departmental publications of the Public Health Department, viz:

Bulletin No. 5 (1947) *"The Production of Methanol from Sewage Sludge Digester Gas"* by John Arthur McLachlan.

Bulletin No. 6 (1946) *"The Design, Construction and Operation of a High Pressure Converter for use in the Synthesis of Methyl Alcohol from Sewage Sludge Digester Gas"* by Jean Robert Gaillard.

The production of methanol from sludge gas involved the following two steps –

(1) Conversion of $CH_4 + CO_2$ in the sludge gas to CO and H_2
(2) Conversion of $CO + H_2$ to CH_3OH

Using a zinc chromite catalyst in a high temperature converter at an operating pressure of 100 atmospheres and a temperature of 350 to 400°C methanol (CH_3OH) of 90 per cent purity was produced.

The sludge gas used had the following composition:

Constituent	*Per cent by volume*
Methane (CH_4)	63 – 68
Carbon Dioxide (CO_2)	30 – 36
Nitrogen	0 – 4
Oxygen	Nil
Sulphur	Trace

The sulphur was removed by a series of iron oxide and ferrous hydroxide scrubbers. The sulphur-free sludge gas was then saturated with water vapour at 70 to 80°C when it contained methane, carbon dioxide and water vapour in the approximate molal ratio 2:1:1. This mixture was then passed through a reaction chamber containing a reduced nickel catalyst at 900°C when the following reactions took place simultaneously –

$$CH_4 + CO_2 \rightleftharpoons 2\,CO + 2H_2$$

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

On proceeding to completion, under the set conditions, the overall reaction resulted in a gas mixture of 2 moles of hydrogen to 1 mole of carbon monoxide plus small amounts of nitrogen and unconverted methane and carbon dioxide.

The "Synthetic Gas Mixture" [carbon monoxide (CO) and hydrogen (H_2)], after passage through activated carbon scrubbers, was passed on to the converter when methanol of the purity indicated was produced.

The methanol produced was converted to formaldehyde by oxidation of methanol vapour over copper gauze to yield formaldehyde solutions containing 34,5 grams HCHO per 100 millilitres.

Wilson[1] drew attention to the wide range of substances which may be produced from methane.

McLachlan and Gaillard[2] carried out an investigation on the sterilization of final effluents from the then existing Johannesburg Sewage Purification Works – Antea, Bruma, Cydna and Delta Works. They concluded, *inter alia*, that complete sterility is only approached with impractical doses of gaseous chlorine of the order of 70 mg/ℓ for 10 min contact and considered that sterilization of effluents by means of chlorine is not a practical measure for combative success against the virus of poliomyelitis.

Two important conferences were held under the Chairmanship of Dr H Nelson (MOH, Pretoria). The first was held at Pretoria on August 20, 1947 and dealt with *"The Grazing of Cattle on Sewage Farms"*.[3] Notable contributors were E G White, H Wilson, M C Robinson, E M Robinson, R J Ortlepp, A L Abbott and B R Spencer. Towards the end of the conference H M de Vaal made a plea for the establishment of a "Central Authority" to deal with

water matters. Dr A J Orenstein[4] submitted a note concerning the prevalence of intestinal disease and typhoid amongst mine workers fed on vegetables irrigated with settled sewage. The conference resolved as follows:

"This conference is of opinion:

A. That with proper safeguards which can be applied in the light of modern knowledge, effluents can be produced which are so innocuous as to present no danger to public health by the grazing of cattle on sewage farms, and so as to be capable of discharge into streams without danger.
B. That such effluents are of great economic value to a country where the conservation and efficient use of water supplies are of paramount importance.
C. That the present practice of broad irrigation of sewage effluents over land and the prohibition of the discharge of such effluents direct to streams may be harmful to the soil and wasteful in certain circumstances.
D. That the practice of prohibiting the discharge of sewage effluents to streams should be reconsidered, and direct discharge of effluents of suitable standard should be permitted.
E. That proper standards of control to include all measures to prevent the spread of stock diseases should be drawn up for the conduct of grazing of dairy cattle on sewage farms and for the discharge of effluents into streams.
F. That grazing of cattle on land irrigated with raw sewage should be prohibited."

The second conference also held jointly by the South African Branch of the Institute of Sewage Purification and the Pretoria and Witwatersrand Public Health Consultative Committee took place in Pretoria on November 4, 1948 and was opened by Dr A J Orenstein. The subject of the conference was *"The Utilization of Sewage Sludges"*.[5] Papers were read by the following:

A L Abbott, J A McLachlan, H Wilson, J H Gear and Veronica Measrock, P R Krige.

The following resolution was adopted unanimously –

"Recognizing that sewage sludge may constitute a danger to public health if not dealt with properly before application to crop-growing lands;

Recognizing, however, that sewage sludge also constitutes a valuable fertilizer which the country cannot afford to lose,

This Conference considers that:

(1) Sewage sludge, correctly digested under alkaline anaerobic conditions, and subsequently dried, and sewage sludge fertilizer composted or manufactured according to an approved technique, may be made available for use on all crops.
(2) In order that the maximum benefit may be derived by the soil from digested sludge, composting of sludge wherever sufficient vegetable matter is available, and especially by farmers obtaining digested sludge, is strongly recommended.
(3) It is a matter of urgent national importance that research be carried out immediately to determine what other methods of treatment may be economically employed for the conversion of sewage sludge into a safe fertilizer."

Dekema and Krige[6] reported on investigations at the Rondebult Sewage Purification Works of the Germiston Municipality on "Two-Stage Filtration versus Single Stage". This was a follow-up of the work previously reported by Dekema and Murray.[7]

Elizabeth S Hogg[8] made a preliminary study of ova and cysts in digested sludge from the Cydna Sewage Purification Works. From her investigations she concluded that sun-drying of digested sludge in layers (not exceeding 3,81 cm thick) for long periods (exceeding 3 months duration) destroys the ova of *Ascaris lumbricoides* (roundworm).

Dr A J Orenstein[9] in *"A Contribution to the Discussion on the Hazard of* Ascaris *Infestation from Sewage"* gave results of experience at the Crown Mines Limited and the Consolidated Main Reef Limited mines. Dried, digested sludge composted with leaves, grass cuttings and stable manure was used as a fertilizer when growing vegetables used to feed mineworkers and both septic tank effluent and biofilter effluent were used for irrigating vegetables and biofilter effluent for irrigating golf-course greens. He concluded that "there is no great hazard to the golfer playing on the Crown Mines Links. That there is no serious hazard to those who make use of the compost or well-dried sludge on their lawns and gardens . . ."

Up to 1950 water pollution research was carried out by the larger local authorities in South Africa. Schrader[10] in his Chairman's address delivered at the Annual General Meeting of the Southern African Branch of the Institute of Sewage Purification on February 9, 1950 stated, *inter alia* ". . . Time does not permit the author to discuss the trend of sewage disposal technique in South Africa, but the papers that have been presented in the past bear evidence that a very live research programme is being carried out by the larger local authorities in South Africa".

It must be stated that this has been continued but has been augmented first by the establishment in 1948 of the Water Treatment Research Unit of the National Chemical Research Laboratory of the CSIR and from 1957 by the National Institute for Water Research (NIWR) and later by the founding of the Water Research Commission in 1971.

Apart from publication in *"Water Pollution Control"* (the journal of the Institute of Water Pollution Control) and its precursor, the Journal and Proceedings of the Institute of Sewage Purification, recourse is now being had to publication of research in other journals and publications and so the results of research in the wastewater field in the Republic are to be found in *"Water SA"* published by the Water Research Commission and also a number of overseas

publications, notably *"The Journal of the Water Pollution Control Federation"* (USA) and publications of the Pergamon Press Limited (Great Britain).

Stander applied himself to the problem of the disposal of effluents from the fermentation industries. He reviewed[11] the methods of disposal and utilization from which review he concluded that controlled anaerobic digestion showed promise for the treatment of distillery wastes. He then developed an anaerobic method for the treatment of molasses slop and wine pot still liquors.

Together with Hide[12] and Elsworth[13] he investigated:

(i) The significance of the solid phase and of volatile acid development in the anaerobic method of treatment and,

(ii) The influence of high concentrations of sulphates on the anaerobic digestion method of treatment at thermophilic (55°C) and mesophilic (33°C) temperatures.

Subsequently, Stander[14] reported on *"A New Method for Increasing and Maintaining Efficiency in the Anaerobic Digestion of Fermentation Effluents"*. This involved the use of a separately prepared inoculum. The method was applied to wine pot still residues and yeast effluent. Together with Snyders[15] the re-inoculation method was applied by Stander as an integral part of the anaerobic digestion method for the purification of fermentation effluents and the procedure was successfully applied to the digestion of wine pot still liquors, yeast waste liquor and molasses slop.

They concluded, *inter alia*, that "The pollution potential of fermentation effluents can be reduced to such an extent by anaerobic digestion on the re-inoculation principle that the final disposal of these waste liquors should not constitute a serious problem."

Samson[16] described a method he had found successful for *"Cleaning Aeration Plates in the Diffused Air System of Activated Sludge Treatment of Sewage."*

Heynike and Westhoff[17] related their experience with *"The Rapid Gravity Sand Filtration of Humus Tank Effluent without Coagulants"*. These experiments using pressure filtration at heads of 1,83 to 3,05 metres were carried out at the Ancor Sewage Purification Works of the Springs Municipality.

A "Symposium on Composting", under the Chairmanship of P R Krige was held at Port Elizabeth on October 5, 1951.

Contributors to the symposium were P R Krige, Dr E R Orchard, A L Abbott and W H Sheath, K Adler.

A number of resolutions were passed aimed at promoting a national interest in the composting of sewage sludge, town refuse, waste vegetable matter, etc.

Gaillard,[18] in a lecture at a Branch meeting of the Institute of Sewage Purification, alerted those present to the likely effects of synthetic detergents in sewage on the performance of process units at sewage works. In South Africa – at that stage – synthetic detergents had still to displace soap for detergency purposes. He indicated the results he had had with Teepol (alkyl sulphate); Teepodol; Tergital 7,4 and 08; Santomerse (alkyl aryl sulphonate); Lissapol N (non-ionic) and Fab (sulphonated monoglyceride).

Keller[19] investigated the influence of heat treatment on the ova of *Ascaris lumbricoides* (roundworm) in sewage.

Hamlin and Wilson[20] gave an historical account of matters relevant to the disposal of sewage in South Africa. This paper was delivered at the Jubilee Conference of the Institute of Sewage Purification at Buxton, England. In dealing with the history of sewage disposal in South Africa they divided the developments into three distinct periods, viz:

(a) 1898 to 1915
(b) 1916 to 1935
(c) 1936 to 1951 (the date of the discourse).

(*Note:* Reference to this is made in Chapter 2 q.v.)

Gaillard[21] presented a paper to the South African Branch of the Institute of Sewage Purification on May 8, 1952, entitled *"The Performance of Biological Filters in Johannesburg"*. He concluded that for straightforward filtration on 1,83 metre deep filters, a loading in excess of 10 000 load units may be expected to result in a poorly nitrified effluent, with a stability less than 100 per cent.

Stutterheim and van Aardt[22] reported on the corrosion of concrete sewers and discussed possible remedies.

Gaillard[23] investigated the treatment of gas liquor and sewage on percolating filters. He concluded, *inter alia*, that where purification is carried out in admixture with settled sewage on percolating filters, the standard by which the effluent is judged should be the 5-day BOD test and not the 4-hour OA test.

The first conference of the South African Branch of the Institute of Sewage Purification was held at Pretoria from August 25 – 27, 1954. The Branch Chairman, Dr G J Stander, gave an address on *"Sewage Purification and Water Conservation"* in which he stressed the vital need in South Africa for making the fullest use of the water available, for domestic, industrial and agricultural use.

Other notable contributors were H M de Vaal, P R Krige, N P Nicolle, J J Sawyers, E J Hall, A S Posthumus, P J J Pienaar.

Mr de Vaal dealt with *"The Implications of the New Water Laws"*. He discussed the report of a Commission set up to inquire into and report upon the laws then in force in South Africa relating to the use of stream water and to make recommendations for their amendment and consolidation. He also discussed the provisions of a Draft Bill prepared by the Commission.

(Subsequently Act No. 54 of 1956 – The Water Act was duly promulgated on June 12, 1956).

The Second Biennial Conference of the South African Branch of the Institute of Sewage Purification took place in Johannesburg from September 17 – 21, 1956. The conference, under the Chairmanship of E G White was opened by Dr H J van Eck, Chairman of the Industrial Development Corporation of South Africa. Dr van Eck delivered an opening address.

The Conference Chairman, in addressing the conference delegates, went on to examine such matters as the increased use of purified effluent in agriculture and by industry as well as the discharge of a greater variety of trade effluents into sewers and the return of purified effluents to streams for recreational and other uses.

Contributors to the conference included G J Stander, J R Gaillard, J A McLachlan, J Thomson, A J Cutten, H T Clausen, E J Hall, K A Murray, A Kinmont, A L Abbott, P R Krige, A J Orenstein, H M de Vaal.

The subjects discussed included aspects of industrial effluent disposal such as by-product recovery, re-use of water, clean housekeeping and the training of chemists, engineers and plant operators.

The Twenty-First Birthday Conference was held at Johannesburg from September 29 to October 3, 1958, under the Chairmanship of J R Gaillard. The President of the Institute of Sewage Purification, H H Hillier, OBE attended and delivered his presidential address. The conference was opened by P K Goosen, Secretary for Water Affairs.

In his Chairman's Address, Mr Gaillard gave a wide-ranging account of matters concerned with the treatment of sewage and concluded by stating "Research and experimental work must be shared by all; each can contribute from his personal experience, whether he be an engineer or chemist, health officer or plant operator . . .".

J A McLachlan made a notable contribution in reviewing the history of the Branch.

Other contributors were R K Williams and C G Wells, L H Impey, H van Eck, H Wilson, H T Clausen, D W Osborn, P R Lowenstein, J J C Heynike. Subjects discussed included aqua privies; septic tanks; sewage stabilization ponds; photosynthetic oxidation; algal ponds; the future of the activated sludge process in South Africa; re-use of industrial effluent; impact of certain industrial effluents on sewers and sewage purification plant performance.

Murray[24] dealt with the relative importance of settleable, suspended and soluble matters in sewage. From chemical and physico-chemical laboratory investigations he stressed the importance of the intermicellar liquor as opposed to suspended material (settleable and colloidal).

Heynike[25] dealt with the impact of some industrial effluents on sewers and sewage purification plant at Germiston. He dealt with starch-glucose, fermentation, steel pickle and silicate industry wastes.

Krige[26] presented a paper to the second biennial conference of the South African Branch of the Institute of Sewage Purification (cf.). This dealt with a novel concept for the utilization of all organic solids in sewage plus other urban wastes by composting. The paper was entitled *"The Future Sewage Purification Plant as an All-Important link between Producer and Consumer of Food"*.

Krige suggested that more use should be made of the sewer as a transport medium for certain wastes normally transported by surface vehicles. He stressed the need for "Transfer Stations" for waste handling. He proposed that a "Waste Treatment Depot" should be established at the main sewer outfall where sewage treatment would be limited to sedimentation and biological treatment of settled sewage.

He proposed that all sewage solids (raw sludge, screenings, grit and scum) be combined with dry organic wastes and composted. Where a bucket system was in use he proposed that all the "night soil" be composted.

Clausen,[27] in a paper entitled *"Some Observations in the Action of Algae on Sewage in Ponds"*, related his observations on the action of algae on sewage in ponds at Welkom and Allanridge in the Orange Free State Goldfields area.

Loffell[28] systematically studied the movement of sludge within a digestion tank during the digestion process.

Bergman[29] carried out experiments to improve circular sedimentation tank design using models. He was concerned with the determination of the "Dispersion Index" which is defined as the ratio of the time required to pass 90 per cent of any incoming water or sewage through the tank to the time required to pass 10 per cent. Ideally the Dispersion Index for a tank should be unity.

Bergman[30] followed this up using radioactive tracers to evaluate sedimentation tank performance and advocated the use of the Dispersion Index (DI) in preference to settleable solids evaluations in the design of sedimentation tanks – the aim being to have a DI value as low as possible.

Gaillard[31] reported on a bacteriological survey of Durban coastal and harbour waters. He was able to define the extent of faecal contamination present.

Barnard[32] dealt with formulae for assessing the charge to be made for the acceptance of industrial effluents into municipal sewers with particular reference to Germiston, the first local authority to pioneer the levying of a charge for disposal of industrial effluents. Johannesburg, initially resistant to the idea, later followed Germiston. However, many yardsticks were canvassed. The original Murray formula was criticised but a new formula for Germiston and also that for Johannesburg had to be revised. From the discussion which took place it appeared that a charge-formula was a matter for individual municipal decision.

Osborn,[33] in a paper entitled *"Some Experiments*

with the Activated Sludge Process in Johannesburg'', described experiments aimed at improving the performance of percolating filters by grafting on to the biofilter plant an activated sludge unit – one at the Cydna Sewage Purification Works using the Contact Stabilization Process and the other at the Bruma Sewage Purification Works using step addition of load.

Krige[34] carried out controlled experiments at the Krugersdorp Sewage Purification Works on the *''Effect of Different Grades of Filter Medium on the Purification of Sewage in Biological Filters''*. He obtained the best results with a grade of medium of nominal size of 3,81 cm. Provision was made for a coarser upper layer. The overall filter depth was 3,66 metres.

Meltzer[35] investigated mathematically the time factor in biological filtration and concluded from his calculations that two-stage filtration, double depth filters or 1:1 recirculation, will each give a 19 per cent increase in the detention time as compared with single stage filters receiving the same daily flow or volumetric loading.

Similarly, he considered that for three-stage filtration, triple depth filters or 2:1 recirculation, a 30 per cent increase in detention time will result.

The 1961 Conference of the South African Branch of the Institute of Sewage Purification was held in Cape Town from March 6 – 10, 1961.

The Conference was opened by Mr P M K le Roux, Minister of Water Affairs. The Chairman, Mr D W Osborn[36] delivered an address on *''Sludge Gas in the National Economy''* in which he drew attention to the many uses to which sludge gas could be put. He referred to its use as a fuel, including the generation of electricity and to the synthesis of organic chemicals. He highlighted the production of cyanide for use in the gold mining industry. He stated that on March 8, 1949, the sale of sludge gas to African Explosives and Chemical Industries Limited, commenced at the Klipspruit Sewage Works of the Johannesburg City Council. A factory was built near the Works at which sludge gas was reacted with ammonia in the presence of a catalyst to form hydrocyanic acid (HCN) which was neutralized in a lime solution and the final cyanide solution distributed, by tanker service, to a number of gold mines for use in their gold recovery plants. Osborn regarded this as an outstanding achievement!

He also drew attention to the work of McLachlan[2] at Johannesburg on the production of methanol and formaldehyde from sludge gas, but pointed out that with the establishment of SASOL (South African Coal Oil and Gas Company) synthesis gas became available on a large scale. This gas is converted by the Fischer-Tropsch process to motor fuel, a large variety of alcohols (from methanol to hexanol) also being available.

Krige[37] outlined the research projects of the National Institute for Water Research extant at that time. He stated that in 1947 the Council for Scientific and Industrial Research (CSIR) created within the National Chemical Research Laboratory a Water Treatment Unit "to investigate the treatment and use of water supplies, sewage and industrial wastes. The functions of the Unit would also include surveys of the effects of industrial and other developments on the quality of water supplies and related effects on plant and animal life in streams". He stated, further, that the Water Treatment Unit acquired the status of an Institute in 1958.

The NIWR was divided into Divisions of Bacteriology, Chemistry, Bio-Chemistry, Hydrobiology and Technology.

It was significant that a problem being investigated was the removal of phosphorus and nitrogen from sewage effluents to prevent eutrophication of impoundments.

He referred to some research projects in the applied field. These included pilot plant studies on the purification of glucose-starch wastes; pilot plant studies on wine distillery wastes; pilot plant studies on the digestion of night soil; marine disposal of sewage and industrial wastes.

Further conference papers were delivered by A L Abbott, G G Cillié, N P Nicolle, B L Loffell.

Bergman[38] dealt with *''The Design of Biological Filter Walls''*. He considered the two approaches to the problem, namely,

(a) the ring-tension approach, and,
(b) the cantilever approach.

Meltzer[39] described experiments on the control of corrosion of concrete and brick-built sewers by lime treatment of sewage. Continuous application of lime to the sewage in a 22,5 kilometre long sewer conveying sewage to the Klipspruit Works at a rate to produce a pH value between 7,8 and 8,5, was said to have reduced the total dissolved sulphides from c. 2,2 mg/ℓ (average) to 0,15 mg/ℓ and free dissolved H_2S from c. 1,3 to below 0,01 mg/ℓ as S, whilst H_2S gas in the sewer atmosphere was reduced to 1 mg/m³. This was achieved by the addition of $^1/_3$rd ton CaO/4 545 m³ (1×10^6 gallons). [$^1/_3$rd ton $\simeq$ 300 kg i.e. 65 to 70 mg/ℓ CaO.]

Meltzer considered that liming was cheaper than chlorination and chloroben treatment and possibly cheaper than artificial ventilation which he contended was only suitable where power was readily available at a number of points along the sewer. Liming was stated to remove odour and render the atmospheric conditions more acceptable for sewer maintenance personnel.

Osborn[40] dealt with sewage purification practice in South Africa and reviewed the effect of "syndets" (synthetic detergents) in sewage on plant performance.

Malherbe H[41] outlined the recovery of viruses from sewage. He dealt with the following viruses:

Polio, coxsackie A and coxsackie B, Echo, Reo and infectious hepatitis, all of which he considered

could be present in sewage. He indicated the factors influencing the survival of viruses in sewage.

The 1963 Conference of the Southern African Branch of the Institute of Sewage Purification took place in Salisbury, Southern Rhodesia (now Harare, Zimbabwe) from May 6 – 10, 1963. The Conference was opened by the Honourable Mr W J Harper, Minister of Water Development for Southern Rhodesia. The Chairman was Mr B S Bergman who delivered an address in which he drew attention to the water resources of Southern Africa and the use of wastewater.

Papers delivered by South African authors were by H Malherbe (*vide ante*), P R Krige, J R Gaillard, J Crawford, D W Osborn, N P Nicolle, V N Bolitho.

Krige[42] presented a survey of the pathogenic organisms and helminthic ova in composts and sewage sludge. (This was an abridged version of Part 7 of CSIR Research Report No. 211 entitled *"The Utilization of Municipal Wastes"*).

Osborn[43] dealt with the corrosiveness of nitrified sewage effluents and their suitability for use as power station cooling water. He dealt with the mechanism of this type of corrosion and possible risks involved in the use of highly nitrified effluents for cooling purposes. He stated that:

"(1) Any water used as make-up to the cooling system having a total alkalinity of less than 7,14 × Ammon.N is liable to become acid due to the production of free nitric acid in the cooling towers.

(2) The use of water with a negative Langelier Index may lead to:
   (a) dezincification of condenser tubes,
   (b) corrosion of ferrous materials including the effluent pumps at the sewage works, and,
   (c) the removal of calcium salts from the cement used in concrete."

Other subjects discussed at the conference included the performance of oxidation and maturation ponds and economic aspects of wastewater purification in South Africa.

A Conference on problems associated with the purification, discharge and re-use of municipal and industrial effluents was held at Pretoria from October 21 – 25, 1963. The conference was arranged jointly by the National Institute for Water Research (NIWR) and the Southern African Branch of the Institute of Sewage Purification. The conference was held in the Rautenbach Hall of the University of Pretoria. Dr N Stutterheim, Vice-President of the CSIR, was Chairman and gave an opening and closing address. Stander[44] set the tone of the meeting in an address entitled *"The Importance of Promoting a Policy for the Re-use of Water"*.

Papers complimentary to the theme of the conference were presented by W A Murray (Department of Water Affairs); O J Coetzee and Nora A Fourie; V N Bolitho; D W Osborn; J J Barnard; J J C Heynicke; S G Shuttleworth; A Kinmont; J R Gaillard.

At the end of the conference an *ad hoc* committee was convened by the Chairman of the Southern African Branch of the Institute of Sewage Purification when a memorandum to the Honourable the Minister of Water Affairs was drafted. This contained the following recommendations:

"(1) That the question of the decentralization of effluent-discharge administration on a regional basis be investigated with a view to its possible adoption in future.

(2) That a Central Effluents Advisory Committee, constituted in the manner suggested, and with functions as described in this Memorandum, be created at an early date, to advise the Minister on disputed discharges and on the broad technical aspects of pollution control.

(3) That should the Minister be favourably disposed to this recommendation, the members of this *ad hoc* committee be consulted on the constitution of the proposed Central Effluents Advisory Committee."

Osborn[45] in a paper presented to the Southern African Branch of the Institute of Sewage Purification gave an account of *"Operating Experience with Double Filtration in Johannesburg"*. In this paper he concluded from the Johannesburg *modus operandi* ". . . that a case had been made out for the omission of primary humus tanks in double filtration . . ."

The 1965 Conference of the Southern African Branch of the Institute of Sewage Purification was held in Durban from May 3 – 7, 1965. The conference was opened by the Administrator of Natal, the Honourable T J A Gerdener. The Chairman of the Conference was Mr V N Bolitho[46] who, in a wide-ranging address dealt with *"The Institute and the Water Pollution Problem in South Africa"*. He dealt, *inter alia*, with the following topics:

- a possible change in the name of the Institute,
- pollution control requirements in South Africa.

Kinmont[47] outlined *"The Sewage Disposal Problem in Durban"* and gave details of the Central, Southern and Northern Sewage Treatment Works.

Gaillard[48] dealt with many aspects of water pollution control in Durban. He pointed out that Durban had to deal with pollution carried into the city by streams from up-country areas, with harbour and shipping activities and with the drift of ocean currents along the beaches, with the regular patrolling of rivers and of the bay to trace illegal discharges, to control contamination by oil, bilge and debris, and to reduce accidental pollution resulting from harbour loading activities.

Other contributors were D V Harris, H van Eck and D E Simpson, H B Bruggeman, W A Lombard, J Hemens.

Melmed[49] compared the Membrane Filtration (MF) method for determining *E. coli* in sewage effluents with the multiple tube fermentation method which estimates the Most Probable Number (MPN)

of bacteria in 100 mℓ. She concluded that the two methods gave the same mean results but dispersion was greater in the case of the MPN method. Using the MF method, Melmed found that it was desirable that samples of effluent should be planted within one hour after sampling. If the periods between sampling and inoculation exceeded one hour she concluded that results must be treated with reserve.

Drews[50] made some field studies of maturation ponds. Pond systems were selected at the following places:

Rooiwal Sewage Purification Works (Pretoria), Parys, Standerton, Louis Trichardt, Dundee, Stellenbosch and Uitenhage – (Situated in a variety of climatic regions).

From this survey Drews concluded, *inter alia*, that:

- Winds largely have a surface effect.
- Pond mixing or turnover will take place as long as ambient temperatures are below pond temperature and when the sun's rays do not warm the water surface.
- Mixing, therefore, takes place more readily on cool nights, and during the cold season.
- Better mixing with the influent can be induced by suitable inlet design.
- Density stratification takes place in ponds most readily on calm summer days and particularly when ambient temperatures are above pond temperatures.
- Dissolution of oxygen from the atmosphere takes place in the surface layer of a pond mainly due to algae.
- Solar radiation seemingly reduces the bacterial content.
- Pond performance increases with pond temperature. However, the actual load applied per unit of pond capacity is the deciding factor.
- Maturation ponds caused a reduction in the number of *E. coli* of the order of 99,61 per cent in summer and 96,86 in winter.

Stander, Oliff and Livingstone,[51] in a paper presented by Stander and Oliff at the Annual Conference (1968) of the Institute of Water Pollution Control at Torquay (Devon, England), dealt with *"Problems in Using the Sea as Part of a Waste Disposal System"*. They dealt with such matters as the quality and quantity of waste; the aesthetic effect of the addition of the waste to the sea water; precipitation and discolouration effects; the position of the discharge area in relation to bathing beaches and fishing grounds; physical characteristics of the sea and beaches; the topography of the sea bed and oceanographic factors.

Bolitho[52] reviewed the operating results of *"Johannesburg Waste Water Purification Plants during 1966 – 67 with special reference to the economics of biological treatment and subsequent treatment"*.

A symposium on *"Difficulties Associated with Sludge Digestion, with Special Reference to Synthetic Detergents"* was presented at a meeting of the Southern African Branch of the Institute of Water Pollution Control held in Johannesburg on September 19, 1968. Papers were presented by D W Osborn, P H van der Merwe and W Hattingh.

A biennial conference of the Southern African Branch of the Institute of Water Pollution Control was held in East London and King William's Town from May 13 – 17, 1968, under the Chairmanship of Dr G J Stander. The conference was opened by Mr P C Botha, Deputy Minister of Water Affairs. A number of well-known overseas guests representing water pollution control bodies in the UK, Holland and the United States attended.

Stander and van Vuuren[53] presented a paper entitled *"The Reclamation of Potable Water from Sewage"*. They described investigations carried out with a pilot plant for advanced sewage purification (455 ℓ/h) from which they concluded, *inter alia* ". . . That their advanced physico-chemical treatment process was able to produce a water of potable quality from humus-tank effluent . . ."

Other South African contributors were R B Reed and G P K Thornton; G P Verster; B A Thomas; R I Laburn; L S Smith; W D Oliff, D J Livingstone and V C Stone; J J C Heynike and F V K von Reiche.

Osborn[54] gave an analysis of replies to a questionnaire sent to 18 municipalities in South Africa. He stated that in 46 per cent of the installations no difficulties were experienced with sludge digestion. Of the remainder, the majority had difficulty in maintaining the optimum pH value of the digesting sludge and controlling volatile acid production, frothing and scum formation, offensive smell, as well as difficulties encountered in re-starting digesters.

Osborn[55] then dealt with *"Adverse Effects of Synthetic Detergents on Sludge Digestion in Johannesburg"*. He concluded that there was strong evidence to implicate detergents as a possible cause of some of the difficulties then being experienced with the digestion process at some of the Johannesburg sewage works. Further, he indicated that thermophilic digestion did not overcome the problems being encountered with detergents.

Van der Merwe[56] reported on *"The Effect of Synthetic Detergents on Sludge Digestion at Rondebult Sewage Treatment Works"*. From his investigations he concluded that mesophilic digestion is a practical proposition up to a maximum of 2,0 per cent of synthetic detergent on dry solids in the raw sludge, provided that thorough mixing of the digester contents is assured and that strict control is exercised over all other factors.

Hattingh[57] submitted a paper on *"Parameters for the Characterization and Control of Anaerobic Digestion"*. He dealt with factors affecting the anaerobic digestion of trade wastes containing a high proportion of organic material. He made a plea for a fundamental study of the process of sludge digestion.

Bolitho[58] presented a comprehensive account en-

titled *"A Long-term Plan for Sewerage Development in the Johannesburg Region"*. In this he dealt with the scope of the Johannesburg wastewater scheme, its regional importance and adequate long-term planning to meet future needs. He examined the capacity of existing outfall sewers and treatment works, possible developments in treatment technology and the adequate augmentation and enlargement of sewers and works to meet future needs. A note on the financing of the plan was included.

Nupen[59] has listed the enteric viruses (polio, coxsackie A and B, ECHO, infectious hepatitis, reo and adeno) in sewage and has described methods for isolating the viruses. She has also described certain concentration techniques and referred to the various processing steps in sewage purification and their effectiveness in removing viruses.

Osborn[60] has reported on the operational experience gained over a period of 30 years in the use of purified sewage effluent for cooling purposes at Johannesburg's power stations. He noted that under controlled conditions no serious corrosion problems are likely to be encountered in power station cooling circuits. The incorporation of a large dam in the Orlando Power Station cooling circuit and the use of double filtration at the Northern Sewage Purification Works to provide a water with a relatively low pH value for the Kelvin Power Station, has prevented the introduction of ammonia and the unwanted precipitation of insoluble phosphate.

Vosloo[61] gave a well-considered account of some factors relating to the design of activated sludge plants. He dealt with such matters as population dynamics, sludge loading rate and its relationship to new sludge production and sludge age. He included consideration of such matters as nitrification, settleability of sludge – including the Sludge Volume Index (SVI), mixed liquor suspended solids (MLSS), the concentration of returned sludge suspended solids (RSSS), as well as oxygen requirements. He dealt with the design of industrial plant units, carbonaceous oxidation and nitrification. He made out a case for having a high-rate process as a first stage – carrying its own sludge – followed by a second stage for removing ammonia by nitrification also with its own sedimentation tank. Vosloo, further, included an account of recent literature (extant at that time 1962 to 1967) and made liberal reference to the work of Downing and his co-workers at the Water Pollution Research Laboratory in England.

Conradie and Smith[62] recorded the use made by the Enstra Mill of the South African Pulp and Paper Industries Limited (SAPPI Ltd.) of purified effluent supplied by the Springs Municipality.

To render the sewage effluent suitable for use at the mill they reported that the following treatment had proved successful, viz: excess lime was added to precipitate magnesium hydroxide together with organic matter and heavy metal ions.

The procedure was as follows:

(a) Addition of slaked lime to ensure a pH value in excess of 10,5 (10,8 to 11,0) followed by settling or flotation,
(b) Solids contact stabilization, consisting of carbonation with carbon dioxide and settling to produce an effluent with a pH value of 9,5,
(c) Re-carbonation to the desired end pH value,
(d) Sand filtration.

Conradie and Smith point out that the process is similar to that of Stander and van Vuuren[63] but for the purposes of pulp and papermaking it is not necessary to include ammonia-stripping, foam fractionation, chlorination or activated-carbon treatments described by them.

Bolitho[64] dealt with *"Cost Dynamics in the Johannesburg Sewerage System as a Basis for a New Tariff Structure"*. His aim was to adopt a progressively realistic approach to the problem of matching changes in the character of the city which alter the recoveries from different classes of user. His thesis was extensive and comprehensive and of interest to civil engineers.

Toerien[65] identified 92 bacterial types from the non-methanogenic phase of anaerobic digestion. All the bacteria isolated and characterized were obligate anaerobes or micro-aerophilic. Rod-shaped bacteria predominated over cocci, spirilla and other types. A number of generic types were identified.

Marais[66] set out three kinetic models for the prediction of the performance of oxidation ponds. His models took into account such factors as the influence of benthic deposits, seasonal changes and long-term effects.

At a Convention *"Water for the Future"* held during "Water Year" 1970, Basson and Melmed[67] described attempts made by them in the application of ionizing radiation for the disinfection of secondarily-treated sewage effluent. They concluded that the method – though the results were satisfactory – (using Cobalt-60 as a radiation source) was too costly.

The biennial conference of the Southern African Branch of the Institute of Water Pollution Control held in Cape Town from March 16 – 20, 1970, was opened by Mr J P Kriel, Secretary for Water Affairs. The Conference Chairman was Dr G G Cillié. Guests from overseas water pollution control organizations included Mr J J Stanbridge, President of the Institute, Professor J K Baars (Holland) and Dr T M Middleton (USA) all of whom addressed the Conference on certain aspects of solid waste disposal, wastewater treatment, etc.

Henzen and Funke[68] gave an appraisal of some significant problems in the re-use of wastewater. They dealt with the water quality requirements for water used for a number of purposes, namely, drinking; food processing; industry such as for cooling, steam generation, process water, product washing, plant and equipment washing, air conditioning, transport of materials, metallurgical processing;

irrigation and recreation.

They emphasized that the largest proportion of water required by industry is used for cooling purposes and pointed out that there is no reason why water of the highest quality should be used for cooling purposes, since concentrations of 4 000 mg/ℓ of dissolved solids and higher can be tolerated in evaporative recirculating systems without undue formation of scale or corrosion, provided the cooling water is given proper treatment.

They considered that sewage effluent and other industrial wastewater can be effectively used for cooling purposes.

Stander, van Vuuren and Dalton[69] dealt with the *"Current Status of Research on Waste Water Reclamation in South Africa"*. They detailed the necessary purification steps, viz. – the removal of coagulable organics, including phosphate by chemical pretreatment with excess lime; removal of synthetic detergents and ammonia by foam fractionation and air-stripping respectively; precipitation of excess lime by carbon dioxide and adsorption of residual matters in solution by adsorption on powdered activated carbon.

Variations of the pretreatment suggested were flotation which was considered effective in removing algae and the use of aluminium sulphate in place of lime, though, it was pointed out that excess lime treatment is particularly suitable for the treatment of effluents containing high concentrations of ammonia as well as having a disinfecting activity at high pH values.

Stander and Clayton[70] presented a significant paper entitled *"Planning and Construction of Waste Water Reclamation Schemes as an Integral Part of Water Supply"*. It was pointed out that the method of reclamation of pure wholesome water from sewage effluent reported by Stander, van Vuuren and Dalton[69] had been proved in a large pilot plant at the Daspoort Sewage Purification Works of the Pretoria City Council. This plant processed $4{,}55 \times 10^3$ m³/day of effluent. Windhoek, the Capital of South West Africa (Namibia), it was stated was, in 1968, the first city in the world to practise large-scale and continuous reclamation of wastewater as an integral part of domestic water supply. Reclamation had taken place for some time and the processes used followed those propounded by Stander, van Vuuren and Dalton[63,69] and were used successfully in the Daspoort, Pretoria pilot plant.

A number of papers were devoted to the marine disposal of effluents and others mainly to advanced treatment of sewage and the reclamation of water from sewage effluents as well as the disposal of solid wastes.

South African contributors to the Conference in addition to those already mentioned were as follows: J P Kriel (opening address); S S Morris; G R Atkins; B F Steeve; G Mann; A T Alexander and B Moffat; S Erasmus and J J C Heynike; E J Hall; H C Blersch and H A de Villiers; S P du Toit Viljoen; W W Malan.

Recent Research and Investigations: from 1971 onwards

With the establishment of the Water Research Commission in 1971 and confronted with the task of promoting and co-ordinating research pertaining to water, additional funds became available to enhance the Republic's total water research effort and this naturally included research in the field of wastewater treatment.

In due course, by 1975, the Water Research Commission started publication (April, 1975) of the Journal *"Water SA"*, which is published quarterly. This is a multidisciplinary medium for the publication of the results of investigations in all fields of water research.

The 1972 biennial conference of the Southern African Branch of the Institute of Water Pollution Control was held in Johannesburg from May 1 – 5, 1972. The conference was opened by Dr P W de Lange who read the speech prepared by the Honourable Mr S P Botha, Minister of Water Affairs. Overseas visitors included Mr J T Calvert OBE and Mr H Fish OBE from Britain; Mr D F Metzler (USA) and Mr R A Canham (Executive Secretary, Water Pollution Control Federation, USA). The Conference Chairman was Mr J Halliday.

Dr G J Stander[71] delivered an address entitled *"Some Critical Research Directions in the Field of Water Pollution Control in South Africa"*. He summed up by stating that "For South Africa the route which should be followed in the optimization of its water is clear. Water supply, water pollution control, wastewater reclamation for re-use or return to rivers and the upgrading of conventional water purification plants constitute an integral part of the country's household."

Bolitho[72] dealt with *"Economic Choices in Sludge Treatment and Disposal"*. He dealt with sludge digestion, non-digestion and aerobic stabilization followed by certain intermediate processes before eventual deposition on land. The intermediate processes included drying on sludge drying beds, lagooning, composting, chemical conditioning and incineration.

He concluded, *inter alia*, by stating that "Land disposal of sludge has so many advantages in cost, convenience and in recycling of organics that every effort should be made to encourage its use, even if this necessitates pumping over substantial distances. Such use should be accompanied by strict control of industrial metals at the source."

Gaillard[73] reported on the installation and performance of a fluidized bed incinerator at the Central Sewage Works of the City of Durban. Other contributors to the conference were as follows: R O Morris; W C S Legge; R J Wells; B Heunis; P H van

der Merwe and (Mrs) S N van Biljon; W A Pretorius; J M Fourie; P B B Vosloo; W W Malan; D W Osborn and J Halliday; H C Blersch; L R J van Vuuren; J A Voysey; F A van Duuren.

Barnard[74] reported on laboratory experiments carried out at the National Institute for Water Research on *"Biological Denitrification"*. He concluded that, with a particular sequence of wastewater treatment units operating on the activated sludge principle, virtually complete de-nitrification was possible without the aid of a carbon source (e.g. methanol).

Pretorius[75] discussed the use of the rotating-disc unit for the treatment of wastewater from small communities. He outlined the factors which affect the performance of rotating-disc units and their use in combination with septic tanks.

A notable achievement in the transfer of technology by an industry was due to Voysey and Giampietri[76] who described the method which they used successfully for the reclamation of sewage effluent for use at the Mondi Paper Mill in Durban.

The pilot plant comprised the following units, all designed for a flow rate of 9,09 m^3/h:

(1) Activated sludge aeration tank with a retention period of 6 hrs and provided with a surface aerator, settlement tank and sludge return system;
(2) Gas chlorination;
(3) Chlorine contact tank (10 min retention);
(4) Three chemical mixing tanks with stirrers (1 min retention in each case);
(5) Chemical dosing equipment;
(6) Combined flocculator and upward flow classifier, with slurry recirculation system;
(7) Rapid gravity sand filter;
(8) Foam fractionator;
(9) Two activated carbon columns.

The secondary treated effluent was obtained from the Southern Sewage Works of the Durban City Council. The sewage works is in close proximity to the mill which produces high grade white paper.

Simpson and Hemens[77] carried out laboratory studies on the treatment of sugar mill effluent by the activated sludge process. They showed that if supplementary nitrogen and phosphorus were provided satisfactory purification of this type of wastewater was achieved.

The 1974 biennial conference of the Southern African Branch of the Institute of Water Pollution Control took place in Salisbury (now Harare), Rhodesia (now Zimbabwe) from April 8 – 11, 1974. The Chairman of the Conference was Mr W W Malan. A number of overseas guests attended including Mr J Finch [President of the Institute of Water Pollution Control (UK)]; Professor W Stumm (Zurich, Switzerland). The conference was opened by the Honourable M H Partridge, Minister of Water Development, who gave an address.

Two significant contributions were given by South African delegates, viz: *"South African Eutrophication Problems; a Perspective"* by D F Toerien and *"Nutrient Removal in Biological Systems"* by J L Barnard.

Toerien[78] pointed out that eutrophication constituted a danger to South African impoundments. He stated that whilst most South African impoundments were still oligotrophic a small number were eutrophic due to the flow of effluents from urban industrial complexes. He considered phosphorus to be the most important algal growth-limiting nutrient in South African impoundments. Oligotrophic conditions seemed to exist at phosphorus concentrations below 30 $\mu g - P$ per litre and eutrophic conditions above 75 $\mu g - P$ per litre.

Barnard[79] dealt with his patented "Bardenpho" process for denitrification and phosphate removal without the addition of chemicals. He gave details of work leading up to the final processing hook-up which was found to be successful.

He stated that at least 85 per cent removal of phosphate in wastewater was achieved but the removal process was not sufficiently understood at that stage of investigation.

Two conference symposia were held, viz:

(1) *"Aeration Devices"* and
(2) *"Package Sewage Treatment Plants"*

(1) Professor G v R Marais[80] dealt with the basic theory of aeration. This was followed by contributions from the following South African delegates: D H H Skinner; J L Barnard; P G J Meiring; J Halliday; J Goodman; D M McCallum and G C de Rome; I R M Greig.
(2) L G S Turvey[81] (Department of Water Affairs) presented a statistical analysis of the operational performance of some package units. The performance of a variety of plants (19 in all) had been evaluated and found to be poor due to a number of causes, including unsatisfactory supervision and inconvenient, out-of-the-way siting of plant resulting in neglect.

W A Pretorius[82] dealt with septic tank disc units, i.e. a combination of a rotating-disc (RDU) unit situated at a septic tank to treat the effluent from the septic tank. He maintained that the simplicity of the set-up and its operation made the combination an ideal package unit for sewage and industrial waste treatment.

The following delegates also participated in this symposium: P B B Vosloo; N P Nicolle; E L Choritz.

Pitman[83] investigated *"Bioflocculation as a Means of Improving the Dewatering Characteristics of Activated Sludge"*. He gave results of a systematic investigation of the operation of a pilot plant constructed at the Northern Sewage Works of the Johannesburg City Council. The influent to the plant was screened, detritus-free domestic sewage. Fine bubble diffused-air aeration was used and siphoning arrangements were provided to draw off a fixed volume

of mixed liquor each day. A completely mixed aeration tank was used followed by two settling tanks in series.

The investigation developed from a study of "capillary suction times" (CST) of the activated sludge into a consideration of "sludge age" within the system and its effect on the dewatering characteristics of the surplus activated sludge discharged at different sludge ages with and without addition of flocculants. Flocculants used included the polymer Zetag 63 and ferric chloride.

From his comprehensive investigations Pitman concluded that if a sewage treatment plant is to be designed for dewatering waste activated sludge – concomitant with a high quality effluent – then the extended aeration process at long solids retention periods (20 to 25 days) and short liquid retention periods (0,5 to 0,7 days) appeared to be an attractive process.

He postulated that the waste sludge from the extended aeration activated sludge plant could be dewatered easily without the use of chemicals.

The 1976 biennial conference of the Southern African Branch of the Institute of Water Pollution Control was held in Durban from June 7 – 11, 1976. The conference was opened by the Honourable Mr A J Raubenheimer, Minister of Water Affairs.

Mr J A Voysey was the Conference Chairman. A number of overseas guests attended: these included Mr G Ainsworth [President of the Parent Body (UK)]; Dr D S Ballantine (USA); Dr J Hoigné (Switzerland); Dr Ir. A B Bok (Netherlands).

Nupen and Morgan[84] drew attention to the dangers of inadequate chlorination of polluted waters. They considered that only chlorination to breakpoint will inactivate hazardous pathogens. Applying chlorine in less than breakpoint concentrations, they indicated, may reduce *E. coli* and coliform organisms but not parasites and viruses.

They stressed the need for correct design and control of chlorination plant and equipment and warned against the possible harmful effects on aquatic life when chlorinated wastewaters are discharged into waterways.

Midgley[85] addressed himself to the problem *"Will there be Enough Clean Water?"* and dealt with South Africa, region by region. He concluded that enough clean water *can* be made available *if* users are prepared to pay for it, provided reasonable restrictions during drought are accepted and that lower quality water is adapted to appropriate purposes.

Heynike[86] dealt with *"Some Aspects of Water and Effluent Management in the Iron and Steel Industry"*. He stated that of all the problems encountered in an integrated iron and steel plant, those generated by the coke ovens and by-products plant had still not been satisfactorily solved.

Langenegger and Viviers[87] reported on investigations with a dissolved air flotation pilot plant at the Daspoort Sewage Purification Works of the Pretoria City Council. The plant was capable of treating 10 kilograms solids per hour. They drew attention to a number of problems arising from the physical qualities of the float layer/concentrate.

Nicholls[88] indicated that by using correctly designed plants and by careful operation of such plants it was considered possible to considerably reduce the nitrate and phosphate contents of an effluent without the use of chemicals.

Barnard[89] identified certain factors which he considered had a bearing on the bulking of activated sludge.

At the biennial conference of the Southern African Branch of the Institute of Water Pollution Control held at East London from May 16-19, 1983, a number of overseas authorities participated, including Professor D Jenkins of the University of California – Professor Jenkins dealt extensively with the causes and control of activated sludge bulking (cf. Jenkins, Richard and Neethling, Wat. Pollut. Control, 1984, 83(4), 455).

Neytzell-de Wilde, Nurse and Groves[90] reported that they had been able to denitrify an inorganic effluent from a nitrogen chemicals complex containing c. 2 800 mg/ℓ N (as NO_3) over a wide range of temperatures (10°C to 31°C) using methanol as carbon source in a continuously stirred tank.

They stated that sludge age is the controlling factor. This varied from 3,6 to 3,8 days at 28°C to 45 to 50 days at 10°C.

Neytzell-de Wilde[91] described a further method he considered feasible for the denitrification of inorganic effluent from a nitrogen chemicals complex using sulphur as the energy source. The bacteria used were thiobacilli.

Melmed and Comninos[92] used gamma radiation to render sewage sludge suitable for unrestricted use as a fertilizer or soil conditioner in the urban environment.

They found that with a radiation dose of 1 kGy, 99 per cent of potentially infective larvae were destroyed in a sludge containing 20 per cent solids. Higher doses up to 10 kGy did not result in a 100 per cent kill.

However, they state that complete inactivation could be obtained with an application of 0,5 kGy radiation to a 3 per cent solids sludge at 50°C and with 0,4 kGy applied to a 3 per cent solids sludge at 55°C.

Digested sludge and activated sludge samples were used.

Bryson and Dardis[93] have devised an electrolytic precipitator for the removal of metal ions from metal works effluents prior to discharge of such effluents into sewerage systems. The precipitator was shown to be successful in treating wash waters containing copper, nickel, chromium and zinc.

Smith and Wiechers[94] investigated the elimination of toxic metal ions from wastewater by an integrated wastewater treatment/water reclamation system.

The investigations were carried out on a 60 kℓ/day pilot plant at the Daspoort Sewage Purification Works of the Pretoria City Council. The sequence of treatment stages were denitrification, chemical mixing, chemical clarification, nitrification, secondary clarification, sludge thickening, anaerobic digestion, roughing filtration, dual media filtration, activated carbon adsorption, final chlorination.

Two solutions, one containing cadmium, chromium, mercury, arsenic and selenium and the other silver, lead and barium, were pumped into the system on alternate days, the points of entry being at various stages of the system.

The overall removal of ions was stated to be satisfactory. However, it was noted that the most significant processes for trace metal removal were denitrification, chemical mixing/clarification and activated carbon treatment.

Barnard[95] reported on the design and operation of three Bardenpho plants in an un-named African country. Two of the plants were operated in rural situations and one in a capital city where well-equipped laboratories and competent staff were available.

Plant No. 1 consisted of a Bardenpho plant run in conjunction with a pond system. A portion of the raw sewage was passed to the Bardenpho plant and the remainder to the series system of ponds. The final effluent from the pond system was fed into the aeration zone of the Bardenpho plant.

Plant No. 2 treated sewage which was surplus to the capability of a biological filter plant and a pond system.

Plant No. 3 was in the form of an extension to an existing conventional biological filter plant. This activated-sludge extension was planned for treating an extra quantity of raw sewage or a greater volume of settled sewage or for recycling biological filter effluent to the nitrification zone. A five-stage Bardenpho layout consisting of the following sequence of treatment compartments was used, viz: Anaerobic basin; first anoxic basin; aeration basin; second anoxic basin; reaeration basin. Timing devices were used for switching aerators on and off.

It was stated that the plant effluent complied with the standards – provided no mechanical malfunctioning took place. However, Barnard considered that when using a certain type of aerator, difficulties were experienced with rags and consequently it would be better to operate with sewage after primary sedimentation.

He maintained that plants Nos. 1 and 2 showed that it was possible to operate a Bardenpho set-up in a rural situation without sophisticated attention.

Cooper, Shuttleworth and Slabbert[96] described work carried out by the Leather Industries Research Institute (LIRI) under the sponsorship of the Water Research Commission. This related to *"The Treatment of Waste Water from the Leather Industries"*. Grants were received from the South African Tanners' Association, the Hide and Skin Industry and the CSIR.

Attention was drawn to the "LIRITAN" minimal effluent sole leather tanning system which they claimed is used worldwide. (This aims at using up all wattle extract in the vegetable tanning process where wattle extract is used by re-using the sludge after treatment with 4 per cent sodium sulphite under boiling conditions.)

Apart from the elimination of wattle extract in tannery effluent the authors drew attention to international research on the treatment of wastewater from the de-hairing process where lime and sodium sulphide or sodium hydrosulphide are used in the initial processing at a tannery.

The curing of hides with salt (NaCl) – (which is disapproved of by the Department of Water Affairs) is now being replaced by preservation methods using low concentrations of antiseptic chemicals. LIRI, they stated, has carried out a great deal of pioneer work in this direction.

The paper points out that no two tanneries produce exactly the same leather, use exactly the same process or chemicals and it is added, nor do they have to deal with the same municipal effluents discharge requirements. Therefore, the authors have recommended a number of process modules which a tannery can assemble to suit its particular problems of wastewater treatment. The following models were preferred, viz:

(1) Aeration of the wastewater to remove sulphide and decrease the pH value, dosing with flocculants followed by sedimentation of suspended matter and drying of the settled sludge and suitable disposal thereof. The settled liquor, free from suspended matters, may then be discharged into ponds, on to irrigation land or may be accepted for discharge into a municipal sewerage system.

(2) Aeration of the wastewater to remove sulphide and decrease the pH value, followed by treatment with coagulants and flocculants. The suspended matter then to be floated-off by a suitable flotation procedure such as air flotation. The floated solids and solids-free liquor to be disposed of as in (1) (above).

(3) Similar initial treatment as in (1) and (2) (above) followed by treatment in a completely-mixed activated sludge plant, a high-rate biological filter or a suitable extended aeration activated sludge plant.

For chrome leather tannery wastewater the following possible effluent treatment systems were put forward for:

(i) mixed tannery effluent and,

(ii) segregated tannery effluents, viz:

(i) Mixed tannery effluent: Aerate all process liquors in balancing tanks for 24 h to remove sulphide.

After aeration follow-up with physico-chemical treatment, using ferric chloride and polyelectrolyte additions plus air flotation. Most of the chromium will have been removed in the float concentrate and the solids-free liquor may find municipal acceptance for discharge into the municipal sewerage system.

Further treatment of the solids-free liquor by high-rate biofiltration or by activated sludge plants may be necessary.

(ii) Segregated tannery effluents: Collect beamhouse wastewater (i.e. sulphide containing) and treat separately as for (i) (above).

Mix separately all other process liquors and either discharge or treat further, on site, by biological means (biological filtration or activated sludge).

Groves, Buckley and Turnbull[97] in dealing with closed looped systems for textile effluents have described closed loop re-cycle systems for wool scouring effluent, desizing effluent and wool-synthetic fibre dyehouse effluent. These investigators have concluded from their work on the above effluents that closed loop re-cycle systems for treating effluents from individual wet processing operations are feasible.

They state that ultrafiltration removes 93 to 95 per cent of the grease in wool scouring effluent and gives a permeate of acceptable quality for re-use. Pilot plant trials using spiral wound ultrafilter membranes at the factory site gave acceptable permeate fluxes and permeate quality for the recovery of synthetic sizing agents (polyacrylate) from desizing effluents.

The work on the recovery of effluent and chemicals in effluents from the textile industry is sponsored by the Water Research Commission.

In a comprehensive paper entitled *"Evolution of Wastewater Purification in Johannesburg, South Africa"*, Osborn[98] indicated that in the early 1970's it became necessary to make far-reaching decisions regarding extensions to the Johannesburg system which was receiving flows which were increasing annually at a rate of 7,5 per cent.

A problem that had to be faced was the removal of phosphorus in the final effluents. The City Engineer's Department, therefore, became interested in the possibilities of the extended aeration activated sludge process as a means to this end.

In consequence, a great deal of research and investigative work has been carried out by the scientific staff of the City Health Department and some notable work has resulted, viz:

Osborn and Nicholls[99] in a well-considered analysis of available information have dealt with the *"Optimization of the Activated Sludge Process for Biological Removal of Phosphorus"*. They state that pilot plant investigations in Johannesburg indicated that the achievement of low phosphorus concentrations in the effluent from the plant was not possible unless volutin-containing bacteria were present. An important organism in this respect is *Acinetobacter* which can cause "luxury" uptake of phosphorus. However, they have given a list of other volutin-containing organisms.

They have dealt with the biochemical pathways for the volutin storage of polyphosphates and summarized the process reactions and requirements for the biological removal of phosphorus.

Buchan,[100] using electron microscopy and dispersive X-ray analysis was able to demonstrate that in seven activated sludge plants exhibiting enhanced phosphorus removal that large accumulations of phosphorus were present in large electron-dense bodies within large bacterial cells.

Further, Buchan[101] in dealing with the nature and location of accumulated phosphorus in activated sludge, found that granules in *Acinetobacter* contained in excess of 25 per cent (m/m) phosphorus with a Ca:P ratio between 0,15 and 0,36. Accumulation was possible under continuous aerobic conditions and was enhanced by the presence of fermentation products from raw sewage.

In a paper entitled *"Microbiology of Nutrient Removing Activated Sludge"*, Hart and Melmed[102] made a study of the organisms in the 150 Mℓ per day Johannesburg Northern Works activated sludge plant which they state is based on the "Phoredox" or modified Bardenpho system.

In this process, they state, that the microbial life is exposed to alternating degrees of stress.

They noted that only after 10 days from start-up of the plant was floc visible. Three weeks after start-up the first clusters of ciliates were seen together with the appearance of rotifers and large zoogleal masses – *Acinetobacter spp* was present in small numbers after two months but one month later (i.e. 3 months from start-up), when plant equilibrium conditions had been attained, the number had considerably increased.

Grape-like clusters of *Acinetobacter* observed in nutrient-removing sludge by ordinary light microscopy were subsequently shown by electron microscopy to contain up to 1 000 individual cells.

A study was made of the heterotrophic bacteria in nutrient-removing sludges from a number of sewage purification works viz:

Goudkoppies; Northern (Johannesburg) (multi-zone plants);

Cape Town (University pilot plant) and

Brits (single basin, limited aeration).

In dealing with the kinetics of phosphorus transformations in aerobic and anaerobic environments, Nicholls[103] found that temporary restriction of the availability of oxygen and nitrate caused certain organisms to accumulate large quantities of phosphorus. The oxygen restriction resulted in a stress condition leading to the uptake of phosphorus. He states that this stress condition can be created by introducing an anaerobic zone into an activated sludge plant. In the anaerobic zone, Nicholls states, phosphorus is released into solu-

tion and on relief of the stress, by reinstating the oxygen supply, phosphorus uptake in excess of that released takes place — resulting in removal of phosphorus from the effluent.

The function of the anaerobic stress zone and its influence on the rate of phosphorus uptake are discussed by the author.

Nicholls[104, 105] has described how, by a similar procedure, nitrogen and phosphorus was removed at both the Alexandra and Olifantsvlei extended aeration activated sludge plants.

Venter, Halliday and Pitman[106] reported on *"Optimization of the Johannesburg Olifantsvlei Extended Aeration Plant for Phosphorus Removal"*. They stated that by switching off aerators at the inlet of the plant, anoxic conditions were created and the circulation of nitrified mixed liquor through the anoxic zone produced good denitrification. Phosphorus removal was obtained by turning off further aerators thus creating anaerobic conditions near the inlet of the plant. In this anaerobic zone release of phosphorus into solution occurred while anaerobic fermentation producing volatile acids took place at the bottom of this zone. They state that when phosphorus removal was optimized, effluent soluble phosphorus concentrations of 1,0 mg P/ℓ were obtained. However, they noted, that when optimization of the plant for phosphorus removal occurred nitrogen removal suffered, particularly in the winter months.

Pitman, Venter and Nicholls[107] described three years operating experience with the Goudkoppies and Northern Works Activated Sludge Plants of the Johannesburg City Council. The following was the treatment sequence in each case:

A sedimentation tank for removal of raw suspended solids, the overflow (settled sewage) was then passed on to a balancing tank followed by the following treatment, viz: anaerobic, anoxic, aerobic, anoxic, final aerobic, settlement of activated sludge, return of a portion of the settled activated sludge to the anaerobic compartment and disposal of surplus activated sludge to waste.

They have concluded that the process of biological nutrient removal can produce effluents containing trace amounts of phosphorus provided certain design and operating criteria are adhered to. With the Johannesburg plants, consistently good nitrogen and phosphorus removals were not obtained but, possibly, could be achieved with a different plant layout. None-the-less they considered that it was doubtful whether this process could give consistently good nutrient removal with weak sewages.

Pitman[108] investigated the settling properties of activated sludges from three extended aeration activated sludge plants designed for biological nutrient removal, namely the Alexandra, Olifantsvlei and Goudkoppies Plants of the Johannesburg City Council. He made use of hydrometallurgical techniques used in the study of the settling and thickening of slurries to investigate the settling properties of activated sludge.

Pitman used a specially designed settling apparatus and plotted the height of the interface with time. He also plotted settling flux curves. His results indicated that the activated sludges from the Alexandra and Olifantsvlei Plants had fairly good settling properties. However, poorly settling sludge from the Goudkoppies Plant showed a prolific growth of filamentous organisms. Further he has indicated how settling results can be used in plant operation and control.

Nicholls[109] tested the Marais-Ekama activated sludge model by applying it to two large-scale activated sludge plants each of 50 000 m^3/day design capacity. The two plants chosen were the Goudkoppies and Northern Sewage Purification Plants of the Johannesburg City Council.

Previously, the model developed by Marais and Ekama at the University of Cape Town had been applied with success to carefully controlled laboratory units. Nicholls, therefore, decided to prove its efficacy in predicting the Chemical Oxygen Demand, Total Kjeldahl Nitrogen, ammonia and nitrate values in the effluents from the two Johannesburg plants.

The feed, reactor contents and effluents of both plants were monitored every two hours (for the above parameters) over a continuous period of four days. In addition the oxygen utilization rate was measured by means of a specially constructed respirometer.

The COD, TKN, ammonia and nitrate values found for the final effluents by using the model agreed with the actual values found for the works effluents.

Accepting the model as satisfactory, Nicholls was able to pinpoint some shortcomings in the plant process layouts.

The work of Marais and Ekama is sponsored by the Water Research Commission.

Professor G van R Marais, Professor of Water Resources and Public Health Engineering of the Department of Civil Engineering of the University of Cape Town has, since 1970 devoted much attention to activated sludge process research. Together with his research students he has published many papers concerned with mathematical modelling applied to the design of activated sludge plants and the prediction of the quality of effluents. The goal of his research was the evaluation of a kinetic model capable of application to conditions of ever widening generality. The work has received the financial support of the Water Research Commission.

Marais and Ekama[110] have considered the activated sludge process at steady state in terms of sludge age and have developed equations for calculating the mass of endogenous residue and inert volatile matter in an operative plant unit. These have been integrated with the oxygen demand.

They consider the rate-determining step in nitrification kinetics is the conversion of organic nitrogen as measured by the Kjeldahl method (TKN) to the ammonium form (NH_4).

Ekama and Marais[111] sequentially modified a dynamic model deduced by them to accord with their experimental results for an activated sludge process. Factors taken into account were substrate storage, nitrification and oxygen respiration.

Dold, Ekama and Marais[112] in reconsidering the model of Ekama and Marais made certain alterations. The principal changes were:

(1) The energy requirement for adsorption was replaced by a bi-substrate hypothesis, viz: a consideration of municipal wastewater as being composed of a rapidly biodegradable (soluble) and slowly biodegradable (particulate) substrate;
(2) The replacement of the modified Blackwell equation by active sites evaluation;
(3) The replacement of the classical endogenous respiration concept by a death regeneration one.

In dealing with further aspects of the activated sludge process Alexander, Ekama and Marais[113] further modified the general kinetic model developed previously to apply to the contact stabilization process.

A model for single sludge denitrification in the activated sludge process was proposed as an extension of the Dold, Ekama and Marais[112] model and was put forward by van Haandel, Ekama and Marais[114] who provided for the inclusion of the kinetic behaviour of the denitrification process in single sludge systems.

Siebritz, Ekama and Marais[115] have dealt extensively with the removal of phosphorus in a paper presented at the 11th IAWPR post seminar conference on *"Phosphate Removal in Biological Treatment Processes"* held at Pretoria in April 1982.

REFERENCES

1. Wilson, H. *"Methane – A Neglected National Asset"*, Presidential Address to Section B, S. Afr. Assoc. Adv. Sci., July 1945.
2. McLachlan, J.A. and Gaillard, J.R. J. and Proc. Inst. S.P., 1946(1), 198.
3. Conference on *"Grazing of Cattle on Sewage Farms"*, J and Proc. Inst. S.P., 1947(2), 189.
4. Orenstein, A.J. J. and Proc. Int. S.P., 1947(2), 205.
5. Conference on *"The Utilization of Sewage Sludges"*, J. and Proc. Inst. S.P., 1949(1), 90.
6. Dekema, C.J. and Krige, P.R. J. and Proc. Inst. S.P., 1947(1), 91.
7. Dekema, C.J. and Murray, K.A. J. and Proc. Inst. S.P., 1942, 318.
8. Hogg, Elizabeth S. J. and Proc. Inst. S.P., 1950(1), 57.
9. Orenstein, A.J. J. and Proc. Inst. S.P., 1949(4), 481.
10. Schrader, H. J. and Proc. Inst. S.P., 1950(1), 58.
11. Stander, G.J. J. and Proc. Inst. S.P., 1950(3), 286.
12. Stander, G.J. and Hide, C.G. *ibid*, p. 290.
13. Stander, G.J. and Elsworth, J.F. *ibid*, p. 303.
14. Stander, G.J. J. and Proc. Inst. S.P., 1950(4), 438.
15. Stander, G.J. and Snyders, R. *ibid*, p. 447.
16. Samson, J. J. and Proc. Inst. S.P., 1950(2), 132.
17. Heynike, J.J.C. and Westhoff, J.W.H. J. and Proc. Inst. S.P., 1950(2), 135.
18. Gaillard, J.R. J. and Proc. Inst. S.P., 1950(3), 276.
19. Keller, P. J. and Proc. Inst. S.P., 1951(1), 100.
20. Hamlin, E.J. and Wilson, H. J. and Proc. Inst. S.P., 1951(3), 243.
21. Gaillard, J.R. J. and Proc. Inst. S.P., 1952(2), 145.
22. Stutterheim, N. and van Aardt, J.H.P. J. and Proc. Inst. S.P., 1953(2), 133.
23. Gaillard, J.R. J. and Proc. Inst. S.P., 1954(4), 419.
24. Murray, K.A. Public Health, 1956, 19(9), 29.
25. Heynike, J.J.C. Public Health, 1958, 21(11), 35.
26. Krige, P.R. Public Health, 1957, 20(3), 35; Loc. cit. 1957, 20(4), 13; J. and Proc. Inst. S.P., 1957(1), 74.
27. Clausen, H.T. Public Health, 1958, 21(10), 7.
28. Loffell, B.F. J. and Proc. Inst. S.P., 1955(2), 151.
29. Bergman, B.S. J. and Proc. Inst. S.P., 1958(1), 50.
30. Bergman, B.S. J. and Proc. Inst. S.P., 1961(3), 218.
31. Gaillard, J.R. J. and Proc. Inst. S.P., 1959(2), 243.
32. Barnard, J.J. J. and Proc. Inst. S.P., 1961(3), 219.
33. Osborn, D.W. J. and Proc. Inst. S.P., 1961(3), 227.
34. Krige, W.P. J. and Proc. Inst. S.P., 1962(2), 150.
35. Meltzer, D. J. and Proc. Inst. S.P., 1962(2), 169.
36. Osborn, D.W. J. and Proc. Inst. S.P., 1962(3), 195.
37. Krige, P.R. J. and Proc. Inst. S.P., 1962(3), 200.
38. Bergman, B.S. J. and Proc. Inst. S.P., 1962(3), 255.
39. Meltzer, D. J. and Proc. Inst. S.P., 1962(4), 366.
40. Osborn, D.W. Public Health, 1963, 63(3), 5.
41. Malherbe, H. Public Health, 1963, 63(9), 3; J. and Proc. Inst. S.P., 1964(3), 210.
42. Krige, P.R. J. and Proc. Inst. S.P., 1964(3), 215.
43. Osborn, D.W. J. and Proc. Inst. S.P., 1964(3), 243.
44. Stander, G.J. J. and Proc. Inst. S.P., 1965(3), 204.
45. Osborn, D.W. J. and Proc. Inst. S.P., 1965(3), 272.
46. Bolitho, V.N. J. and Proc. Inst. S.P., 1966(3), 213.
47. Kinmont, A. J. and Proc. Inst. S.P., 1966(3), 235.
48. Gaillard, J.R. J. and Proc. Inst. S.P., 1966(3), 239.
49. Melmed, L.N. (Mrs) J. and Proc. Inst. S.P., 1966(3), 272.
50. Drews, R.J.L.C. J. and Proc. Inst. S.P., 1966(3), 280.
51. Stander, G.J., Oliff, W.D. and Livingstone, D.J. Wat. Pollut. Control, 1968, 67(2), 143.
52. Bolitho, V.N. Wat. Pollut. Control, 1969, 68(4), 42.
53. Stander, G.J. and van Vuuren, L.R.J. Wat. Pollut. Control, 1969, 68(5), 513.
54. Osborn, D.W. Wat. Pollut. Control, 1969, 68(6), 662.
55. Osborn, D.W. Loc. cit., p. 664.
56. Van der Merwe, P.H. Wat. Pollut. Control, 1969, 68(6), 669.
57. Hattingh, W. Wat. Pollut. Control, 1969, 68(6), 672.
58. Bolitho, V.N. Wat. Pollut. Control, 1970, 69(1), 79.
59. Nupen, E.M. (Mrs) Wat. Pollut. Control, 1970, 69(4), 430.
60. Osborn, D.W. Wat. Pollut. Control, 1970, 69(4), 456.
61. Vosloo, P.B.B. Wat. Pollut. Control, 1970, 69(5), 486.
62. Conradie, P.J. and Smith, E.J. Wat. Pollut. Control, 1970, 69(5), 496.
63. Stander, G.J. and van Vuuren, L.R.J. Wat. Pollut. Control, 1969, 68(5), 513.
64. Bolitho, V.N. Wat. Pollut. Control, 1970, 69(5), 501.
65. Toerien, D.F. Water Res., 1970, 4(2), 129.
66. Marais, G. van R. Second Internat. Symp. for Waste Treatment Lagoons, Kansas City (1970).
67. Basson, R.A. and Melmed, L.N. (Mrs) Convention, Water Year, 1970.
68. Henzen, M.R. and Funke, J.W. Wat. Pollut. Control, 1971, 70(2), 177.
69. Stander, G.J., van Vuuren, L.R.J. and Dalton, G.L. Wat. Pollut. Control, 1971, 70(2), 213.
70. Stander, G.J. and Clayton, A.J. Wat. Pollut. Control, 1971, 70(2), 228.
71. Stander, G.J. Wat. Pollut. Control, 1973, 72(2), 235.
72. Bolitho, V.N. Wat. Pollut. Control, 1973, 72(2), 195.
73. Gaillard, J.R. Wat. Pollut. Control, 1973, 72(2), 190.
74. Barnard, J.L. Wat. Pollut. Control, 1973, 72(6), 705.
75. Pretorius, W.A. Wat. Pollut. Control, 1973, 72(6), 721.
76. Voysey, J.A. and Giampietri, A. Wat. Pollut. Control, 1974, 73(5), 480; J. Wat. Pollut. Control Fed., 1979, 51(3), 518.
77. Simpson, D.E. and Hemens, J. J. Wat. Pollut. Control Fed., 1973, **45**, 2194.
78. Toerien, D.F. Wat. Pollut. Control, 1975, 74(2), 134.
79. Barnard, J.L. Wat. Pollut. Control, 1975, 74(2), 143.
80. Marais, G. van R. Wat. Pollut. Control, 1975, 74(2), 172.
81. Turvey, L.G.S. Wat. Pollut. Control, 1975, 74(2), 193.
82. Pretorius, W.A. Wat. Pollut. Control, 1975, 74(2), 196.
83. Pitman, A.R. Wat. Pollut. Control, 1975, 74(6), 688.
84. Nupen, E.M. (Mrs) and Morgan, W.S.G. Wat. Pollut. Control, 1978, 77, 4(1), 45.
85. Midgley, D.C. Wat. Pollut. Control, 1978, 77(1), 14.
86. Heynike, J.J.C. Wat. Pollut. Control, 1978, 77(1), 56.

87. Langenegger, O. and Viviers, J.M.P. Wat. Pollut. Control, 1978, 77(1), 29.
88. Nicholls, H.A. Wat. Pollut. Control, 1978, 77(1), 99.
89. Barnard, J.L. Wat. Polut. Control, 1978, 77(1), 103.
90. Neytzell-de Wilde, F.G., Nurse, G.R. and Groves, J. Water SA, 1977, 3(3), 113.
91. Neytzell-de Wilde, F.G. Water SA, 1979, 5(1), 14.
92. Melmed, L.N. and Comninos, D.K. Water SA, 1979, 5(4), 153.
93. Bryson, A.W. and Dardis, K.A. Water SA, 1980, 6(2), 85.
94. Smith, R. and Wiechers, S.G. Water SA, 1981, 7(2), 65.
95. Barnard, J.L. Wat. Pollut. Control, 1984, 83(4), 443.
96. Cooper, D.R., Shuttleworth, S.G. and Slabbert, N.P. Wat. Pollut. Control, 1984, 83(4), 450.
97. Groves, G.R., Buckley, C.A. and Turnbull, R.H. J. Water Poll. Control Fed., 1979, 51(3), 499.
98. Osborn, D.W. J. Water Poll. Control Fed., 1979, 51(3), 467.
99. Osborn, D.W. and Nicholls, H.A. Prog. Wat. Tech., Vol. 10, Nos 1/2, 1978, 261-277.
100. Buchan, L. Water SA, 1981, 7(1), 1.
101. Buchan, L. Water Sci. and Tech., Vol 14, Nos 9-11, 1982, 1497.
102. Hart, Margaret and Melmed, Leah N. Water Sci. and Tech., Vol. 14, Nos 9-11, 1982, 1501.
103. Nicholls, H.A. 9th IAWPR Conf. Seminar, Copenhagen, June, 1978.
104. Nicholls, H.A. Prog. Wat. Tech., Vol. 8, No. 6, 183-185, Pergamon Press Ltd. 1977.
105. Nicholls, H.A. Prog. Wat. Tech., Vol. 8, No. 4/5, 639-652, Pergamon Press Ltd., 1977.
106. Venter, S.L., Halliday, J. and Pitman, A.R. Prog. Wat. Tech., Vol. 10, Nos. 1/2, 279-292, Pergamon Press Ltd., 1978.
107. Pitman, A.R., Venter, S.L.V. and Nicholls, H.A. Wat. Sci. Tech., Vol. 15, 233-259, Pergamon Press Ltd., 1983.
108. Pitman, A.R. J. Water Poll. Control Fed., 1980, 52(3), 524.
109. Nicholls, H.A. Wat. Sci. Tech., Vol 14, 1982, 581-598.
110. Marais, G.v.R. and Ekama, G.A. Water SA, 1976, 2(4), 163.
111. Ekama, G.A. and Marais, G.v.R. Water SA, 1977, 3(1), 17; J. Water Poll. Control Fed., 1979, **51**, 534.
112. Dold, P.L., Ekama, G.A. and Marais, G.v.R. Prog. Wat. Tech., 1980, **12**, 47.
113. Alexander, W.V., Ekama, G.A. and Marais, G.v.R. Water Research, 1980, **14**, 1937.
114. Van Haandel, A.C., Ekama, G.A. and Marais, G.v.R. Water Research, 1981, **15**, 1135.
115. Siebritz, J.P., Ekama, G.A. and Marais, G.v.R. 11th IAWPR Conf. Seminar, Pretoria, April 1982.

Chapter 7 PROBLEMS ENCOUNTERED IN THE MINING INDUSTRY IN SOUTH AFRICA IN RELATION TO SEWAGE DISPOSAL

The sewage from a mine originates from two sources, viz. –

(1) Underground;
(2) Surface.

Mine sewage is derived from (i) residences, offices and other surface buildings provided with toilet and washing facilities; (ii) changerooms and compounds and (iii) underground.

The flow of sewage from the offices and residences* follows a pattern similar to that of a town. However, the flow from the compounds and changerooms follows an entirely different pattern and can give rise to treatment difficulties in a conventionally designed sewage purification works.

Underground sewage which is normally based on a bucket or tank collection system is transported by skip to the surface and the receptacle contents (urine and faeces) are flushed with water into the sewerage system at a specially designed intake situated on a trunk sewer leading to the sewage purification works. At the intake the contents, after adequate flushing with water (ten volumes of water to one volume of underground sewage), the buckets or other receptacles are usually steam-cleaned before being returned for re-use underground.

(1) Underground Sewage

Underground Sanitation: Initially this was based on a bucket/pail system.

Improvements in the system originally stemmed from a desire of management to reduce the sanitary work-force employed at a mine.

Rushton[1] has indicated that prior to 1941 the sanitation gang employed at the Daggafontein Mines Limited worked on night shift and all sanitary pails were carried from the shaft stations to the latrines and back by sanitation workers. During 1941 the system was changed and all pails were transported on the mine haulage system using trucks provided with a specially designed frame to hold six pails in an upright position.

On other mines (e.g. Vogelstruisbult Gold Mining Areas Limited) where man-handling of buckets alone took place, the buckets were transported by sanitary workers using a large-scale version of an egg stand provided with legs and handles and resembling a bier with holes cut in the platform to accommodate the buckets in an upright position. A "bucket-crate" required to be of a size to allow of its easy placing in a skip for haulage to the surface.

Mobile Latrines: Nosworthy[2] has stated that towards the end of 1947 it was decided to scrap the system of permanently placed brick latrines underground on the Daggafontein Mines Limited and convert to mobile-type latrines.

Each mobile-type latrine was built into a one-ton (0,907 tonne) standard truck and was provided with four seats. A sanitary car was partially filled with water and disinfectant added; a quick-release valve was provided for emptying and cleaning.

Nosworthy has indicated further, that –

(1) Cleaned empty sanitary cars are sent down the shafts at 19h00 each evening and stored near shaft stations to await the arrival underground of the sanitation workers the following morning;
(2) The arrival of the sanitary workers is arranged to coincide with the start-up of the haulages. The sanitary workers hook-on the sanitary cars to the haulage ropes and accompany the sanitary cars to the respective latrine enclosures;
(3) Each sanitary worker on arrival at a latrine enclosure shunts the necessary number of sanitary cars into the enclosure, seals down the lids on the used cars and trams these full cars to the haulages where they are fastened to the ropes by the haulage workers. The sanitation worker then cleans up, disinfects, and, if necessary, whitewashes the enclosure before proceeding to the next enclosure;
(4) On arrival at a shaft station the sanitary cars are despatched to the surface as soon as possible and are trammed to a disposal shed where the contents of the cars are discharged into the sewerage system leading to the sewage purification works. Whereafter, the cars are cleaned ready for subsequent return for re-use again underground.

*In some cases these may constitute a fair-size township, which, in a number of cases, develops into a local authority.

Use of Septic Tanks: Schumann[3] has given information about the use of septic thanks (*in situ*) underground for treating underground latrine sewage at the Roan Antelope Mine in Zambia based on a United States practice he had observed on a visit to the United States of America.

The effluent from the septic tank is discharged into the mine drainage system. If the flow in the mine drain is low additional water is added from the machine water column. The mixed drainage water and septic tank effluent after drip treatment with chloride of lime solution is then caused to discharge from the mine in the usual way.

Comment: This method is not considered to be a satisfactory one since septic tank effluent requires further purification before discharge to the environment. However, if a mine makes a great deal of water and, in consequence, the dilution of the septic tank effluent is considerable, further purification will take place in a mine dam on the surface, the overflow from which, after a long detention period may be of satisfactory quality.

Underground Investigations

The transport of empty sanitary receptacles (e.g. buckets/pails, sanitary cars) underground and full ones up to the surface leads to a loss of "shaft hours" which could be more valuably employed in transporting ore to the surface for recovery of gold in the reduction plant.

An experiment was carried out on the twelfth level of one of the shafts of the West Driefontein Gold Mine some years ago to overcome the wastage of "shaft hours" and to provide better facilities underground. An opening in the rockface near a driveway was blasted out and a small activated sludge plant using draught-tube aeration was installed therein: adequate latrine facilities were provided and the discharge from these was treated in the activated sludge plant. The purified effluent from this plant was discharged into the adjoining drain leading to the underground dams on the same level: the water from the dam was then pumped to the surface and satisfactorily disposed of.

Note: The West Driefontein Mine makes a considerable amount of water – in excess of 30×10^6 gallons (136 363 m^3) per day.

At the South West Vertical Shaft of the E.R.P.M. (East Rand Proprietary Mines Limited) the problem was tackled in a different way, the activated sludge plant being a mobile package unit on the rail tracks.

It suffered from a number of disadvantages, viz. –

(i) No privacy for the users – the lavatory seats being affixed to the top of the activated sludge unit which was a steel, horizontally arranged cylindrical tank.
(ii) Aeration was effected by means of compressed air from the Jackhammer lines.
(iii) Due to the high underground temperature (3000 to 3300 metres below surface) virtually hot air* was being used for the aeration of the activated sludge and very little, if any, effluent emanated from the mobile unit due to evaporation. However, no doubt, shaft hours were saved and the plant could be hauled to the surface since it was on rails leading to the nearest shaft station.

In the case of the West Driefontein Plant privacy was not overlooked. However, it became necessary to enclose the works area with expanded metal to prevent untoward actions of certain miners in throwing rocks into the plant to satisfy their form of humour thereby causing damage to moving parts. The plant was proving to be a success when the West Driefontein Mine was flooded.

Note: There seems to be a need for providing better sanitary facilities underground. Changing to newer mobile methods or *in situ* activated sludge plants from the older system of permanently placed brick or corrugated iron latrines underground might, if nothing else prevent the proliferation of rats near bucket latrines of this sort apart from saving shaft time.

Apart from reducing the shaft hours for rock haulage the bucket system leads to abuse such as the surrepticious direct disposal of urine from full and overflowing urine-containing buckets at urinals into the drains.

Comment

Prerequisites for sanitation underground are, –

(1) The productivity of the mine must not be affected adversely;
(2) The health of the workers must be safeguarded.

Whilst subscribing to the above requirements any system should also be aesthetically acceptable to the users. For this reason sporadic attempts have been made to install such systems, e.g. the West Driefontein Mine experiment.

A system involving haulage of underground sewage to the surface for purification in a sewage purification works on the surface can be operated to conform with the above prerequisites.

P B B Vosloo experimented with a "chemical closet" for use underground and P G J Meiring investigated the use of mobile activated sludge units such as that used underground at the East Rand Proprietary Mines Limited.

Yet, again there is the possibility of employing toilet units such as those used in large passenger aircraft.

However, where disinfectants and coloured reagents are added these added reagents must not

*At working places at these depths in this mine the air is cooled.

upset normal sewage purification processes at the sewage purification plant on the surface or be toxic in any degree.

Lastly, of necessity any system installed must be robust to withstand rough treatment by users, operators and transport handlers.

(2) Surface Sewage

Designing a sewage purification works for a mine introduces problems not normally encountered by local authorities. It will be realized that for a sewage purification works incorporating a biological filtration system or activated sludge plant it is desirable that the flow of sewage throughout each day should be uniform.

This is not the case at mine shafts and compounds since we have a period of high flow for a time after each shift whereas during shifts the sewage works is starved of sewage. What happens in practice in the case of a plant employing biological filters, is the following: The primary sedimentation tank and filter(s) become septic (anaerobic action having set in). Then with a high flow at the end of a shift the active zoogleal slime, nitrifying humus, etc. are flushed from the media (usually crushed stone) thus considerably reducing the aerobic purifying power of the biological filter. With this sequence of events much of the metal (iron) work becomes covered with metal sulphide and all units, including sand filters, become black and smell of hydrogen sulphide (H_2S) and the effluent is of poor quality and, of course, the filters do not perform their designed task.

This can be overcome by installing a balancing tank of adequate size, the contents of which should be kept agitated (not necessarily aerated) and final purified effluent re-circulated into this tank to help keep the contents satisfactorily aerobic and maintain an adequate feed to the plant – as used on one of Genkor's mines. (Refer to Flow Diagram, page 108).

During the period of low flow, i.e. while the workers are underground, the contents of the balancing tank should be fed at an adequate rate to maintain a uniform flow to the plant throughout each day.

At the end of shifts, when the flow to the plant increases considerably due to the use of ablution and sanitary facilities by the returning workers, the recirculation of final effluent to the balancing tank should be somewhat attenuated to prevent hydraulic overloading of the sedimentation tank.

Mealie meal

(i) At mine compounds the Black mine workers usually dispose of surplus mealie meal from their plates, etc. after a meal into the compound's drain. This causes an accumulation of mealie meal in the raw sludge at the sewage purification works and upsets digestion of sludge in the digesters. The resulting "digested" sludge has a yellowish colour instead of a black "tarry" appearance, the odour is unpleasant and the sludge has a low pH value.

Consequently, every mine compound should be provided with means for preventing mealie meal gaining access to the sewers. Some compounds have specially designed mealie meal traps – others use Dortmund-type sedimentation tanks – the overflow from which is allowed to discharge into the sewers. The settled solids, in both cases, can be disposed of to piggery operators if uncontaminated with sewage.

(ii) Mealie meal can also give rise to problems with biological filters.

It is good practice – particularly with mine sewage purification works using biofilters – to arrange for the top layer (0,45 metre deep) to be of 7,6 cm diameter media.

The reason for having a coarse top layer is to avoid sealing-off the surface of a filter by the excessive growth of fungal slime capable of covering the voids between the media if it is of the usual fine size (2,54 cm to 3,81 cm).

At a mine sewage purification works (Kloof Gold Mining Company Limited), where the media was 2,54 cm in size throughout, it was found that shortly after start-up of this new works a thick mat of tough slime covered the surface of the filters thereby preventing percolation and caused the sewage distributed over it to spew over the walls of the circular filters. The sewage fed to the works originated from a mine compound having c. 9 000 Black mineworkers fed on a diet rich in mealie meal.

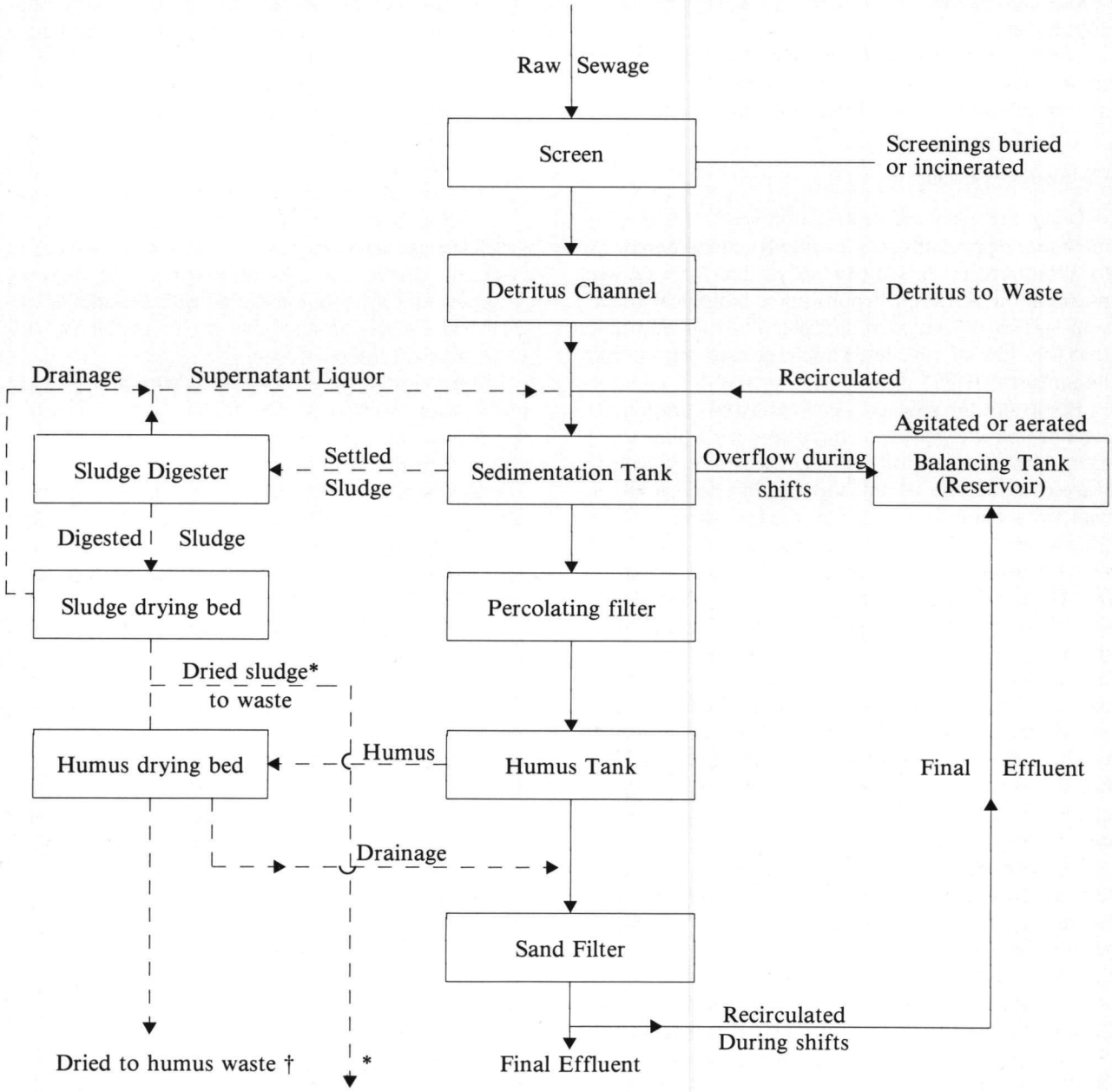
This condition was rectified by removing the top 90 cm of media: this was removed by the contractor and replaced by 7,6 cm media. The filters, after recommissioning with the coarse top layer, never gave trouble subsequently.

Re-cycling of Purified Sewage Effluent: The re-use of purified sewage effluent in place of a public water supply in the gold mining industry must be encouraged. However, where mining companies operate their own sewage purification works and re-use the purified effluent in reduction plants, it is necessary to sound a note of warning that unless the sewage purification works is satisfactorily operated, the gold recovery process may be adversely affected thereby resulting in increased gold residue values.

Purified sewage effluent of General Standard quality can be used in place of pure wholesome water (e.g. Rand Water Board water) in gold recovery plants. This has been proved in laboratory investigations. However, a certain amount of resistance to the substitution of purified sewage effluent for Rand Water Board water has existed.

This prejudice is somewhat misplaced and absonant and has been based largely, (i) on fear of the microbiological content of the effluent and its conse-

FLOW DIAGRAM FOR MINE SHAFT SEWAGE PURIFICATION WORKS



LEGEND

_ _ _ _ _ _ Intermittent flow

_____ Continuous flow

*Dried solids may be used as a fertilizer if dug into ground.
†Not allowed for surfaces dressing of lawns, etc.

quent effect on the health of reduction workers and (ii) on the likelihood of introducing cyanicides* (cyanide-consuming substances) into the cyanidation circuit due to the presence of organic material in such effluent, thereby necessitating preliminary chemical and physical (aeration) treatment and so increasing costs.

A case can be cited where a large gold mine (The East Driefontein Gold Mining Company, Limited) was using purified effluent from the mine's sewage purification works in the reduction plant. The sewage purification works was a conventional one and was well designed and constructed. However, sometime after start-up difficulties were experienced in the reduction plant and the gold residues became inor-

*Pyrrhotite, and marcasite – to a lesser extent – tend to decompose in cyanide solution. When pyrrhotite is present in an ore difficulties arise in regard to cyanide consumption and gold extraction. The subject of "Cyanicides and Refractory Ores" is dealt with by Dorr and Bosqui.[5]

dinately high, thereby forcing the metallurgical consultants to substitute Rand Water Board water for the sewage effluent.

On inspecting the sewage purification works it was found that during the period of adverse recovery of gold by the reduction plant a new sewage works superintendant had been appointed at the sewage purification works. Unfortunately, this employee had had no previous experience of sewage purification and for a period of about three months had not desludged the sedimentation tanks. Consequently the contents of the sedimentation tanks had become septic due to anaerobic action and masses of black scum covered the surface of the sewage in the tanks.

Naturally, all the sewage treatment plant process units suffered and the effluent was poor and unsatisfactory for use in the mine reduction plant.

Note: It is advisable to desludge once every eight hours or at least once every twelve hours. If this had been done and the plant had been operated according to instructions "all would have been well".

Suffice it to say that mining companies should endeavour to recycle as much water as possible in reduction plants – including the use of purified sewage effluent. However, the operation of sewage purification works should be satisfactorily controlled, at all times, to produce an effluent conforming with the requirements of the Department of Water Affairs extant in Government Notices.

Sinkholes and Sewerage: Due to the presence of sinkholes in Carletonville and other dolomitic areas some sewers – to avoid fracture – have been sited above ground.

This method of laying sewers has a number of advantages as well as disadvantages, viz. – Plastic pipes can be used in place of concrete pipes. Should a fracture take place the damaged section of sewer can be easily detected and repaired at short notice. Early attempts were made to introduce lengths of non-rigid plastic liners into already established concrete outfall sewers. This was done to prevent leakage in the event of the concrete sewer being fractured. However, in practice, it was found that portions of the liners became disengaged from inside the concrete sewers and were washed down to the sewage purification works thereby causing chokage on the way and at the sewage purification works.

High density plastic pipes placed above ground offer the best solution.* Such pipelines have proved satisfactory in Natal for the marine discharge of sewage and industrial effluent. However, a certain degree of discernment is necessary in the selection of the type of plastic material to be used as failure – by fracture – has occurred at one sewage purification works in Natal and a switchover to a more suitable plastic pipe became necessary.

However, where sewage is conveyed by plastic or other pipes above ground the sewage in lengthy sewers will tend to become septic in warm weather before arrival at a sewage purification works.

During the hot summer months this disadvantage may be circumvented by periodically adding chloride of lime at suitable intakes/manholes along an outfall or trunk sewer.

*Plastic-lined steel pipes, laid above ground, have also been experimented with.

REFERENCES

1. Rushton, M.W. Assn. Min. Mngrs. S. Africa, Papers and Discussions published by Transvaal and Orange Free State Chamber of Mines, 1942-1945, **2**, 844.
2. Nosworthy, S.S. Assn. Min. Mngrs. S. Africa, Papers and Discussions published by Transvaal and Orange Free State Chamber of Mines, 1956-1957, pp. 709-714.
3. Schumann, A.W. Assn. Min. Mngrs. S. Africa, Papers and Discussions published by Transvaal and Orange Free State Chamber of Mines, 1956-1957, pp. 714-715.
4. Private Communication, Gold Fields Laboratories, Johannesburg.
5. Dorr, J.V.N. and Bosqui, F.L. *"Cyanidation and Concentration of Gold and Silver Ores"*, McGraw Hill Book Company, Inc., New York, Toronto, London, Second Edition, 1950, pp. 238-252.

Chapter 8 PRACTICAL ASPECTS OF WASTEWATER TREATMENT AND POLLUTION CONTROL IN SOUTH AFRICA

1. Expedient Planning to Prevent Pollution of the Aquatic Environment

Pollution: What constitutes pollution cannot be precisely defined. If it bears relation to the use made of water for drinking purposes we must be guided by the recommendations of the World Health Organization in addition to any other generally accepted norms. For the discharge of effluents into rivers quality criteria recommended by the South African Bureau of Standards have been accepted and are legally enforcable. But these are not finite and unchanging as has been witnessed by the amount of research and discussion on the phosphorus and nitrogen contents of sewage effluents in relation to the eutrophication of water impoundments into which they eventually flow. However, our knowledge and experience is such that we do know that polluted waters are difficult to purify economically by modern-day-practice of sewage purification and industrial effluent treatment. We also know what effluents are likely to cause problems in open and built-up areas of the country.

Siting of Industries: Quite a deal of thought and consideration should be given to the siting of a particular industry. An industry set up in one area may not give rise to difficulties whilst in another it may give rise to continual trouble and intensive surveillance of the establishment in regard to its methods of housekeeping and discharge of effluent. The Department of Planning is actively concerned with the siting of industries and whilst, in many cases, it is concerned more with decentralization to provide employment for Blacks in the border areas, nevertheless, through its *"Komitee van Sewe"* ("Committee of Seven") on which the Departments of "Water Affairs" and "National Health and Population Development" are represented, it does concern itself with matters relevant to the correct siting of industries.

Industrial Townships: Industries giving rise to air pollution and the discharge of difficultly treatable and handleable effluents should be situated in special industrial townships far from residential areas but provided with suitable commuting services between them and the nearest dormitory areas. This would seem to be sound town planning. However, in the past the parochialism and civic pride of small towns has led to the establishment of large industries within their midst which has resulted in many difficulties from the points of view of odour, visible atmospheric discharges and intractable industrial effluents.

To realize the force of this statement we only need to view Pretoria, at one stage of Iscor's operation when pollution of the atmosphere became a problem and Sasolburg in relation to the problems of effluent disposal brought in its trail by its proximity to the Barrage of the Rand Water Board.

Local authorities, particularly those inland wishing to encourage industries within their areas of jurisdiction should show a preference for "dry industries" which do not give rise to industrial effluents; or industries practising recycling of effluent leading to a situation of "no-discharge" as is the case with "Sasol II" and "Sasol III".

Industrial Sewers: An example of planning which could be more universally practised is that of providing separate industrial sewers. An example of this is the so-called "Cyril Lord Pipeline". This industrial sewer of fibre glass and plastic conveys saline industrial effluents from the Cyril Lord Textile Factory to the sea at East London. A connection to this from Berlin, a growth point industrially, enables a number of saline and other difficult effluents from this industrial township to be disposed of into the sea.

It is often advisable to provide industrial sewers for reasons other than salinity. For example, Worcester has a sewerage system conveying domestic sewage for treatment at a conventional sewage purification works and a number of corrosion-resistant sewers for conveying wine distillery and food wastewaters to a "sewage farm" for disposal on land.

An overseas example which may be quoted is that of Birmingham[1], England, where gas works liquor discharged with sewage to the sewage purification works upset the functioning of the sludge digesters. However, when the gas works liquor was discharged by separate industrial pipeline and was fed into the *settled sewage* the mixture was satisfactorily purified by biological filtration.

Locality-bound Industries: There are a number of industries which have to operate in a particular area. Chief amongst these are the gold and coal mines since where the minerals are found dictates the sphere of operations both of mining and processing. However, in the case of certain base minerals e.g. minerals containing manganese, phosphorus, aluminium, iron and zinc it has been the practice to transport the raw materials to central areas with the necessary infrastructure to facilitate processing. In some cases this has not been a satisfactory *modus operandi* from a water pollution control point of view. For example, phosphate mineral (apatite) raw material from Phalaborwa contains fluoride and this is a matter for concern at places such as Sasolburg and Richards Bay where processing of the ore takes place at fertilizer plants. (For details concerning pollution from the mining industry reference should be made to Chapter 15 which deals with this problem.)

Apart from the mining industry there are other industries which, from considerations of practicability and profitability, have to operate at or near the sites of their available raw materials. Included in this category are such industries as timber and sawmilling; fruit and vegetable processing; fish processing and wine making.

In the case of locality-based industries the effluents require treatment even if situated on remote farm or wooded land. In the case of fruit and vegetable processing it is often possible to re-use the treated effluent in admixture with the irrigation water for irrigating crops and so reduce the usage *per se* of irrigation water.

The effluents from fish processing can be satisfactorily treated by dissolved air flotation and use can be made of the recovered solids as fish meal for feeding to chickens, etc.

Saw-mills give rise to problems when timber treatment forms part of the operations and these are not properly controlled to avoid pollution of the aquatic environment from the chemical impregnating solution used.

(Chapter 15 deals with the wine and brandy production industry).

Feedlots: A feedlot may be defined as a place where animals of a given species (e.g. cattle, pigs, chickens) are kept confined in both open areas and enclosed buildings and are submitted to artificial feeding in order to obtain the highest productions at predetermined periods of the year.

Most trouble can arise from large cattle feedlots. Intensive feeding methods are used and the animals confined to pens. Lacking in exercise and well-fed they put on weight rapidly and produce better quality meat when slaughtered. However, great quantities of manure and urine result from the very large number of cattle handled by a large feedlot. Disposal of these animal wastes presents a major problem.

Consequently, feedlots should be so situated that their operations do not cause detrimental change in the water quality and the ecology of the areas in which they are situated.

Manure and urine runoff during rain-storms, if allowed to flow into rivers, can give rise to fish kills and to pollution of impoundments due to eutrophication resulting and bacteriological contamination of water supplied for drinking from such impoundments.

The intensive feedlot rearing of cattle is not only a water pollution hazard, if uncontrolled, but also gives rise to odour which can result in public complaint.

Therefore, careful thought must be given to the siting of feedlots to ensure that in their operation the water environment is protected and little aerial pollution occurs. It should be necessary to place a limit on the number of animals per annum allowed for a particular feedlot.

What applies to cattle feedlots, of course, applies to intensive pig rearing and battery chicken establishments though to a progressively attenuated degree.

Regionalization of Sewage Disposal: A Ministerial Commission under the Chairmanship of Mr J L Stallebras dealt with and reported on this matter but the report was not made public.

One matter considered was the problem of "bridging finance" to pay for trunk sewers where the number of users at the time of construction of such sewers was insufficient to offset the loan repayments for such sewers.

However, there is little doubt that water supply and sewage disposal in a particular drainage area should be controlled by a drainage/water board.

The proliferation of small sewage works and package units is not conducive to a satisfactory state of affairs in a drainage area where large well-operated and controlled works are desirable to ensure that pollution of the water environment does not occur. (Experience has shown that due to lack of adequate supervision and lack of experience of those in control, package units perform poorly in many cases.)

Black Townships: The provision of sewage in Black townships comes within the purview of Administration Boards. In the case of Coloureds, the Department of Community Development takes an interest in providing sewage facilities.

Unfortunately, these two bodies are not all that well endowed with funds – particularly the Administration Boards. Consequently, we find that in small towns the European area is provided by the local authority with a sewerage system whilst the Black township has a bucket system. This is unfortunate and a unitary system should be aimed at to avoid the drawback of a bucket system and to ensure that pollution does not occur due to the operation of

such a dual system.

The Chemical Industry: Many chemical manufacturing processes give rise to effluent problems. However, in many cases, the chemical abilities of manufacturers have been put to good effect in solving these problems, particularly where there is an economic incentive to produce saleable by-products from intractable wastes which would otherwise pollute the environment.

However, unlike many of the more prosaic and standardized processing industries the chemical industry is constantly beset by economic hazards of plant obsolescence brought about by the necessity to innovate to keep pace with the needs of the community, necessitous changes of feedstocks, the introduction of newly discovered chemical processes, the ingenuity of competitors and company mergers.

This being so a chemical industry is subject to change within comparitively short periods of time which calls for forward planning in regard to the use of water and the disposal of effluents and other waste products.

When allowing the establishment of a new chemical plant/complex, these factors must be taken into consideration and provision made for necesary safeguards of likely eventualities.

Holiday Resorts: Holiday resorts call for special attention. Unfortunately, in many cases, insufficient thought and attention has been given to the treatment of sewage from such communities with fluctuating populations.

A sewage purification works or facility installed for an off-season population will clearly be inadequate during the holiday season when there is a considerable increase in the number of contributors (in some cases, as much as 16 times).

Consequently, the sewage purification facilities must provide for both situations and be capable of producing a satisfactory effluent at all times.

Marinas: These should be carefully planned from the point of view of water pollution prevention to ensure that:

(1) Adequate means are available for the handling, purification and disposal of sewage;
(2) No areas of water are likely to be stagnant;
(3) No dumping of solid or liquid wastes from boats and other water craft, jetties or waterfront buildings is allowed to occur.

2. Indicators of Operation Efficiency and Needed Corrective Action at Sewage Purification Works

The *status operandi* of a sewage purification works may be gauged by making a number of observations, viz.

(1) Flow

Meter Installed: It is important to obtain a fairly accurate assessment of the average dry weather flow of sewage arriving at the sewage purification works.

Where a meter is installed this should be examined to determine whether it is functioning correctly: records must be kept of the flow. Peaks and duration of peak flows should be noted to decide whether certain process units are being hydraulically overloaded.

No Meter Installed: Where no meter has been installed the following procedure should be followed:

(i) Where the raw sewage is pumped to the sewage purification works the daily flow may be calculated from a knowledge of the pump(s) capacity and the periods of operation during a 24-hour period. The capacity(ies) of the pump(s) can be checked by noting the time taken to fill a receptacle or process unit of known volume.
(ii) Where the sewage flows by gravity to the sewage purification works a rough estimate of the daily flow should be made by rigging-up a V-notch at a suitable point in the flowline and the flows calculated (from V-notch readings) at regular intervals and recorded. If this is not possible, then the total number of contributors to the scheme will give a rough indication of the flow on the basis of 136 ℓ per capita for domestic sewage in a White built-up area. (For Non-White communities the per capita contribution may vary between 68 to 90 ℓ and, in some cases, 113 ℓ depending on the living circumstances of the community and the availability of water.)
(iii) Where sanitary pail contents (''night soil'') from a bucket system are transported the number of ''night soil'' buckets should be noted and the volume of ''night soil'' calculated.

The number of contributors should also be obtained. This, of course, can be checked roughly from a knowledge of the total volume of ''night soil'' and allowing approximately 1,0 ℓ of ''night soil'' per contributor per day for underground mine collection systems and 1,7 ℓ for surface collection systems.

Comments: At many sewage purification works the main flow meter recording the flow of screened sewage to the sewage works is neglected and does not receive regular servicing. In fact, in some cases, regrettably, corrosion and neglect have rendered this important instrument a sorry ornament.

For a suburban White community the normal flow of sewage is of the order 136 ℓ per day. However, for Black and Brown communities flows as low as 36 ℓ and as high as 545 ℓ per capita per day have been encountered. The low flow quoted was that from a Coloured community in the Cape. This township constitutes the dormitory suburb for an industrial town nearby with the result that the residents use little water at home for toilets, ablutions, etc. – these

facilities being available at the factories. The high flow quoted was for a mine compound for Blacks where no control on the use of water was exercised and the Blacks used the showers excessively. Flushing of the urinals/toilets was also on a liberal basis.

In the case of mine compounds the usage of water should be controlled to ensure a fairly uniform flow and to reduce the overall usage to within the limits 136 to 227 ℓ per capita per day. This can be done by suitable adjustments to urinals, toilet flushing frequencies, showers, washing facilities as well as the enforcement of satisfactory disciplinary measures.

Water should not be allowed to run to waste during the night or while workers are underground.

It should be remembered that a sewage purification works of any type operates best when the flow of sewage is evenly distributed during each 24-hour period.

The use of pumps in reticulation systems and at sewage purification works often gives rise to problems of overloading of process units due to the relative capacities of the pumps and pump sumps in relation to the average flow. This arises when a large capacity pump is installed to cope with sewage entering a sump. Ideally, at least three pumps should be installed – one to pump continuously, the second to switch-on when the flow overtakes the first pump and a third pump to act as a stand-by to serve as additional pumping capacity in an emergency.

In many cases the root cause of malfunctioning of a sewage purification works is surging of the flow resulting from incorrectly selected pump sizes and pumping sequences.

Sewage works constructed for the purification of the sewage from mine compounds suffer from the drawback that while mine workers are underground the flow of sewage through the works may be low or – to all intents and purposes – nil. On the other hand, after the mine workers end a shift and come to the surface the flow through the sewage works is excessive. To overcome this drawback a suitable surge/balancing tank should be installed ahead of the sewage purification works.

The contents of the tank should be agitated continuously and purified sewage should be re-circulated into it thereby preventing the sewage from becoming septic and, also, ensuring a uniform distribution of sewage to the sewage purification works throughout each 24 hours. (This is dealt with in Chapter 7 cf.).

Another point to be taken into account and associated with mining activities, is that within a short period of time the number of contributors may increase considerably due to new underground developments. Quite often these sudden increases of sewage flow resulting therefrom give rise to overloading of an associated sewage purification works unless, of course, provision for these increases in the number of contributors was provided for in the original designs and construction has matched the designs.

(2) Screening and Detritus Removal

Screening: Screens are necessary and, provided these are given adequate attention and supervision, no trouble should arise. Some sewage purification works have two sets of screens – a coarse/bar screen followed by a fine screen.

In some of the larger sewage purification works the coarse/bar screens are automatically raked. These, sometimes, may give trouble when a stone or other hard object causes the raking machanism to jam.

Some works may employ a macerator which macerates and, at the same time, screens the incoming sewage. These are not very common in the Republic.

Comments: The methods used for disposing of screenings must be satisfactory and must not give rise to secondary pollution.

In most cases screenings are buried in trenches or are incinerated.

Detritus Removal: After screening, sewage is caused to flow through detritus channels which are so designed and operated to reduce the velocity of flow of sewage to approximately 0,3 m/s. This results in readily settleable solids such as sand and other gritty materials settling out.

The attainment of 0,3 m/s velocity is made possible by the use of adjustable penstocks or by design of the cross-section of the channels to ensure a velocity of 0,3 m/s irrespective of the flow of sewage to the sewage purification works.

Comments: Detritus, which is normally contaminated grit, should be disposed of by burial or other suitable means (e.g. sanitary landfill) not resulting in secondary pollution. Some sewage purification works overseas (operating on a combined drainage system) use specially designed detritors – the detritus being suitably washed or aerated, dried and stockpiled for building purposes.

At some sewage purification works in the Republic the detritus may contain vegetable seeds arising from the diet of Blacks in mine compounds.

In many oxidation pond systems no screens or detritus channels are provided. This results in unsightly "floatables" on the surface of the ponds.

In conventional sewage purification works failure to remove detritus may lead to excessive abrasion and wear of moving parts e.g. pumps and can also give rise to pipe chokages and affect digester operation due to compaction of solids in the conical base of the digester thereby preventing the drawing-off of digested sludge.

(3) Sedimentation

After screening and the removal of detritus it is necessary to remove as much as possible of the suspended organic matter.* This is done by sedimen-

*In the case of Extended Aeration Activated Sludge Plants primary sedimentation of sewage is not practised.

tation in sedimentation tanks.

The most common design of sedimentation tank used in South Africa is the "Dortmund"-type tank which is essentially a circular tank with a conical bottom. The inlet can be of the upward or downward flow type placed centrally and conveniently below top water level. Normally a stilling box is provided. This consists of an open cylinder surrounding the inlet region of turbulence.

A circumferential scum board is provided. This is so set above the scum level and so positioned to provide a suitable annular space between it and the overflow weir of the tank. This in turn, is surrounded at a lower level by the overflow channel adjacent to the wall of the tank.

Scum which collects on the surface of a tank in operation should be removed frequently by water jet or continuously by mechanical means. The scum is normally discharged into the raw sludge sump. The sludge draw-off pipe should operate under a hydrostatic head of c. 1,8 m and should have a diameter of 15 cm. Smaller diameter pipes dealing with raw sludge and, in fact sewage, have a tendency to choke.

Comments: The overflow from a sedimentation tank should be of a faint-grey colour and reasonably clear. If the sewage contains effluents from industries, etc. which colour the sewage this, of course, will not be so.

The overflow channel of a sedimentation tank in operation should not be flooded. The settled sewage should fall freely into the overflow channel. If this is not the case then the sedimentation tank is hydraulically overloaded.

If the contents of a tank are black and there is evidence of black lumps floating on the surface with, possibly, associated gas bubbles, this indicates that the sewage in the tank has become septic (acid anaerobic action having taken place). In some cases, of course, it may be due to the sewage having been septic before arrival at the sewage purification works. This could occur in very hot weather in the case of sewage works receiving sewage from long outfall sewers, outfalls containing siphons or outfalls receiving septic sewage from conservancy tanks.

If the condition is due to septic conditions having taken place – *per se* – in the tank, then this has been caused by infrequent desludging of the tank (provided, of course, the inflow has continued at the normal rate).

A case of this nature occurred in a large sewage purification works dealing with sewage from one of the present operating gold mines, due to the employment of a new operator somewhat ignorant of sewage plant operations. This malfunctioning completely upset the sewage purification works to the extent that the quality of the final effluent had deteriorated and could no longer be used in the reduction plant due to gold losses and blinding of filter cloths.

A sedimentation tank should be desludged at least twice per day and done in such a manner and at such times that no nuisance will arise – particularly to residents in the neighbourhood.

(4) Biological Filtration

Normally the effluent discharging from a biological filter should be clear with greenish flocculent praticles of humus in suspension. The odour is of a pleasant nature.

A biological filter may be overloaded due to excessive flow, application of poorly settled sewage, incorrect sizing of media, uneven distribution of sewage or malfunctioning of the distributor.

In any one of these events a filter may become "ponded". This is noted by certain surface areas of the filter forming ponds due to clogging of the media.

Comments: The sizing of the media should be investigated. When a filter is constructed the filter media must be carefully graded: crusher fines should be absent. In fact, the media should be washed to clear the crushed stone or clinker of any adherent fines and the whole filling operation should be carefully supervised. The holes in the distributor arms should be inspected.

In practice it has been found that many contractors install distributors with holes drilled in the distributor arms (pipes) and these are not provided with non-corrodable nozzles. In consequence corrosion sets in and the diameter of the holes alter with time thereby giving rise to excessive application of sewage to certain sections of the filter.

Ponding in a filter can be overcome by taking the particular filter out of action, spreading a layer of chloride of lime (powder) ($CaOCl_2$) on the surface of the filter, thereafter allowing the filter to operate for a few minutes and then "shutting it down" for a few hours. After the lapse of a few hours the filter should be started up again and a very large flow must be passed through the filter to flush it out. It will be found that after the application of the chloride of lime the zoogleal slime disengages from the media and can then be flushed through the filter bed by increased application of sewage.

After this treatment the flow of settled sewage to the filter bed should be returned to normal. In a matter of a few weeks or so the filter should recover its performance. In the case of very severe ponding it may be necessary to repeat the treatment. In such an event the re-maturing of the filter will take longer.

Quite often the seal at the central distribution box of a filter is broken/leaking. This results in a large application of sewage in the central area of the filter and so gives rise to a poorer quality effluent. This is a matter for good "housekeeping" on the part of the sewage works operators and superintendent.

The importance of having a sufficiently coarse top layer of media in a biological filter is not readily apparent. Usually the bulk of the media consists of

material having diameters of approximately 3,8 cm. However, a coarse top layer of material approximately 7,6 cm in size is necessary to prevent the growth of tenaceous slime between the aggregate to effectively cover the void areas and so form a completely impervious mat, thereby causing the sewage to spill over the walls of the filter and prevent percolation of the sewage through the filter bed.

(5) Sludge Digestion and Sludge Drying

The sludge drawn from a digester should be black in colour and have a faint tarry odour. At many sewage purification works sludge sampling valves are provided to check the nature of the contents of a digester at certain fixed levels.

Digested sludge is withdrawn from the bottom of a digester. So-called "middle-third"/supernatant liquor forms the layer between the digested sludge and the scum layer on the top.

Supernatant liquor may be drawn off from time to time but this is not essential if the contents of the digester are frequently circulated. Many operators draw off supernatant liquor and circulate infrequently in an endeavour to accommodate more raw sludge in a digester. This is hardly advisable if the capacity of a digester is inadequate.

The contents of a digester should be circulated. The best way of doing this is by circulating sludge from the bottom to the top of a digester and this should be done at least once per day.

Circulating from the bottom to the top helps to break up the scum layer biologically and physically. This is necessary since if the scum layer is left indefinitely it may become a close-knit surface which will impede the escape of sludge gas to the atmosphere above it. There have been cases – notably with rectangular-shaped digesters – where this has resulted in explosive rupture of a digester.

In practice the scum layer will be found to contain grease, hair, match sticks, etc. These have originated from the scum removed from the surface of the sedimentation tank(s) since it is customary to process this scum with the raw sludge.

Supernatant liquor withdrawn from a digester should be settled and the settled liquor together with the drainage from the sludge drying beds should be returned to the incoming sewage.

Comments: If the digested sludge is not black and lacks a faint tarry odour the pH value should be determined using a pH test paper. A satisfactory value is a pH value of 7,2. If the test paper indicates a pH value below 7,0 the sludge drying beds should be examined.

A sludge drying bed which has almost dried out (5 to 7 days exposure) should be selected and a section of the top (crusted) layer turned over using a rake or other convenient implement. If fly larvae of the ordinary house fly *(Musca domestica)* are present in the sludge, then it is a clear indication that digestion is not good.

This is probably due to the digester capacity being inadequate. It may of course, be due to the drying bed area being too small resulting in the sludge remaining wet/damp within the life cycle of the fly (c. 7 days in summer to c. 10 days in winter).

At mine sewage purification works the presence of excessive amounts of mealie meal in the sewage can give rise to poor digestion of sludge. In some cases the digested sludge can have an orange-like colour and be acid in reaction. If this is so, effective mealie meal traps must be installed at the compound(s).

In cases where it is unlikely that further digestion capacity is likely to be provided within a reasonable period of time, the fly problem can be contained by turning over the surface of each bed after 3 to 4 days' drying and sprinkling on the exposed surface p-dichlorobenzene. This will kill the fly larvae. Flies emerging from pupae may be eradicated by spraying the surrounding concrete or brickwork of the beds with a solution of "Dazfly" in paraffin. (p-Dichlorobenzene and "Dazfly" may be obtained from Klipfontein Organic Products Limited – "KOP", Kempton Park, Transvaal.)

(6) Activated Sludge Treatment

When operating satisfactorily an activated sludge plant should not give rise to unpleasant odour and, in fact, should have a pleasant odour.

The circulating solids should have a greenish colour similar to humus from biological/percolating filters (and the odour not quite so earthy).

In the Republic, at present, many of the smaller installations are of the "Pasveer Ditch" or "Huisman Orbal" types. In larger installations the preference seems to be for surface aeration using fixed or floating-type turbine aerators. However, aeration by "compressed air" is used for small and large installations, the "compressed air" (from compressors or blowers) being applied to suitable diffusers or bubble caps fitted in aeration tanks/channels or aeration basins.

The effluent from an activated sludge plant after settlement should be sparklingly clear.

Comments: If the plant is malodorous it is probably due to insufficient aeration. In these circumstances the number of aerators being used and the *modus operandi* of the aerators or the quantity of air delivered should be investigated and a change in the number of aerators or air supply and the sequence of operation of aerators altered to increase the amount of aeration.

A 1 000 mℓ sample of the activated sludge from the aeration channel/basin should be taken in a measuring cylinder and the sedimentation volume noted after the 1 000 mℓ aliquot of activated sludge has settled for 30 min. The sedimentation volume should be within the limits of 30 to 50 per cent.

If the sedimentation volume, after 30 min settling,

is low (less than 30 per cent) steps should be taken to return more activated sludge to the aeration channel(s)/basin from the activated sludge settlement tank(s). Where the volume exceeds the upper limit the amount of activated sludge returned to process from the settlement tank(s) should be reduced.

Surplus activated sludge should be withdrawn daily and disposed of on sludge dryingbeds or in lagoons.

Activated sludge, while drying, particularly if rewetted can give rise to an acrid smell. At certain sewage purification works attempts have been made to overcome this by spraying the beds with solutions of odour-masking agents.

If activated sludge rises in the activated sludge settlement tanks it may be due, *inter alia,* to septic conditions in the settled activated sludge in the settlement tanks due to infrequent withdrawal of sludge or over-aeration or caused by the formation of nitrogen (N_2) bubbles resulting in rising of the sludge.

Another condition which can arise is excessive foaming due to the presence of the filamentous organism *Nocardia.* This type of foaming does not materially alter the performance of an activated sludge plant but steps should be taken to continuously remove the foam (e.g. by skimming or re-design of settlement tank overflows). The removed foam should be suitably disposed of and not allowed to re-enter the aeration system.

If the activated sludge settles slowly and has a slightly greyish colour presenting a voluminous gelatinous-like mass and no clearly-defined meniscus, it is in a "bulked" condition. This can be due to overloading of the plant. In such a case the flow and "strength" of the sewage being fed to the plant should be checked against the design capacity of the plant.

Also, the flocs should be examined microscopically for the presence of filamentous organisms (e.g. *Beggiatoa alba, Sphirotilis natans, Thiothrix* etc.).

(7) Clorination

Chlorination equipment and the procedure require regular attention. If the final effluent being chlorinated contains visible suspended solids or is cloudy, then most of the chlorine dosed to the effluent will react with the organic solids present and so elimination of *E.coli* will not be effective.

Comments: There is a tendency by some sewage works managers to overlook chlorination of the final effluent. Quite often the chlorine cylinder(s) are allowed to empty, with no stocks being available, thereby resulting in an interruption of the disinfection process.

Some works use solutions of hypochlorite. Stock solutions should be freshly made up otherwise their effectiveness diminishes.

Yet again – mainly in the case of smaller installations – pills are used. The drawback, in some cases, is failure to timeously replenish the supply of pills in the basket container. In any case, the method is somewhat perfunctory.

(8) Oxidation Pond Treatment

When an oxidation pond system is used, the average daily dry weather flow must be ascertained and also the retention periods of the ponds should be known.

A satisfactory oxidation pond system should consist of the following:

Two primary ponds (in parallel) each having a retention period of 20 days followed by (in series) one secondary pond with a retention period of 10 days and three ponds of 5 days retention each. The depths of the ponds should be approximately 1,2 m.

Comments: In practice it is not necessary (though preferable) to have two primary ponds at "start-up". One will suffice initially provided this is taken out of circuit, allowed to dry and cleaned out after 5 years or sooner – subsequent to the second one being put into circuit.

The effluent from an oxidation pond system must not be allowed to discharge into a watercourse. However, the effluent may be collected in an irrigation dam with a retention period of not less than 10 days. The effluent in the dam may be used for the irrigation of fodder crops, timber trees, etc., but not vegetables or fruit normally eaten in the raw state.

In hot mosquito-ridden regions of the Republic oxidation ponds should be designed to prevent mosquito breeding. This can be lessened by providing ponds with smooth sloping cement walls or in the case of grass-covered walls by ensuring that the grass in regularly cut.

In cases where oxidation pond systems give rise to smell, this can be overcome by re-circulating final effluent to the first pond. To prevent shortcircuiting in the primary pond(s) the incoming sewage should be discharged into the pond(s) at more than one point.

(9) Maturation Pond Treatment

Maturation ponds should not be regarded as the final means of eliminating inefficiencies of a sewage works. It is true that they act as a buffer and can effect further purification if not overloaded.

Their main function is as a means for disinfecting the sewage effluent and reducing the *E.coli* content. In this respect they serve as an alternative to other forms of disinfection such as chlorination, ultraviolet light and ozone treatment.

In practice at least 3 ponds should be provided, each with a retention period of not less than one day. Ideally a total retention period could be 14 days. The depth of a maturation pond should not exceed 3,0 m.

Comments: In a series of maturation ponds it will be found that the quality of the effluent will improve

progressively – from pond to pond – up to a certain stage. Likewise there is a "die-off" of *E.coli* – but, due to the growth of algae the chemical quality deteriorates later particularly in respect of free and saline ammonia (NH_3) content.

Maturation ponds should be fenced off to prevent the ingress of animals. It is, of course, not practicable to prevent the entrance of birds. These can reinfect the effluent from the point of view of *E.coli.* (Note: Some municipalities have arranged the final effluent pond systems at their sewage purification works to become bird sanctuaries).

(10) Grass-Bed Treatment

In recent years a number of grass beds have been installed at sewage purification works for the tertiary treatment of effluent.

In England grass beds have been used, with success, for treating humus tank effluent from biological filtration plants and also final effluent from activated sludge plants.

Comments: The grass beds should be so constructed and so placed as to prevent the ingress of stormwater during rainstorms. The effluent must be evenly distributed from a suitably engineered feed-channel provided along the upper end of each grass bed. (Spray irrigation should not be used.)

Beds should be systematically taken out of circuit for short periods and the grass cut. However, not more than one grass bed should be put out of operation at a time.

There should be (preferably) at least four (4) grass beds and the rate of application of sewage effluent should not exceed 3 000 m^3/ha.day.

Grass cuttings must not be fed to animals but may be burned or composted with other organic materials. The grass grown in the beds should be a variety that will grow well under permanently wet conditions.

(11) Conveyance Water

There is a natural tendency for some mines to use underground water wherever possible in place of the normal domestic supplies. This is done for economic reasons or where the source of domestic water is inadequate.

Some of the smaller mines in arid regions have to rely on a certain amount of underground water to meet their overall water requirements.

In such cases it is advisable to know the composition of such water since, if the water is hard and contains salts such as sulphate and is used as conveyance water (wholly or in part) in the sewage reticulation system, problems of smell, corrosion and malfunctioning of the sewage purification works can occur.

Comments: Mine waters should not be allowed to enter the sewerage system leading to a sewage purification works except in specially investigated cases where the quality of the water is such that it could be used for domestic purposes.

(12) Reuse of Purified Sewage Effluent

With a view to establishing the correct hierarchical use and also maximum use of water, all industries (including mining, metallurgical, chemical as well as a number of processing industries) should be encouraged to reuse sewage effluents and process effluents where this is possible.

In the gold mining industry, for example, purified sewage effluent of General Standard quality can be used in the place of Rand Water Board water. However, to make a commitment in this regard the mines must be assured of the quality and, sometimes, the quantity must be guaranteed.

In-as-much as sewage effluent available to a mine usually emanates from a sewage purification works owned and controlled by the operating company, the attainment of a good quality effluent can be maintained by such mining company provided competent operators are employed to run and maintain such sewage purification works.

Comments: Where mines, e.g. gold mines, diamond mines and metallurgical recovery plants using gravity concentration methods for the recovery of economic minerals are in a position to use purified sewage effluent, they should be encouraged to do so.

However, regular inspections of the sewage purification works and regular analyses of the final effluent reused must be carried out by competent persons and the responsible metallurgists should be assured, at all times, of the quality of the effluent being reused.

Points to note with regard to an effluent being reused are cloudiness caused by fine suspended matter of a semi-colloidal nature in effluent, the presence of *E. coli* and non-conformance with the promulgated values set out in the General Standard for 4 h Oxygen Absorbed, Suspended Solids and Free and Saline Ammonia.

(13) Underground Sewage

Sanitation facilities underground consist of latrines provided with sanitary pails or mobile tanks for collection of excreta from lavatories and urinals. The buckets and tanks are regularly transported to the surface by skip and their contents disposed of into the sewerage system via a special intake.

Certain mines, notably West Driefontein Gold Mining Company Limited and East Rand Proprietary Mines Limited (ERPM), have experimented with package units underground.

At West Driefontein an activated sludge unit (with mechanical "downdraught tube" aeration) was in operation before the flooding episode at this mine. This plant was running reasonably well and the effluent was discharged into one of the underground

dams and the contents of the dam pumped to the surface.

At ERPM a mobile activated sludge package unit operating on the diffused air system was used. The air used was provided from the underground compressed air reticulation pipelines.

Comments: Where bucket or mobile tank systems are in operation for handling faeces and urine from underground workers, it is necessary to ensure that at sewage intakes on the surface the bucket and tank contents are adequately diluted with suitable water to the extent of 1:10 by volume. Disinfectants should not be used but the buckets and tanks may be steam-cleaned.

It will be realized that if a day's collection of faeces and urine from a shaft or number of shafts is discharged into a sewage intake on the surface it will constitute a rather large slug of organic load on the sewage purification works receiving this load which is not desirable. The discharge should be "fitted-in" to best advantage with the pattern of flow and load to the sewage purification works by arrangement with the authority controlling the respective sewage purification works.

In certain cases, of course, there may be difficulties due to the fact that transportation of "underground sewage" to the surface can interfere with or reduce shaft haulage time for ore skips.

(14) Package Units

Package units are mainly of the activated sludge type. However, a number using conventional biofiltration are operating. The bio-disc filter is now becoming quite common.

These units are essentially sewage treatment units which can be used for a number of years for small communities or as temporary sewage purification works for new mine shaft compounds, small mines, construction camps, isolated industries, hotels, hostels, caravan parks, hospitals, military camps, etc. etc. They also serve as useful interim sewage purification facilities for new townships and certain municipal built-up areas not conveniently situated in regard to the existing sewerage system.

Comments: Experience has shown that many of these plants do not produce effluent of General Standard quality as claimed by the suppliers at the time of installation of the package units. In many cases this is due to poor supervision – and, sometimes, lack of interest. In many cases the package unit is regarded as a finite mechanical contrivance called upon to perform a specific job and not a biological plant requiring constant supervision.

To overcome the drawbacks of power failure (unless alternative electric or mechanical power is available) an emergency dam with a retention period of at least 24 h should be provided. Means should be provided to ensure that when the plant comes into operation subsequently the sewage in the emergency dam can be fed into the package unit during periods of low flow.

Bio-disc units can be coupled to septic tank overflows – existing or planned – and have a number of advantages for certain situations. They can be made to operate odour-free.

A close watch should be kept on package units by those responsible for their operation to ensure that they function satisfactorily at all times.

3. Industrial Prescience and the Avoidance of Distressful Effluent Problems.

The following citations may serve as guidelines for industrialists. The examples quoted are but a few of those which require consideration.

(1) Fertilizer Industry

The presence of nitrate and phosphate in the effluent from this type of industry is undesirable since these two ionic species, particularly the latter (phosphate), lead to the eutrophication of water impoundments. Fluoride which may be present in the apatite-ore used as feedstock will reveal itself in the effluent to render it unfit for discharge into the water environment. Likewise, dumps and factory dust can give rise to similar pollution during rainstorms unless proper precautions are taken.

(2) Extractive Metallurgical Industries

Often in processing certain ores, concentrates, etc., the effluent may contain uneconomic quantities of certain elements and ionic species which consititute a danger to the receiving waters. These include selenium, tellurium, lead, zinc, chromium, nickel, sodium as well as soluble salts containing chloride and sulphate.

(3) Electroplating Industries

Electroplating industries should take action to recover such metals as copper, nickel, chromium and zinc which should not be allowed to enter the sewerage system. Added to this is the necessity to destroy all cyanide residues. (This can be done, preferably, by alkaline chlorination.)

There have been notable cases of zinc-containing effluents from galvanizing industries upsetting the operation of sludge digesters at sewage purification works.

(4) Transformer, Capacitor and Brake Fluids

The use of polychlorinated biphenyls (PCB's) as dielectrics is a matter of concern. Since (in South Africa) there is no satisfactory agency to handle the wastes from disused transformers, etc. containing PCB's which are toxic, the dumping of these on land

and in situations gaining access to the water environment will result in PCB's lodging in the flesh of birds and fish.

Until such time as a suitable high temperature furnace (1 300°C with hydrochloric acid scrubbing) is available for handling these compounds in waste material they remain a potential menace to the environment.

(5) Pesticides

Pesticides have been classified according to their uses, viz:

Insecticides, herbicides, fungicides, rodenticides, acaricides (miticides), nematocides, molluscicides, fumigants.

However, use-paterns change from time to time depending on enforced environmental constraints.

Organochlorine Compounds: Of the persistent pesticides, those that resist bacterial degradation are the chlorinated hydrocarbons, e.g. DDT, Lindane, Aldrin and Dieldrin and these compounds are regarded as long-term contaminants of the total environment.

Benzene hexachloride (BHC)(1,2,3,4,5,6-hexachloro-cyclohexane) is prepared by the chlorination of benzene. However, the γ isomer (Known as Lindane) which is the most active and toxic is only one of a number of stereo-isomers found in the chlorinated product from which it is extracted by methyl alcohol, acetic acid or benzene leaving a waste product consisting mainly of the α isomer which is also toxic and creates a problem of disposal.

Fungicides: Textiles made by a factory in Hammersdale (Natal) are soaked in a solution of the fungicide phenyl mercuric acetate. The spent liquor – of the order of 5 to 6 tonnes per month – has been discharged into the local sewers leading to the Hammersdale Wastewater Purification Works (run by the Department of Water Affairs). It is not without significance that the performance of these works has been of great concern to the Department of Water Affairs. Pretreatment measures at the factory are rigorously applied.

Herbicides: Herbicides in use in South Africa which have given cause for concern due to inadvertent discharge or pond-seepage and run-off from factory premises and sites include paraquat, diquat and the triazine group atrazine, triazine and propazine.

(6) Pretroleum Industry

Difficulties have arisen in the petroleum industry by the inadvertent discharge of a catalyst containing arsenic which was considered to have been discharged as a slug into one of the Republic's important rivers. This accidental discharge indicated the necessity in a factory with a vast array of pipelines and valves for careful colour-coding and vigorous surveillance.

Petrol Storage – Tank Scale: Sludges containing tetra-ethyl of lead present problems of disposal. One petroleum company alone was found to have 60 containers each with 200 ℓ of such sludge stored in an unprotected yard (in Natal). This represents the accumulation of years and is a potential danger to the environment. Treatment with an oxidant (e.g. potassium permanganate) and removal to an approved disposal site would overcome this danger.

Fluoridated Caustic Phenolic Liquors: A similar problem exists in Durban where 500 tonnes per month of this type of spent liquor is produced by an oil refinery.

(7) Fires at Chemical Factories

Fires have taken place in premises on the Reef (Witwatersrand) storing:

(1) pharmaceuticals,
(2) agricultural chemicals, including herbicides, insecticides and fungicides, and,
(3) a variety of inorganic chemicals and paint components.

In the last case (3) the firemen, in extinguishing the conflagration with water from fire-hoses caused contaminated water to pollute the neighbourhood.

The chemicals which contaminated the water included the following:

Hydrofluoric acid, nitric acid, sulphuric acid, magnesium salts, sodium cyanide, polysulphides, phosphates, chromium salts, sodium hydroxide, phenol and phenolic derivatives, nickel, lead and polyurethanes.

A sample of the contaminated water taken at the factory some six(6) hours after the fire gave the following annalysis:

pH Value	4,4
Total dissolved solids	31 340 mg/ℓ
Cyanide (CN)	nil
Chemical Oxygen Demand (COD)	20 916
Phosphate (PO_4)	42 700 mg/ℓ
Chromium (hexavalent)	395 mg Cr/ℓ

The cyanide had been converted to hydrocyanic acid gas.

(8) Use of Trivial and Code Names

The use of trivial names on containers may often camouflage the toxicity of the contents. In Durban, a store containing the fungicides "Maneb" and "Nameb" – (dithiocarbamates) caught fire and about 9 tonnes of the toxic wastes were washed into the Umgeni River as a result of the vigorous efficiency of the Durban fire brigade! Fortunately, the river was in

spate at the time.

(9) Cattle Dips

Originally arsenic compounds were used in cattle dips. The use of arsenical dips has now ceased. However, the presence of old disused cattle dips in the bed of a large site for a proposed dam as well as the surrounding areas gave rise to an investigation which indicated that:

(i) The cattle dips were still potentially dangerous after many years disuse of arsenical dipping mixtures;

(ii) The soluble arsenic trioxide in the dip could be converted to insoluble ferric orthoarsenite and the resulting sludge could be removed for safe disposal elsewhere.

(10) Antibiotic Wastes

A well-known chemical factory in Witbank produces, *inter alia,* antibiotics and flocculants containing methyl methacrylate and calcium cyanamide. In the past the combined wastes from the factory were discharged into unlined evaporation dams and seepage from these caused pollution of the Olifants River. The company has since constructed and put into operation a coal-fired incinerator operating at 600°C with spray injection of the liquid wastes: 2 500 ℓ/h can be handled thereby alleviating the pollution problem.

(11) Disposal of Effluent Containing Nitrate

A well-known explosives and chemicals manufacturing firm disposed of effluent containing nitrate by spraying the effluent on to veld areas at controlled rates. This afforded good pasturage for stock cattle. The purpose of the procedure was to prevent nitrate from gaining access to the Hartebeespoort Dam. More recently the company has embarked on a more ambitious scheme by the construction of pretreatment facilities whereby by the use of algal culture the nutrients (nitrates, etc.) are removed from the effluent and no longer present a menace to the Hartebeespoort Dam from the point of view of eutrophication of this important impoundment.

(12) Molasses Slop

Residue effluent from the fermentation of molasses to produce ethyl alcohol, butyl alcohol and acetone must not be allowed to discharge into a sewerage system. Two fermentation industries using molasses as feedstock/substrate dispose of their industrial effluents by arrangement with the Durban Corporation by deep sea discharge.

On the other hand, a factory in Germiston employs a suitable evaporation technique and produces a well-known cattle feed improver from its effluent and so has overcome its effluent problem. Previously, the molasses slop was disposed of on land by broad irrigation.

(13) Starch Wastes

Steep liquor produced in the manufacture of starch and dextrin from maize constitutes a major effluent problem. At a factory in Germiston steep liquor has been evaporated to produce a cattle feed enrichment product and the remaining effluent mixture, after liming to a pH value of 7,0 is allowed to discharge – at a controlled rate – into the municipal sewerage system.

Note: Reference should be made to Chapter 15 which deals in depth with the control of pollution from effluents from a number of major industries using large quantities of water. The industries dealt with include the following:

Mining; Sugar; Textile; Cellulose fibre (pulp and paper); Iron and Steel; Wine and Brandy; Tanning; Brewing (beer and sorghum beer).

4. Some Principles of Pollution Control

Basic guidelines of pollution control include the following:

(1) Industries should be sited to minimize pollution. For example, an industry which produces an effluent with a high non-toxic salt content could readily discharge this into the sea, whereas it could be faced with an economically insurmountable problem inland.

(2) The principle of "treatment at source" should be applied. It is generally far easier to treat a small highly contaminated stream of effluent than to remove the same amount of contaminant after it has been diluted by other effluents.

(3) Separation of effluents at source should be applied. For example, a factory might have an organic effluent which could be treated in a municipal sewage purification works and a saline stream which could be evaporated in impervious dams.

(4) Highly saline effluents should be re-circulated (e.g. for ash transmission in a power station) or used consumptively (e.g. for ash quenching in a steel mill).

Effluents containing a high concentration of dissolved matter may, in certain cases, be innocuous but where any of the constituents are a threat to the water environment, this effluent should be suitably treated or concentrated and the waste products disposed of either by incineration or by transportation to an approved waste disposal facility.

(5) Difficult organic effluents, where possible, should be treated in admixture with sewage at a sewage purification works.

(6) The principle of the hierarchical use of water should be applied wherever possible i.e. high

quality water which has been used for one process should be passed on for re-use to another requiring water of lesser quality and so on.

(7) In some cases it may be found that the undesirable waste of one company may be used as feedstock or ingredient for another company's operation; or for neutralizing, or otherwise reacting with another effluent from a nearby industry – thereby mutually eliminating a pollution problem.

(8) In many cases the use of a continuous process is preferable to a batch process since the pollutional load is spread over a period of 24 hours daily, whilst with a batch process, virtual slugs of waste are discharged over short periods thereby constituting shock amounts discharged into the sewers and resulting in dificulties at the sewage purification works.

Therefore, all discharges from industries should, at all times, be at controlled rates.

(9) Domestic sewage should be treated so that it poses no threat to health – this sometimes proves difficult if industrial effluents have to be handled as well. In this connexion industrialists should familiarize themselves with the industrial effluent by-laws of the local authority within whose jurisdiction they wish to establish or operate. These by-laws invariably list the limits of certain constituents in effluents for discharge into sewers.

Industrialists discharging effluent into rivers should ensure that their effluents conform with the quality requirements set out in Government Notice R.991 of May 18, 1984 and subsequent Notices.

(10) Apart from difficulties arising from the discharge of industrial wastes into the sewers of local authorities other disposal difficulties have to be faced, viz:

Metal sludges from electroplating industries; pickling sludges; oil sludges; sludges from tar distillation; paint sludges; and a variety of sludges from the chemical industry.

There is little doubt that industry should be given some assistance with this problem by municipalities, regional authorities or certified agencies providing the necessary solid and liquid waste disposal facilities to treat intractable and toxic wastes of all kinds.

(11) Industries with a waste problem should not seek to establish themselves in an area administered by a small local authority with a small sewage purification works. It is preferable to set up in an area administered by a large local authority.

(12) Good rapport between all industrialists and the authorities – municipal, provincial and central government – is necessary, at all times, to assure an awareness of all concerned to the likely effects of new industrial developments which may present pollution problems.

REFERENCE

1. O'Shaughnessy, F.R. Private communication.

Chapter 9 WATER RIGHTS

Irrigation in Ancient Times

The relationship of living beings with water has, at all times, been a close one as water is necessary for existence.

However, man's change from a nomadic existence involving hunting and gathering of food to one of food growing and the domestication of certain animals brought a new dimension into his more settled form of existence. This was the importance of rivers to supply water for irrigation of crops and to operate mills for the recovery and processing of grain from the products of his agriculture.

Thus a number of important ancient river valley civilizations came into being e.g. In Egypt – the Nile Valley; in Mesopotamia – the Tigris-Euphrates Valley; in India – the Indus Valley; in China – the Yellow River Valley; and in Peru – the Andean River Valleys of the coastal area.

The systems of irrigation of these ancient river valley civilizations are not known but would vary according to the river regimes, crops grown and the nature of the climate.

Smith[1] has drawn attention to four methods of ancient irrigation, viz. – the Egyptians of the Nile Valley practised basin irrigation adapted to the annual flooding of the Nile but in other settlements, notably Mesopotamia, in the course of time dams were constructed and canals developed to control the river flow to attain perennial irrigation in the Tigris-Euphrates plane. Perennial irrigation has the advantage that the number of crops grown annually can be increased.

Apart from these two methods of irrigation, viz. "basin" and "perennial" using dams and canals, the two others which have been used were "terrace" irrigation and "wadi" irrigation.

The former has been practised, for example, in Syria, Palestine, India, China and "pre-Columbian" America. The terrace method found application in hilly terrain where water is caused to flow down a hillside by means of a series of terraces and channels.

The wadi system of irrigation was practised in the Negev and Yemen. This involved building an earthen dam some 2 000 ft. (c. 609 m) long and 14 m high. The purpose of the massive wall was not to impound water but merely to serve as a means of raising the floodwaters in order to irrigate more land in the Wadi Dhana. This is one of the biggest ancient dams and is situated about 3 miles (c. 4,8 km) above Marib. It was built in the 8th century BC and represents successful wadi irrigation using a single dam.[1]

It will be appreciated that the functioning of these irrigation systems of the ancient world must, inevitably, have called for firm administrative control. It has been stated that these irrigation cities gave rise to the first standing armies stemming from the necessity to protect the defenceless farmer and his land.

Hammurabi, 6th King of the Amoritic dynasty of Babylonia (2067 – 2025 BC) and a famous figure of ancient history was associated with the great law code promulgated for use in the courts of his empire.

It is not surprising that there was a code dealing with the use and misuse of water.

Hammurabi's code was as follows:

"If a man neglect to strengthen his dyke and do not strengthen it, and a break be made in his dyke and the water carry away the farm-land, the man in whose dyke the break has been made shall restore the grain which he has damaged.

If he is not able to restore the grain, they shall sell him and his goods and the farmers whose grain the water has carried away shall share (the results of the sale).

If a man open his canal for irrigation and neglect it and the water carry away an adjacent field, he shall measure out grain on the basis of the adjacent fields.

If a man open up the water and the water carry away the improvements of an adjacent field he shall measure out ten GUR of grain per GAN."

The Genesis and Evolution of Water Rights

The concept of water rights has been handed down by the Romans dating back to the time of Justinian who became Emperor of the Roman Empire in 527 A.D. and, in due course, consolidated Roman law.

Roman law was adapted by the Dutch in Holland to suit their thinking and ideas of administration and justice. Hall and Burger[2] have indicated that "In the seventeenth century Groenewegen, in De Legibus

Abrogatis ad Just. 2.1.23, stated that all streams were State property and this doctrine persisted throughout the eighteenth century . . ."

Yet again Vos[3] states, "The Roman law seems to have been adopted in the Netherlands" and remarks that Voet enunciated three basic propositions which he summarized thus,

(1) An owner may do as he pleases with water rising on his own land unless there are prescriptive rights to the contrary;
(2) If the water of a public stream is not in public use (as when the stream is not navigable) the water may be diverted;
(3) The same applies to *Heeren-Wateringen* and *Ban Wateringen.*

Further, he defines a public stream as one that flows perennially, and that it belongs to the people.

Vos points out that although Hall and Burger[2] have concluded that in the early days of South African settlement the State was *dominus fluminis,* de Wet is less definite on this point.

Be this as it may, the fact that the early settlement of the Cape of Good Hope from 1652 onwards was due to the Dutch, their legal precepts must, naturally, have followed the general framework of Roman Dutch Law.

Historical

On August 30, 1650, the Hollandsche Oos-Indiese Kompanjie (otherwise referred to as the Dutch East India Company) decided to establish a victualling station at the Cape and "so, after a passage of one hundred and four days from Texel, on the morning of Sunday the 7th of April 1652 Mr van Riebeeck and his party looked on the site of their future home[4] . . ."

Note:

(1) According to Eric A Walker in his *"A History of Southern Africa"*, Longmans, 1962, p. 31, three ships, Goode Hoop, Drommedaris and Reiger dropped anchor in Table Bay on April 6, 1652, after a run of four months from Texel.
(2) In *"Five Hundred Years – A History of South Africa"* edited by C F J Muller, Academia, Pretoria, Cape Town and Johannesburg, 1981, p. 20, A J Böeseken, former Editor-in-Chief, Archives Publications states, "He (Van Riebeeck) had a small fleet of five ships under his command. Two were too heavily laden and were not able to leave at the same time as the others, but the Drommedaris, Reiger and Goode Hoop sailed from Texel on the 24th December 1651. The Drommedaris and the Goode Hoop reached the Cape on the 6th April 1652, the Reiger arrived the next day, and the Walvis and the Oliphant finally reached their destination on the 7th May."

As soon as Van Riebeeck's party were in a condition to defend themselves, they were to take possession of sufficient rich and fertile ground for gardens, and also of suitable pasture land for cattle . . .

The Dutch foothold was to be simply a refreshment station for provisioning the passing ships of the Dutch East India Company. The Company had no thought of settlement and its officers looked forward only to the day when they would be promoted to more lucrative posts in the Indies.

Van Riebeeck's gardener, Hendrik Boom, planted seeds after the first rains. Later on, in May 1656 permission was given to all the men who had families with them to cultivate as much land as they were able to cope with, free of tax and rent for the first three years. Hendrik Boom assisted and he together with nine others became the first European farmers (free burghers). They were established in the Liesbeeck Valley on small farms of 13½ morgen[5] (i.e. 11,4 hectares/28,6 acres).

After a stay of 10 years at the Cape, Van Riebeeck "sailed east to make his fortune".

Seventeen troubled years followed at the Cape until the arrival of Simon van der Stel in 1679. Thereafter, colonization was encouraged and settlers were given farms in the fruitful Eerste River Valley at Stellenbosch subject to certain conditions including approval of crops grown and the right of the Company to receive a tithe of their grain crops.

According to Linscott[6] irrigation was first practised in 1699. Governor Willem Adriaan van der Stel, eldest son of Simon van der Stel, had obtained a farm (near Somerset West) which he named Vergelegen and on this farm he constructed a dam, planted 400 000 grape vines and sowed a quantity of wheat.

Water Law

In order to understand the Water Law of South Africa as codified in the Water Act 54 of 1956 as amended to date by the Act of 1984, it is necessary to have an insight into the historical development of the Republic.

Thompson[7], in a paper compiled for presentation to the United Nations Water Conference held at Mar del Plata, Argentina in March 1977 and, also[8] in a paper compiled for the Republic's "Water Year", 1970, gives accounts of water law in South Africa.

He states that during the Dutch regime the utilization of water from rivers was governed by the legal concepts applicable in the Netherlands at the time – namely the rule of *dominus fluminis* which means that no water may be abstracted from a running stream without the consent of the Government.

We have seen how, in the early settlement days at the Cape, that the Governor appointed by the Chamber of the Dutch East India Company in Holland had somewhat peremptory local powers subject only to the oligarchical authority of the Chamber in Amsterdam. Hence the rule of *dominus fluminis*

would naturally apply since such a rule would be to the advantage of the Company.

Towards the end of the eighteenth century the Dutch East India Company went into decline and the Cape was occupied by the British from September 1795 to February 1803. Then followed rule by the Batavian Republic from February 1803 to January 1806. Then followed the Second British Occupation and the evolution of the Cape Colony.

The "Great Trek" of 1836 resulted in the formation of independent republics beyond the Orange River. These were later conquered by the British.

The end of hostilities in 1910 saw the formation of the Union of South Africa from the two separate colonies of the Cape and Natal and the former Republics of the Orange Free State and the Transvaal. Later by referendum of voters, on October 5, 1960, 52 per cent of the electorate voted in favour of the formation of a Republic and 48 per cent against.

A majority mandate having been obtained, the Republic of South Africa became a reality on May 31, 1961.

Riparian Rights

The English attitude towards water rights is one of riparianism i.e. that a landowner contiguous to a stream is entitled to the use of water naturally reaching his property, provided he allows water not required by him to pass unpolluted for the use of the riparian owner downstream.

In this connexion Wisdom[9] has quoted a statement by Lord Wensleydale in the case of Chasemere vs Richards (1859) in England wherein he ruled "that the right to the enjoyment of a natural stream of water on the surface *ex jure naturae* belongs to the proprietor of the adjoining lands as a natural incident to the right to the soil itself; and that he is entitled to the benefit of it, as he is to all other advantages belonging to the land of which he is the owner".

Again (in England) in dealing with the rights and duties of riparian owners Wisdom[10] supplies the oft quoted statement of Lord Denman in the case of Mason vs Hill (1853), viz. –

"The possessor of land through which a natural stream runs, has a right to the advantage of that stream flowing in its natural course, and to use it when he pleases for any purpose of his own not inconsistent with similar rights in the proprietors of the land above and below. A proprietor above cannot diminish the quantity or injure the quality of water which would otherwise descend, nor can a proprietor below throw back the water without his licence or consent".

In 1813 a proclamation at the Cape by Sir John Cradock during the second British Occupation introduced a new system of land tenure namely that such natural rights as appertain to land belong to the owner of such land.

Hall and Burger[2] state that "at the Cape the old principle of the State as *dominus fluminus* struggled for survival". The lawyers appointed to the bench were mainly Enlish-trained and they regarded the rule of *dominus fluminus* as incomprehensible and it was only when certain matters of dispute were the subject of learned judicial definition that the water law of the country could eventually be formulated to a degree of reasonableness.

During the period 1856 to 1880 a number of significant judicial pronouncements on cases dealing with water rights were decided in the court of the Cape Colony.

According to Vos[11], in 1856 a momentous decision on the water law of South Africa was given in the case of Retief vs Louw in which Judge Bell propounded the principle that the use of *aqua profluens** was common to riparian owners even though the stream was not large enough to be a *flumen.** He also held that the water could be used for human and animal life, secondary use for irrigation and tertiary use for mechanical purposes.

In 1876 Lord de Villiers, Chief Justice of the Cape, laid down the following important rules which have formed the foundation of South African water law, viz. –

(a) The use of the water of a public stream had to be divided into primary and secondary uses.
(b) Primary use was for the support of human and animal life; secondary use was for other purposes.
(c) The upper owner was entitled to the use of all the water for primary purposes, but was not allowed to use it for secondary purposes if he deprived lower owners of primary use.
(d) The upper owner was entitled to use only a reasonable share of the water for irrigation and had to allow the lower owners' reasonable share for irrigation to flow down.

In 1880 in the case of van Heerden (appellant) vs Wiese (respondent) in the Appeal Court of the Cape Colony, the important issue arose as to whether the Ongers River in the Division of Victoria West was a public or a private stream. In a momentous and far-reaching decision Chief Justice Lord de Villiers held, that:

Our law recognizes two classes of natural streams or water courses, viz. public and private.

Under the designation of public streams are included all perennial waters, navigable or not, and all streams which, although not large enough to be considered as rivers, are yet perennial, and are capable of

*In Roman law *aqua profluens* was divided into private and public streams. *Aqua profluens* flowing in a public stream was *res communis* in the sense that it belonged to the State which could grant certain rights therein. A stream was public if it was both perennial and a *flumen* i.e. of fair size and not a *rivus* (small). It was regarded as perennial if it normally flowed throughout the year. If it was not perennial, it was a *torrens*.

being applied to the common use of riparian proprietors.

A river may sometimes become dry in the heat of summer without forfeiting its character as perennial, and therefore, public river.

The general rule that a person may deal as he chooses with water rising on his own land, is subject to the limitation that the water thus rising is not the source of a public stream; and also that no rights have been acquired to the water by prescription.

During the period 1877 to 1899 three acts were passed dealing with irrigation but these acts were silent on the matter of water rights. These acts were Act 8 of 1877; Act 26 of 1882 and Act 40 of 1899 subsequently repealed by Act 32 of 1906. These Acts were enacted by the Governor of the Cape of Good Hope, with the advice and consent of the Legislative Council and the House of Assembly.

In Act 32 of 1906 of the Cape of Good Hope an attempt was made to consolidate existing case law and the matter of water rights given cognizance.

In the Transvaal, the law was as laid down by the Supreme Court in the Cape. However, in 1908 by Transvaal Act 27, an effort was made to consolidate the law. In the Transvaal two kinds of streams were recognized, viz. – public streams which could be regarded as analogous to the perennial streams enunciated by Cape law and private streams which categorized all other rivers and streams.

The Orange Free State and Natal followed what had been laid down in the Supreme Court in the Cape, there being two kinds of streams – public streams, which included all perennial rivers or streams, whether navigable or not, and all streams which, though not large enough to be considered rivers were yet perennial and were capable of being applied to the common use of proprietors; private streams were all other streams.

In Natal, under the Governorship of Walter Healy-Hutchinson, Act 10 of 1899 was enacted to empower the Governor "To acquire land for open Railways, and to take and lead water required for Railway purposes."

Earlier enactments in Natal were Law 26 of 1887, "To enable Individuals and Companies to lead water for purposes of Irrigation through lands not their own". And, Law 26 of 1891, "To promote irrigation". One of the provisions of this Act, was that where water is required to be taken out of a river or stream such works shall be so constructed as to provide, as far as circumstances will permit, for the return of all water not necessarily consumed in irrigation to the river or stream from which it was taken.

Provision was also made to protect any person from being deprived of any water or right of water. The above two Laws, 26 of 1887 and 26 of 1891, were repealed after the Act of Union by South Africa Act 8 of 1912 – the so-called "Irrigation and Conservation of Waters Act, Act 8 of 1912". This was amended in 1932 and regulations under this Act were published in 1940 and further regulations appeared on 25 May 1945.

In England, English law[12] has been formulated and codified by Water Acts, 1973 to 1977 on English experience of English rivers which are slow-flowing but ever-running – unlike South African rivers which can be raging torrents during "cloud-bursts" or completely dried up in the dry season.

To try and apply a law based on English rivers to the South African situation does not seem appropriate.

In the United States the same sort of problem has arisen.

Water Rights in the USA

Towards the end of the 1870's a conflict arose in the United States between two interpretations of water rights, viz. – the common law doctrine of "riparian rights" adhered to in the Eastern States and the Western States' advocates of "appropriation rights".

The appropriation doctrine declares that water belongs to the public, but a right to use it may be obtained by individuals or agencies provided they comply with certain procedures and principles. The doctrine as applied to natural water courses means the exclusive right to the first appropriation. Since the (US) national policy was to obtain the largest practical use from public land, and the riparian doctrine of the East, with emphasis on benefits only to lands contiguous to the streams was not well adapted to the West, the system of prior appropriations emerged in Utah, California and New Mexico.[13]

In Utah the doctrine of prior appropriation had been the law in practice from 1847 when the Mormons arrived in Salt Lake Valley and diverted the water from the stream channel to irrigate the dry alluvial plains several miles away.

Brigham Young, the leader of the Mormons, made it known early on that streams belonged to the people. The code of ethics was: "Those first in time are first in right but beneficial use is the limit and measure of the right".[14] Beneficial use means that the appropriator use only the amount of water needed and the remaining supply be left for someone else to appropriate.[15]

The appropriation doctrine is in vogue in seven inter-mountain states, viz. – Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming. In the eight bordering (encircling) states there is a combination of appropriation and riparian rights known as the "California doctrine" and, of course, in the states to the East, representing the majority number, the doctrine of riparian rights holds sway.

Although the appropriation doctrine has served and protected irrigation developments in the West it has been pointed out that it has certain shortcomings in the context of modern problems.[16]

The Development of Irrigation Law in South Africa

Krummeck[17] has condensed irrigation law according to the following subdivisions:

(1) Legislation designed to encourage the building of irrigation works, primarily for the conservation of such water as cannot be led directly to land.
(2) Legislation for the controlling of such schemes.
(3) Legislation to deal with water rights and the exercise of such rights for the irrigation of land.

He observed the following order of preference in regard to the use of water viz. –

(i) For drinking purposes;
(ii) For railway purposes;
(iii) For irrigation;
(iv) For irrigation canals;
(v) For industries.

He deals with early legislation from 1856 to 1912 and considers such matters as "perennial" and "intermittent" streams; "public" and "private" streams; "normal" and "surplus" water. His statements were, of course, based on Act 8 of 1912.

The Irrigation and Conservation of Waters Act 8 of 1912 attempted an equitable consolidation of rights and approved practices in relation to water usage and irrigation. Riparian rights were entrenched and provision was made for the establishment of a State Department of Irrigation headed by a Cabinet Minister – at that time the Minister of Lands who was empowered to authorize the construction of Government water works and to exercise his rights in the distribution of water from such water works as he deemed fit.

The Act aslo provided for the establishment of a Water Court to deal with the apportionment of water and disputes arising therefrom. This court also had jurisdiction in the apportionment of water from a public stream for use by non-riparian users where it was considered that this was in the public interest or if it was of opinion that water was available, surplus to the requirements of riparian users of water in a particular stream.

We see, therefore, that at this stage inroads were made into the traditional water rights of owners of riparian land and the Minister and the Water Court judges were given powers to apportion water to other users who were owners of non-riparian land.

The Water Act

Act 8 of 1912, as its name implies, was concerned with irrigation. But, with the development of industries requiring water, it was necessary to provide new legislation to cover the use of water by industrialists and also to provide for quality standards of effluents discharged into rivers.

Act 8 of 1912 was accordingly repealed by Act 54 of 1956 – The "Water Act". The present Water Act continues as the substantive legal framework – emblazoned and emended from time to time, as circumstances dictate – to ensure equitable distribution and use of the Republic's limited water supplies and the safeguarding of the quality of such supplies.

Use of Water for Industrial Purposes

Dr F E Kanthack,[18] in his presidential address to the Associated Scientific and Technical Societies, stated *inter alia,* "There has, in the past been far too much concentration on the problem of the use of available waters of the Union exclusively for the irrigation of land. Whilst the irrigation of land under various kinds of crops is undoubtedly of the greatest importance to South Africa, the whole question of the conservation and use of water must be viewed from a much wider angle. What really matters is the conservation and use of the greatest possible volume of surface water in such a manner as shall be in the best interests of the country as a whole. These interests are by no means confined to irrigation, whether in settlements, large or small, or to farm irrigation generally . . ."

. . . "Apart from the domestic requirements referred to, provision must be made for industrial requirements, which are becoming more and more essential to the country's welfare."

. . . "Although previously alluded to in this address, I must repeat that what is really required is a complete breakaway from the principles of what is known as the 'Riparian Principle', namely the exclusive right of an owner to the reasonable use of the water of the public stream to which he is riparian."

However, in giving support to the use of water for industrial purposes Kanthack has stressed . . . "that in all cases where water is used in any industrial process, full provision must be made to ensure that any effluent therefrom must be rendered completely innocuous before it is allowed to reach a public stream. Having been concerned with many problems of this kind, I am fully aware of the difficulties and expense involved in these matters".

Wellington[19], in dealing with South African Water Law, states "Kanthack has rendered a valuable service to the country by his analysis of the legal restrictions to water use and the urgency of the emendation of the water laws (Act 8 of 1912). Industrial development is very seriously retarded by the fact that the 'riparian principle', derived mainly from English common law, is entirely unsuited to the needs of an expanding economy in a country such as South Africa. Under Roman Dutch law as well as English common law the owner of riparian land has the right to use the stream-flow past his land in perpetuity for 'reasonable domestic purposes' i.e. primary purposes. For secondary purposes, such as irrigation, no conditions were originally laid down, since irrigation was not needed in Western Europe where the need was rather to get rid of excess water".

Before dealing with the provisions of the Water

Act (Act 54 of 1956) the explanation of certain terms and what they connote in the context of the Act is necessary. These include such terms as '"public water", "private water", "normal flow", "surplus water", etc.

Public Water

This constitutes water which flows in a known and defined channel and is capable of common use for irrigation on more than one original riparian property. Therefore, a stream containing public water must have a defined channel, traverse more than one original riparian property and the mean annual run-off must be sufficient for the beneficial irrigation of crops on all such properties. Furthermore, on each property sufficient, suitable soil must be available for the cultivation of crops within reasonable reach of the stream. Beneficial cultivation, of course, presupposes that a ready market is available for such crops.

From the above, it will be clear that disputes can arise and to take care of such situations disputes are referred to the Water Court which is empowered with certain functions such as the allocation of water and the declaration of the private or public nature of a water source.

Private Water

This is water which rises or falls on any land of one proprietor/owner and is not capable of use on other properties. This normally included water from a borehole or well unless the borehole or well is an artesian source from which the water flows freely into a defined channel and is sufficient to enable beneficial irrigation of other properties. In certain cases, depending on the topography, meteoric water falling on a property, and subsequently stored, can be considered private.

Normal Flow

This is limited to the maximum quantity of water available in a stream for beneficial irrigation during peak demand, but without storage, and this constitutes the flow usually during the four months immediately preceeding the rainy season.

Normal flow, in fact, relates solely to the visible flow in the stream and excludes water available in the sandy bed of a stream, not flowing visibly even though such water may be capable of beneficial use for irrigation.

It follows naturally, that any stream is devoid of a normal flow unless its water is derived from springs, seepage, melting snow, swamp drainage or other sustaining sources.

Surplus Water

This is the water found in a public stream, whether flowing visibly or not, other than normal flow. The majority of rivers and streams in the drier parts of the country normally contain surplus water only.

Water Rights

The abstraction and use of water is regulated in terms of the Water Act.

The Act provides for two types of user, viz. –

(1) Users in a Government water control area;
(2) Users in an unproclaimed area.

In case (2) above, only riparian owners are entitled to use (without further authority) the water of a public stream to which their properties are riparian for agricultural and domestic purposes including the watering of animals but excludes industrial use.

Rights to the Use of Surplus Water

Riparian owners are entitled to the use of surplus water reaching their properties which they can use beneficially (i.e. without wastage) for the purposes indicated previously and they can use such water without regard to the needs of downstream owners. The reason for this is based on practicality, since in practice the quantity of water available annually, on average, from the normal flow of a stream can be determined with reasonable accuracy and can be apportioned to the riparian owners. However, the quantity of surplus water available from year to year cannot be apportioned in advance due to the unpredictable nature of such flow.

Surplus water requires to be stored to be of any practical value. Due to the fact that impounding of the water by a riparian landowner would require the construction of a large and costly storage dam to impound an appreciable portion of the total quantity of surplus water available annually from a large river. The construction of a large storage works is normally undertaken by the government or an irrigation board (a statutory body with supervisory functions) and the needs of each irrigator can then be met on an equitable basis and also times of use to suit his requirements.

Rights to the Use of Normal Flow

In the case of normal flow, however, each owner riparian to a public stream is entitled to abstract his rightful share from such stream and to use such water for the purpose indicated previously.

What constitutes the rightful share of the normal flow of a public stream is decided by a Water Court whose function it is to decide on such matters bearing in mind the total quantity of water available and the needs of other riparian users.

In this connextion the Water Court takes into consideration the areas of land available to each riparian owner which may be beneficially irrigated and, also,

any other water resources available to particular users to arrive at a fair apportionment.

The normal flow of a public stream having been apportioned, a riparian owner is entitled to the use of his rightful share thereof, subject to the following conditions:

(a) An owner may not use water wastefully and any water not used by him must be let down the stream in an unpolluted state.

Irrigation of the veld or leading water into brak pans, hollows or swamps from which no benefit will be derived is regarded as wasteful and non-beneficial use of water.

(b) Water may not be used for irrigation if a lower riparian owner is thereby deprived of the use of water for domestic purposes and for the watering of his stock, provided that such lower owner first satisfies his needs for domestic and stock watering purposes from water available to him for irrigation.

(c) While an owner of land riparian to a public stream is, for the purposes of apportioning the normal flow, entitled also, to the use of water flowing in any tributary of such stream, even though his property may not abut on such tributary, the needs of the owners whose properties are riparian to the tributary must first be satisfied fully from the normal flow of the tributary before such owner riparian to the stream can claim a share therein.

If the normal flow of any public stream has not been apportioned by the Water Court, each riparian owner may use what he considers to be his rightful share thereof, but he shall be at risk of curtailing such use when the normal flow is duly apportioned by such Court.

Rights to Use of Private Water

Private water is regarded as private property and as such is for the sole and exclusive use of the owner of the land on which it exists. Notwithstanding, he may not transfer it across his boundary without the permission of the Minister.

The reason for this is that it may be an important co-source of a public stream and as such it could prove to the detriment of owners riparian to the public stream if water is diverted from the private source in large quantities for irrigation on land non-riparian to the public stream.

Government Water Control Area

By declaring particular drainage areas to be Government water control areas the Water Act has shown a return to the doctrine of *dominus fluminis*.

It will have been noted that the Water Court is the traditional authority empowered to apportion public water and to authorize the use of public water on non-riparian land. In a Government water control area, however, this authority rests with the Minister and such water need not necessarily be supplied by a Government water work.

Furthermore, the Minister is not bound by the restrictions applicable to the Water Court. For instance, he is not required to apportion water in proportion to the area of irrigable land available on each property, but has the unfettered right to act in the best interests of the public. However, he is not allowed to act arbitrarily. This being so, he does not have to apportion all available water to riparian owners but may reserve such water as he may deem fit for other public purposes and apportion only what is left to the riparian owners.

Naturally, he is bound to grant to certain users the quantities of water which have been used legally and beneficially, in his opinion, by them at the date of proclamation of the water control area.

A water control area may include non-riparian land. The granting of the aforesaid powers of the Minister is within the discretion of the State President.

Further Powers of the Minister

The transfer of the powers of the Water Court to the Minister marked the beginning of a gradual process which has been pursued in subsequent amendments to the Act of 1956. In section 9A, promulgated in 1967, for instance, it is laid down that, notwithstanding any provisions to the contrary in the Act or in any other law and notwithstanding any right any person may have in respect of public water or, the use thereof, the Minister may, whenever in his opinion a water shortage exists or is likely to arise in any area and, therefore, also in an uncontrolled area, regulate, limit or prohibit the use of public water in such area. Thus he may prohibit or curtail the use of water for agricultural purposes so that any water there may be available, will be used for domestic purposes.

Again in section 9B promulgated in 1975, it is laid down that, notwithstanding any provisions to the contrary in the Act or in any other law, no person may construct a water work for the impoundment or diversion of public water in excess of certain limits except under the authority of a permit issued by the Minister.

Further, no person, whether or not he owns riparian property and whether or not he is entitled to the use of public water for agricultural or urban purposes, may use such water for industrial purposes without the permission of the Water Court, but the Water Court may not grant such permission if the quantity of water to be used annually exceeds certain limits, unless the Minister has issued a permit for such use. Neither can the Water Court grant permission for the use of water for urban purposes if the quantity of water to be used annually exceeds certain limits, unless the Minister has authorized such use.

From the above, it is clear that the Minister is in a position to exercise overall control in cases where large quantities of public water are used and in such instances the jurisdiction of the Water Court is subject to the authority of the Minister. After all this is only right inasmuch as the Minister and *NOT* the Water Court is responsible for advanced planning and management of the Republic's water supplies.

The Water Court arrives at its decision strictly on judicial grounds based on the evidence submitted to the court. If, therefore, a case is not presented correctly or fully, the decision of the court might not be in the best public interest.

On the other hand, the Minister is in position to have any matter thoroughly investigated by the competent and experienced staff of the techincal divisions of his Departement – he is not restricted by judicial considerations alone and so can formulate his decisions also on policy considerations.

Reuse of Purified Wastewater

The 1956 Act regards the purification of wastewater or effluent resulting from the use of water for industrial purposes as an integral part of the process of using the water and requires the user to purify the said wastewater or effluent to a standard prescribed by the Minister in consultation with the South African Bureau of Standards and to return the effluent so purified to the public stream from which the water was originally abstracted, so that it may be available for further use. Different standards of quality may be prescribed for different industrial effluents, or for effluent to be returned to specified streams or for water used in specified areas. An industry supplied with water by a local authority in its area of jurisdiction is required to conform with the industrial effluent acceptance by-laws of the local authority and the responsibility for controlling the quality of the effluent from the municipal sewage purification works which treats the industrial effluent in admixture with sewage devolves on the local authority.

Where it is not practically possible to purify any effluent to conform with the prescribed standards, the industry or local authority concerned may apply to the Minister for exemption from compliance with the requirements of the Act and the Minister may grant such exemption to the extent that he deems fit, either in the standard of purification or in respect of the disposal of the effluent. If, for instance, it is undesirable to return a partly purified effluent to a public stream and further purification is impracticable, the Minister may authorize the disposal thereof by irrigation or evaporation (which, of course, is wasteful of water – but unavoidable). In making decisions of this nature the Minister consults other authorities with due regard to the practical, economic and other relevant considerations.

Finally, it must be stated that it is an offence for anyone, not only an industry or a local authority, to pollute any public or private water in such a way as to render it less fit for the purposes for which it could ordinarily be used, or for the propogation of fish or other aquatic life, or for recreational or other legitimate purposes.

REFERENCES

1. Smith, N. "Man and Water", Peter Davies, London, 1976, pp. 1-6.
2. Hall, C.G. and Burger, A.P. "Hall on Water Right in South Africa", 4th Edition, Juta and Co., Ltd., Cape Town, Wynberg, Johannesburg and Durban, 1974, p. 1.
3. Vos, W.J. "Prnciples of South African Water Law", 2nd Edition, Juta and Co., Ltd., Cape Town, Wetton and Johannesburg, 1978, pp. 1-2.
4. Theal, G.M. "History of South Africa", George Allen and Unwin, Ltd., London; C Struick, Cape Town, Vol. III, p. 10.
5. Walker, E.A. "A History of Southern Africa", Longmans, Green and Co., Ltd., London, 3rd Edition, New Impression, 1962.
6. Linscott, C.O. "A Short History of Irrigation in South Africa", S. Afr. Irrigation Magazine, 1924, **3**(2), 51.
7. Thompson, J.D.M. "United Nations Water Conference: The Water Law in South Africa and its Application for the Optimum Utilization of Water Resources". Mar del Plata, Argentina, March 1977.
8. Thompson, J.D.M. "Waterregte in Suid-Afrika", Water Year, Department of Water Affairs, Pretoria, 1970.
9. Wisdom, A.S. "The Law of Rivers and Watercourses", Shaw and Sons Ltd., London, 1979, p. 38.
10. Wisdom, A.S. Loc. cit., p. 87.
11. Vos, W.J. Loc cit., p. 3.
12. Wisdom, A.S. Loc. cit., p. 151.
13. Guy-Harold, Smith. Editor, "Conservation of Natural Resources", 4th Edition, John Wiley and Sons Inc., New York, London, Sydney and Toronto, 1971, Chapter II, "Irrigation in the United States", Bowman Hawkes H, University of Utah, pp. 257-265.
14. Guy-Harold, Smith. Ibid.
15. Guy-Harold, Smith. Ibid.
16. Fassett, G.W. "Colorado Water Rights – An Engineer's Case Studies", Amer., Water Wks. Assoc., July 1932, pp. 324-331 and also Editorial, loc. cit., p. 323.
17. Krummeck, D.T. S. Afr. Irrigation Magazine, 1924, **3**(3), 128.
18. Kanthack, F.E. "Industrial Development in the Union of South Africa in Relation to Water Courses", Ann. Proc. Sci. Tech. Soc. S. Africa, 1946/47.
19. Wellington, J.H. "Southern Africa – A Geographical Study", Economic and Human Geography, Cambridge Univ. Press, Vol. II, 1960.

Chapter 10 PROVINCIAL AND LOCAL AUTHORITIES: RESPONSIBILITIES AND AUTHORITY

"For forms of government let fools contest:
Whate'er is best administered is best:"
Alexander Pope (1688 – 1744)
"Essay on Man"

"All government, indeed every human benefit and enjoyment, every virtue, and every prudent act, is founded on compromise and barter".
Edmund Burke (1729 – 1797)

Provincial Authorities

As originally constituted the provincial authorities were formed as subordinate regional authorities of a unitary state (now the Republic of South Africa). However, their legislative authority is confined to such matters as education (other than higher education); health, hospitals and charitable institutions; local government and administration; roads and public works; parks; fauna and flora preservation; recreation; libraries; art galleries and cultural amenities in general; the licensing and control of trade, and "generally all matters which, in the opinion of the State President are of a merely local or private nature in the province; and all other subjects in respect of which Parliament may by law delegate the power of making ordinances to the provincial council".*

The powers of provincial councils are delineated in a number of acts.†

The provincial councils may enact ordinances provided any such ordinances do not conflict with an act of parliament. Broadly speaking the structure of provincial councils and their *modus operandi* follow that of parliament.

The Chief Executive Officer for each of the Republic's four provinces is the Administrator who is appointed by the State President (acting on the advice of the cabinet). All executive functions of each provincial authority are vested in the administrator of such province.

The functions of provincial authorities that are the concern of the Department of Water Affairs include the use of water and the installation of sewage purification and disposal facilities in situations and circumstances requiring the direct involvement of provincial authorities (e.g. facilities for resorts, schools, hospitals, institutions, etc.)

Finance: Normal and recurrent expenditure of a provincial authority is covered by funding, as follows:

(1) Money voted by parliament;
(2) Money provided by the National Transport Commission in terms of the National Road Act, 1935 (Act No. 42 of 1935);
(3) Taxes and charges accruing in terms of the Financial Relations Consolidation and Amendment Act, 1945.

In terms of Section 6 of the Financial Relations Consolidation and Amendment Act, 1945, some 50 per cent of the net annual expenditure of each province is covered by transfer from the parliamentary consolidated revenue fund.

Loans for capital or non-recurrent expenditure incurred by provincial authorities may be provided for by parliament for the erection, construction, acquisition, extension or improvement of any work of a permanent nature.

Control of Local Authorities: The provincial authorities regulate the activities of local authorities by ordinances : local government ordinances being in force for the four provinces, viz. –

Cape: Cape Provincial Ordinance No. 20, 1974.
Ordinance to consolidate and amend the law relating to municipalitites, village management boards and local boards (Promulgated on 29 November 1974).
Cape Provincial Ordinance No. 18, 1976.
Ordinance to consolidate and amend the law relating to divisional councils (Promulgated on January 1, 1977).

Natal: Local Authorities Ordinance, 1974 (No. 25 of 1974).

*Section 84(1) (l) and (m), Constitution Act, 1961.
†South Africa Act, 1909; Constitution Act, 1961; Financial Relations Consolidation and Amendment Act, 1945 (Act No. 38 of 1945); Financial Relations Amendment Act, 1957; (Act No. 38 of 1957); plus a number of special fields of activity and interest within the ambit of their respective functions.

Assented to by the State President-in-Council on 23rd May, 1975. (Derived from former Local Government Ordinance, 1942).

Orange Free State: Ordinance No. 8 of 1962
To consolidate and amend the laws relating to municipal councils and village management boards. (Promulgated on 17th May, 1962).

Transvaal: Local Government Ordinance, 1939 (being Ordinance 17 of 1939) – referred to as the principal Ordinance – later, amended by Ordinance, 1981.

All these ordinances provide for such matters as sanitation, sewerage and drainage works.

Protection of Divisional and Municipal Services Works: In the Cape identical provisions are made for the protection of municipal and divisional services works respectively in terms of Section 141 of Ordinance No. 20 of 1974 (Municipal) and Section 142 of Ordinance No. 18 of 1976 (Divisional Councils).

The following are the provisions for divisional councils as promulgated in Section 142 of Ordinance No. 18 of 1976. For municipal councils the provisions are the same – merely substituting "municipal" for "divisional".

"142. (1) No person shall, except with the consent of the council and subject to such conditions as it may impose –

(a) construct, erect or lay any building, structure or other thing over or in such a position or in such a manner as to interfere with or endanger any divisional service works;
(b) excavate, open up or remove the ground above, next to, under or near divisional service works;
(c) damage, endanger or destroy or do any act likely to damage, endanger or destroy any divisional service works;
(d) make any opening in any sewer, public drain, water main, gas main or electricity main or abstract or divert or cause to be abstracted or diverted any sewage, water, gas or electricity therefrom;
(e) discharge, permit to enter or put into any sewer –
  (i) any stormwater;
  (ii) any gas or steam;
  (iii) any liquid (not being domestic waste water) of a temperature higher than forty-three degrees Celsius;
  (iv) any liquid refuse from an abattoir;
  (v) any petrol or oil or substance containing petrol or oil;
  (vi) any refuse or waste resulting from any industrial, trade, manufacturing or chemical process;
  (vii) any liquid which has a pH value of less than five comma five or greater than twelve;
  (viii) any volatile inflammable solvent or organic solvent immiscible with water;
  (ix) any substance which has an open flash point of less than ninety-three degrees Celsius;
  (x) *any explosive, inflammable,* poisonous or other dangerous or noxious substance;
  (xi) any substance which gives off or produces or is likely to give off or produce any explosive, inflammable, poisonous or other dangerous or noxious gas or vapour, or
  (xii) any substance or thing which, whether alone or in combination with other matter, may –
    (aa) constitute or create a nuisance to the public;
    (bb) injure or endanger the health of persons;
    (cc) interfere with the free flow of sewage in such sewer;
    (dd) damage any sewer or any land or divisional service works used for or in connection with the treatment or disposal of sewage, or
    (ee) affect injuriously the re-use of treated sewage or any process whereby sewage is treated;
(f) discharge, permit to enter or put anything other than stormwater into a public drain;
(g) discharge, permit to enter or put into any sewer or public drain any substance or thing likely to damage it or interfere with the free flow of sewage or water therein, or
(h) discharge, permit to enter or put into any natural watercourse into which stormwater is drained or water from divisional service works is discharged or from which water is taken for the purposes of any divisional service, any substance or thing likely to damage it, to interfere with the free flow of water therein or to contaminate or impair the quality of the water therein.

(2) Any person who contravenes any provision of subsection (1) shall be guilty of an offence.

Comment: The above provisions can well serve as a model to be followed throughout the Republic and elsewhere.

Additionally, in terms of sub-section (xii), (ee) of Section 142(1) it is necessary for local authorities to pass adequate "trades waste" or "industrial effluent" acceptance by-laws for approval by the respective provincial council and, in turn, acceptable to the Department of Water Affairs.

All offences must be punishable and appropriate steps should be taken by a local authority.

There has been a tendency for local authorities to copy the by-laws of the larger local authorities such as Cape Town, Durban and Johannesburg. However, for smaller local authorities with difficult industrial effluents to contend with, stricter limits of concentration of pollutants are necessary as the

amount of dilution which takes place in the sewerage system will be less than is the case with a larger municipality.

Applications from industrialists wishing to establish in a municipal or divisional area should be carefully examined to assess the likely impact of the effluent arisings on the operation of the local authority's sewage purification works and the quality of the final effluent produced by such sewage purification works.

Local Authorities

The first appearance in South Africa of a form of local government was in 1796 when the Burgher Senate was established.*

According to Theal† the duties of the Burgher Senate were "to represent to the Government matters affecting the colonists, to keep the roads in order, to provide watchmen for the town, to propose to the head of the Government the best means of levying taxes for those purposes, to farm out the public windmills, to fix tradesmen's wages, etc., in short, to perform all duties – except judicial – of the burgher councillors and the commissioners of the high court of justice in former times".

The Burgher Senate was abolished in January 1828, by Ordinance 34 of 1827‡ wherein it was stated that it appeared to His Majesty's Government "that the various duties which have from time to time been assigned to the Burgher Senate in the Colony have, from increase of population and other causes, become of too complicated and too laborious a nature to be exercised by one body, constituted as the Burgher Senate now is and that it would be more beneficial for the general interests of the country that such duties should be divided under different heads and executed by distinct and separate officers under the immediate control of the Government".

This ordinance did away with local government as then practised but did not meet with the approval of the settlers.

The Government then carried out municipal duties in Cape Town. However, in 1836 by Ordinance 9 of 1836, municipal boards in towns and villages of the Cape Colony were created. This ordinance paved the way for subsequent General Municipal Laws but did not apply to Cape Town and its purlieus. In 1839 Cape Town was constituted a municipality and its authority was more fully set out by Ordinance 1 of 1840.

In 1882 Ordinance 9 of 1836 was set aside and newer legislation was introduced. This Municipal Ordinance of 1882 was subsequently replaced by the Cape Municipal Ordinance of 1912 which, with amendments passed from time to time, remains substantially in force.

In the Cape today local government is controlled by the following:

(1) Municipal Councils – (Urban Councils),

(2) Divisional Councils.

In South Africa local authorities represent the third tier of government in the system of Central, Provincial and Local Authority. However, there are a number of categories of local authority. In addition to the urban local authority we have the following:

(1) Rural local authorities,
(2) Peri-urban local authorities.

(1) Rural Local Authorities

The only essentially rural local authority is that represented by the Cape divisional councils which are managed in terms of Ordinance No. 15 of 1952 – as amended and consolidated later by Ordinance No. 18 of 1976. These authorities may levy taxes on fixed property. Their areas of jurisdiction follow those of the magisterial districts as is also the case with school boards, regional post offices, etc.

(2) Peri-urban Local Authorities

These are concerned with areas which are both rural and urban in character. The largest peri-urban authority is the Transvaal Board for the Development of Peri-Urban Areas and was constituted under the Ordinance for Constitution of a Peri-Urban Health Board, 1943 (Ordinance No. 20 of 1943 – Transvaal).

A somewhat similar set-up is the Natal Local Health Commission constituted in terms of the Ordinance on the Commission for Local Health (Control over Public Health Service), 1941 (Ordinance No. 20 of 1941 – Natal).

In the Orange Free State the Smallholding Areas Control Board was established in 1954 under the Ordinance on Smallholdings, 1954 (Ordinance No. 17 of 1954 – OFS).

South African local authorities have power to pass by-laws which are subject to the approval of the provincial authority concerned. Central government and provincial legislation takes precedence over local authority by-laws.

The major functions of urban local authorities include licensing of businesses and motor vehicles, traffic control, public transport, market facilities, abattoir services,§ roads, electricity and water supply, refuse removal, sewerage, stormwater drainage, building control, town-planning, parks and recrea-

*Walker, E.A. *"A History of Southern Africa"*, Longmans, Green & Co. Ltd., London, 1962, p. 126.

†Theal, G.M. *"A History of South Africa"*, George Allen & Unwin Ltd., London (printed in Cape Town by C Struik).

‡Centlivres, A. vd S. Introduction to *"Municipal Law"* by Donges, T.E. and van Winsen, L.D. Juta & Co. Ltd., Cape Town, 1940.

§Abattoir developments are now undertaken on a regional basis by the Abattoir Corporation of South Africa.

tional facilities, libraries, museums, cultural amenities, housing, fire-fighting, ambulance services, various environmental health services, clinics, special services to non-whites, limited subsidization of charitable institutions, valuation of fixed property for rating purposes, and urban renewal.

Urban local authorities far outnumber other types of local authority.

Promotion of Local Government Affairs

On 30 June 1983 the Promotion of Local Government Affairs Act, 1983 (Act No. 91 of 1983), was promulgated which *inter alia* provides for the establishment of a council for the co-ordination of local government affairs. The object of this council is to advise the Government with regard to the co-ordination of those functions of local authorities which are of general interest to local authorities, as well as those matters relating to local authorities which should in the national interest be co-ordinated.

The Council is intended as an advisory body with no executive powers and the functions of the Council will include the making of recommendations with regard to –

(1) those matters requiring co-ordination that should receive priority;
(2) the co-ordination of functional activities of local authorities such as fire-fighting or civil defence programmes;
(3) the creation of metropolitan and/or regional bodies to perform the same functions as do the local authorities, but on a wider scale;
(4) legislation affecting local authorities.

Recommendations under (3) could very well deal with such matters as regional sewage purification schemes.

The present functions, responsibilites and authority of local authorities and their extent are likely to be metamorphosed and transmogrified with the devolution of power envisaged in a new political dispensation.

Water Supply and Sanitation

The 1983 South African Municipal Yearbook gives information* on "Water Supply and Sanitation Services" for South Africa and South West Africa.

Water Supply: Most of the water used is supplied by waterboards, from State water schemes throughout the country, by regional water services corporations in Natal, West Transvaal Regional Water Company (Proprietary) Limited as well as from municipal dams owned by a number of local authorities.

Most of the water used is surface water and is derived from rivers and impoundments in catchment areas. However, underground water is also used, viz. – borehole water, spring water, dune well and dune well point water. There are 56 instances of borehole water and 15 instances of spring water used *per se* or in addition to other supply sources of particular local authorities. Dune water is used in 4 instances and in some drier regions reliance has to be placed on the collection of rainwater.

Sanitation: Information supplied in the 1983 South African Municipal Yearbook† shows that:

(1) for local authority – White areas : 70 per cent are either completely or partially sewered and of these 48 per cent are completely sewered;
(2) for Non-White areas : 46,7 per cent are either completely or partially sewered and of these 28,9 per cent are completely sewered.

These figures do not reveal an ideal situation but, nevertheless, represent a great improvement from the situation some fifty years ago when the "bucket" or "sanitary pail" system practised by local authorities was the "order of the day".

Regional Wastewater Treatment and Disposal Schemes

If a study is made of the topography of an area in which a number of local authorities are situated it will be realized that drainage areas are not synonymous with municipal areas. This being so, sewage purification and disposal of effluent should be planned in concert with drainage areas and not with municipal areas.

Unfortunately, in the past, there has been a tendency evinced towards parochialism on the part of local authorities and they have shown a certain reluctance towards divesting themselves of the responsibility for providing sewage purification facilities for their municipal areas of jurisdiction.

On the other hand there are certain local authorities which are unable to provide sewage disposal facilities and would welcome linking-up with a regional scheme.

This would, in the long run, envisage regional schemes run independently of local authorities in much the same way as a large water board such as the Rand Water Board operates in the supply of water to a large area including the Pretoria, Witwatersrand, Vereeniging (PWV) complex and as far afield as Rustenburg.

From a pollution control point of view the operation of a large regional wastewater treatment plant is more desirable than a proliferation of small plants in a drainage area. The regional works would represent one well-controlled emission point as opposed to a

*1983 South African Municipal Yearbook, Table H, pp. 290-317.
†Table H, pp. 290-317.

number of discharges of dubious quality from inadequate plants controlled by less experienced and less qualified personnel.

There is a school of thought that considers that water supply and sewage purification and disposal of effluent are intimately linked in that effluents are discharged into rivers which constitute the water supply. This being so, a water supply body would avoid pollution of its water source by ensuring that the effluents discharged from its sewage purification works are always of satisfactory quality.

Of course, as in all matters, finance is an overriding consideration and the financial problems involved in mounting and maintaining a regional wastewater treatment scheme would also have to be weighed against the gain in pollution control. But the latter consideration should be given preference.

In this connexion it is pertinent to quote the following extract taken from an article by Venter,* Town Treasurer of Johannesburg:

". . . As long as the importance of local government in the constitutional structure is guaranteed, and we are assured of adequate sources of revenue, I frankly do not think that it matters ultimately where we lose, say our sewerage systems,† to a regional body and acquire police and hospitals in their stead. The paramount consideration must be that the existing political status of local government should not be diminished by any new political dispensation".

Note: It should be noted:

"sewerage" is the system of sewers conveying sewage;

"sewage" is the polydisperse liquid suspension which flows in the sewers.

Funding of Projects

The installation of a sewerage system for a local authority is a costly endeavour for a council. The cost involved in reticulating the sewage to a sewage treatment works far outweighs the cost of a modern sewage purification works to treat the sewage. For this reason small local authorities are placed in a dilemma. In order to overcome this, septic tank-french drain combinations are allowed on erven not less than 0,405 hectare (1 acre) in extent provided the location and the soil are considered suitable.

Where this is not possible, which is the case for most built-up areas, conservancy tanks, with a minimum capacity of 4,54 m^3 (1 000 gallons) per household are permitted and the local authority provides a tanker service to regularly empty such conservancy tanks and transport the contents (now septic) to a disposal site for treatment in an oxidation pond system. For hotels and other large establishments larger conservancy tanks have to be provided.

The cost of operating an efficient tanker service is, of course, an escalating one due to fuel-price increases, etc. As the contributing population increases a point is reached where a sewerage system has to replace the conservancy-tank system and funding is required.

Acquisition of the necessary capital is obtained by a local authority through loans – usually obtained through the respective provincial authority. For large municipalities embarking on new projects it is possible to float loans for the purpose directly or through the aegis of the respective provincial authority.

A point to bear in mind is that disposal of sewage in an oxidation pond system is wasteful of water which is lost by evaporation and in some cases by seepage. In consequence the Department of Water Affairs does not allow this method of treatment for a daily quantity of sewage in excess of 700 m^3.

Consequently, when this stage has been reached, a local authority is faced with the necessity for providing a properly engineered sewage purification works capable of producing an effluent suitable for discharge into a watercourse‡ on conditions laid down by the Department of Water Affairs.

A note of warning is necessary – A small local authority with a low growth rate (less than 2 per cent per annum) is cautioned against ambitious sewage purification schemes where, due to the paucity of ratepayers, the cost to such ratepayers may prove an inordinate burden. Here linking up with a regional scheme could be the answer.

*"*Future Developments in Local Government Finance*" by Venter, H.H.S. Town Treasurer, Johannesburg, 1983 South African Municipal Yearbook, p. 27.

†By "sewerage systems" he probably includes sewage reticulation and sewage purification.

‡Effluent from oxidation ponds systems are not allowed into watercourses. However, in an endeavour to use such effluent beneficially advantage can be had by providing an irrigation/conservation dam with a storage capacity of at least 10 days flow of effluent : the stored effluent may be used for irrigating certain specified crops and timber trees.

Chapter 11 DISCHARGE OF PURIFIED EFFLUENTS INTO WATERCOURSES

SIGNIFICANT LEGAL CASES AND CIRCUMSTANCES LEADING TO LAWFUL RECOGNITION OF SUCH PRACTICE IN SOUTH AFRICA

I SEWAGE EFFLUENT

The most significant case in this connexion is that of Jerolim Vucinovich vs. Johannesburg City Council. This case was heard in the Witwatersrand Local Division of the Supreme Court on May 1, 1939 and judgement was delivered by Judge Ramsbottom in favour of the plaintiff, Vucinovich; whereupon the defendant, Johannesburg City Council, later appealed.

The appeal took place on March 12 and 13, 1940 before a panel of judges, viz. – de Wet C J, Watermeyer J A, Tindall J A, Centlivres J A, Feetham J A, and judgement was given on May 3, 1940.

Mr. Justice Feetham, for reasons given, concluded that the appeal of the appellant, Johannesburg City Council, failed and dismissed the case with costs in favour of the respondent, Vucinovich. The other four Judges of Appeal, de Wet C J, Watermeyer J A, Tindall J A and Centlivres J A concurred.

The case was accordingly dismissed.

Now let us look at the content of this case and its significance as a "watershed" as far as the *modus operandi* and philosophy of methods of sewage disposal in South Africa are concerned.

Here are some of the facts as stated by Judge Ramsbottom at the original hearing prior to the appeal later.

"In 1903 the Johannesburg Town Council decided to institute a system of waterborne sewerage and to this end to exercise the powers conferred on it by Ordinance 64 of 1903. The Council desired to purchase the farm Klipspruit, which was then outside the municipal boundary, and to use it as a sewage farm. The consent of the Lieutenant-Governor was needed, and after receiving the report of a commission appointed to inquire 'into the propriety of the intended work and the objections thereto' the Lieutenant-Governor gave his consent on September 16th, 1904. The form of his consent was to allow 'the utilization of Klipspruit Farm No. 58 (now No. 8), Witwatersrand as a sewage farm'."

"The first sewage arrived at the farm in November, 1907, and the method employed for its disposal was to deposit the raw sewage on the ground without pretreatment. This created a nuisance and an action for an interdict and damages was brought against the Council. The case, Herrington vs. Johannesburg Municipality (1909, T.H. 179), was tried before Bristowe J, in this Court and judgement was given for the plaintiff. The learned Judge found that a nuisance had been committed, and that the Ordinance did not take away the right of action of injured parties. As the result of that case the Council changed its method of disposing of the sewage and adopted a method of pretreatment which, with improvements from time to time, has been employed on the farm Klipspruit up to the present time. Instead of raw sewage being deposited on the land, it is subjected to treatment, the essential features of which are as follows : The larger solids are removed by passing the sewage through screens; the sewage then passes through detritus tanks in which grit and other heavy solids in suspension are deposited; it then passes to settlement tanks where the bulk of the remaining solids in suspension are removed – the heavier solids are deposited, and the lighter solids which come to the surface and form a scum are taken off; these solids which are known as sludge are buried or otherwise disposed of, their disposal is of no importance in the present case. The effluent which remains after this pretreatment, though relatively free from solids in suspension, contains a large amount of putrescent organic matter in solution, and this effluent must of course be disposed of day by day."

"At the time when the Klipspruit sewage farm was established, the method of broad irrigation was the one usually adopted in the inland towns of South Africa, and Sir Edward Thornton stated in his evidence that at an Inter-Colonial Health Conference held in Cape Town in 1903 it was recommended that not less than 100 acres should be provided for every one million gallons per day of effluent to be disposed of after pretreatment for the removal of suspended solids, and this is the standard which is still recommended to-day. This standard is recommended so as to ensure the purification of the effluent – not to

prevent the inundation of lower land. After the Herrington case in 1909, the defendant adopted the system of removal of solids which I have described, and ever since then, except for the two million gallons per day which now is artificially filtered and for half a million which is sold to a neighbouring farmer, it has disposed of the whole of the effluent at Klipspruit by the method of broad irrigation. The amount to be disposed of each day has increased enormously; in 1910 to 1911 the average daily flow was approximately one and a half million gallons while in 1938 to 1939 it was very nearly 7 million gallons. The area under irrigation has varied from time to time, but it has always been more than sufficient to comply with the requirement of 100 acres to one million gallons per day."

"The plaintiff is the owner of land which adjoins the defendant's farm, Klipspruit No. 8. The plaintiff resides upon his land, and since the year 1908 he has been carrying on dairy farming operations thereon. The defendant, acting under statutory powers, uses the farm Klipspruit as a sewage farm and disposes of a large volume of water daily by irrigating the surface of its land. Some of the water thus disposed of has percolated underground and has reached the land of the plaintiff (which lies at a lower level than the farm Klipspruit) so that the water table has been raised to within three or four feet of the surface. The result of this has been to flood and render useless the cellar of the plaintiff's house, his incubator room, and five silos in which he stored the winter feed for his cattle; the incubator room and four of the silos have collapsed. In addition, the plaintiff's water supply has been pulluted with chemical substances so that it cannot be used for domestic purposes. The plainstiff now claims an interdict restraining the defendant 'from conducting, maintaining and carrying on the said sewage farm and sewage disposal as to cause plaintiff the nuisance complained of or any nuisance'; he also claims damages in the amount of £6,475 12s."

In his declaration the plaintiff alleges that "in the course of carrying on sewage disposal on the said site (i.e. the farm Klipspruit) the defendant wrongfully and unlawfully caused, allowed and permitted, and still is wrongfully and unlawfully causing, allowing and permitting sewage effluent and/or water to drain and percolate into plaintiff's farm in such quantities and in such manner as to cause the nuisance" which I have described. The defendant, in its plea, denied "that it caused, allowed or permitted or that it is causing or allowing or permitting sewage effluent to drain or percolate into the plaintiff's farm either in the quantities alleged or at all, and specifically denies the nuisance alleged." The defendant then denies that in consequence of percolation the natural normal level, volume and quality of the underground water beneath the plaintiff's farm has been seriously disturbed, and then pleads in the alternative that if any sewage effluent has drained or percolated into the plaintiff's land it denies that this has been the cause of raising the water table or polluting the plaintiff's underground water. In the further alternative the defendant pleads that "if the sewage effluent has drained or percolated into the plaintiff's farm so as to cause the nuisance alleged – the defendant says that the said nuisance is the inevitable consequence of the proper and ordinary conduct of the defendant's farm as a sewage farm and/or disposal works in the exercise of the powers conferred upon the defendant by virtue of sec. 161 of Ordinance 11 of 1926." In the course of the trial it was admitted that the raising of the water table and the pollution of the plaintiff's water supply was caused by underground percolation from the farm Klipspruit, and the plea that this was the inevitable consequence of the exercise of the defendant's statutory powers became the main defence. In his replication, the plaintiff denied that the nuisance is the inevitable consequence of the proper and ordinary conduct of the defendant's sewage farm and disposal works and alleges that it is caused by the defendant's failure to take precautions which were and are available and reasonably practicable to prevent the nuisance; particulars are given."

"The plaintiff purchased his land in 1908, when it was bare ground and immeditately began to establish his dairy farm. There was then no water on the farm, and he dug a well 70 feet deep, getting a little water at 60 feet. In 1914 he bored for water next to the well, going down in the well, to a depth of 100 feet; both holes yielded about 3 000 gallons per diem. About 15 years ago the plaintiff enlarged his house and constructed a cellar 8 feet 9 inches deep in dry ground; the cellar was lined with concrete and had a granolithic roof. In 1925 he constructed two silos each 32 feet deep and in 1932 he constructed three more silos, one 32 feet deep and two 26 feet deep, all with concrete cellars and cement plastered inside. In 1930 the plaintiff again drilled for water without success and in 1934 he built an incubator room 6 feet deep in the ground.

In 1934 the defendant began to plough and plant the area above the plaintiff's ground which I shall refer to as area 4 (C). The preparation was completed within a year, and irrigation was then started. In August, 1936, the plaintiff found that there was water in his silos and that it was seeping in from the sides. He took the matter up with the defendant and correspondence followed, to which I shall have to refer later. In December, 1936, his drinking water began to have a nasty taste and he also noticed that it curdled milk, would not lather, and would not mix with dip. The water in the silos continued to rise and the two 26 feet deep silos collapsed in February, 1937. In August, 1937, water was discovered in the incubator room, which has now collapsed, and in the cellar. Between July and December, 1937, the defendant did not irrigate area 4 (C) because he was improving the ground by removing boulders. During this period the level of the water in the cellar and in-

cubator room went down until they were empty though still damp; the level in the silos and boreholes also receded. But in 1938 irrigation on area 4(C) started again, water reappeared in the cellar and incubator room and the level in the silos and boreholes began to rise. When summons was issued on October 14th, 1938, the water was standing in the cellar, which is under the dwelling house, some three or four feet from ground level, and was standing at much the same level in the incubator room and in the silos which had not yet collapsed. In January and February, 1939, two of the 32 feet silos collapsed, and the only silo which is still existing is one which the plaintiff was afraid to empty for fear that it would also collapse. When the water level dropped as the result of the stopping of the irrigation in 1937, thinking that the defendant had decided no longer to irrigate area 4 (C), the plaintiff planted maize, intending to use it for silage, but before he could use it irrigation was restarted and although the plaintiff tried to use the crops by building it into stooks, it was wasted.

It was at first disputed that the defendant's operations were the cause of the raising of the water under the plaintiff's land and the pollution of his boreholes, and a great deal of the plaintiff's evidence was directed to proving these facts. That the irrigation is the cause is now admitted."

The Appeal

In the original trial case presided over by Judge Ramsbottom the Johannesburg City Council relied on Section 161 of Ordinance 11 of 1926 which authorizes the carrying on of sewage disposal work by a municipality, provides that a municipality shall not be liable for any nuisance or damage "which is the inevitable consequence of the proper and ordinary conduct of any sewage farm or sewage disposal works established, maintained or carried on under the provisions of this section".

In the appeal case Judge Feetham drew attention to a scheme of underdrainage outlined by Mr Stewart of Stewart & Oliver, consulting engineers, which Mr Stewart in his evidence considered could have ameliorated conditions had such a scheme been implemented in good time.

This under-drainage scheme provided for the cutting of a series of underground drains, at a depth of 4 feet 6 inches to 6 feet, one such drain to be cut just above, and parallel with, each of the carrier trenches used to distribute the sewage over the land, except in the case of the uppermost carrier. These drains would be half-filled with stones and below the stones would be laid open-jointed drainage pipes. Each of these drains would serve as an "interceptor", and catch some of the seepage water which makes its way underground down the slope. Drains connecting these intercepting drains would lead the water away from them so as to discharge it, if sufficiently pure, direct into an adjacent spruit, or, if it required further purification, into sand filters, whence it would be conducted to a spruit.

Analyses of Samples

The following analyses carried out by James Gray (one of the founders of the South African Chemical Institute) in 1936 some years prior to litigation are worthy of interest.*

His finding must have goaded Mr Vucinovich into action against the Johannesburg City Council.

James Gray, F.I.C.

Analytical Chemist and Assayer.
Chemical Laboratory & Assay Office
2 Loveday Street
Johannesburg
11th December 1963

Ref. No. 8009

Certificate of Analysis

This is to certify that the following is the result of analysis of the sample of water submitted by yourself, on date 8th instant:

	In parts per 100 000 parts.
Total solids, at 110°C	34,66
Total solids, after ignition	33,60
Chlorine	23,3
Sulphuric anhydride	Nil
Free ammonia	0,28
Albuminoid ammonia	0,12
Nitrites	Trace
Nitrates	Nil
Oxygen, consuming, 4 hours	0,054
Alkalinity, as calcium carbonate	3,0
pH value	8,6

From the above analysis, I am of opinion that the water has been contaminated by sewage.

(Signed) *JAS. GRAY*
Analytical Chemist and Assayer.

To: J Vucinovich, Esq.
P.O. Kliptown
Johannesburg

Samples of Water from Excavation at Klipspruit†

Lab. No. 651. Samples taken 22nd November 1937.
Reported on 10th December 1937.

**These and the analyses following were obtained through the courtesy of the Chief Scientific Officer of the City Health Department, Johannesburg.*
†Analyses performed in the "Cydna" Laboratories of the Johannesburg City Council : H Wilson, City Biochemist.

1. Secondary Digestion tank excavation:

	In parts per 100 000
Oxygen absorbed in 3 minutes	0,14
Oxygen absorbed in 4 hours	0,15
Chlorine in Chlorides	17,2
Nitrogen as Nitrite	0,012
Nitrogen as Nitrate	4,0
Nitrogen as free and saline Ammonia	0,068
Nitrogen as Albuminoid Ammonia	0,05
Biochemical Oxygen Demand (5 days test)	0,25

Lab. No. 642.

2. Primary digestion tank excavation:

	In parts per 100 000
Oxygen absorbed in 3 minutes	0,14
Oxygen absorbed in 4 hours	0,16
Chlorine in Chlorides	38,8
Nitrogen as Nitrite	trace
Nitrogen as Nitrate	1,52
Nitrogen as free and saline Ammonia	0,083
Nitrogen as Albuminoid Ammonia	0,02
Biochemical Oxygen Demand (5 days test)	0,20

Exhibit 7

Chemical Laboratory & Assay Office
2 Loveday Street
Johannesburg
5th August 1939

JAS. GRAY F.I.C.
Analytical & Consulting Chemist.

Telegraphic Address "Testube"
P.O. Box 5254
Phone: 33-1851

Reference No. 7327/33

Certificate of Analysis

This is to certify that the following is the result of analysis of the
Seven Samples of water
Marked as under, "Klipspruit Farm No.49"
Sampled by myself on date 29th ult.

	7327 Cellar	7328 Water in 2 collapsed silos	7329 Golf Course Municipal Test Hole
	In parts per 100 000 parts		
Total Solids, at 110°C	170,32	208,8	133,12
Chlorine	64,0	100,8	57,0
Sulphuric anhydride	8,06	7,05	Trace
Nitrogen as nitrate	3,05	0,96	0,10
Nitrogen as nitrite	minute trace	0,006	0,012
Saline ammonia	0,02	0,008	0,025
Albuminoid ammonia	0,034	0,034	0,032
Oxygen consuming, 4 hrs.	0,072	0,065	Trace
Alkalinity, as $CaCO_3$	15,0	18,0	3,0
Lime	18,9	24,5	13,0
Magnesia	17,24	34,44	16,4

To: L. Malan Esq.

(Signed) J G
Analytical Chemist & Assayer.

Deductio

From a sewage disposal point of view the inference to be drawn from the findings of the learned judges, was, that provided an effluent is satisfactorily or sufficiently purified, it may be discharged into a watercourse.

However, the fact that as no quality criteria were laid down meant that discharges of effluent by other local authorities would only be of a permissive nature and would, in all probability, have to be defended in court against the likely complainants.

The criteria determining the suitability of an effluent for discharge into a watercourse only came at a much later stage : this will be dealt with later.

II MINING EFFLUENT

A significant case was an action for a perpetual interdict and damages brought by Prinsloo against the Luipaardsvlei Estates and Gold Mining Company, Limited.

The overriding influence of the gold law over common law rights was enunciated in this case by Advocate J T Barry K.C. (at the time) acting for the defendant mining company. His statement, in this connexion, to court as recorded in the proceedings is as follows:

"J T Barry, K.C. : The plaintiff cannot rely on his common law rights, as these have been modified by the gold law. Plaintiff's rights and remedies under that law (Act 35 of 1908) are to be found in regulations 22 and 23. The farm Rietvlei is not proclaimed land, but it falls under the jurisdiction of the Mining Commissioner – see the definition of 'proclaimed field' in Act 35 of 1908. My argument is based on the assumption that the owners of Rietvlei are in the position of lower riparian owners outside proclaimed land. The English cases cited by plaintiff decide in plaintiff's favour that a person exploiting minerals is liable if he pollutes the water of a public stream. But these decisions are distinguishable from the present case, as there the miner exploits his own minerals on his own land. In South Africa, he exploits minerals on another's land under licence from the State. One must assume that the Legislature intended to make it possible for the licence holder to work his claim. It is a mistake to confuse the rights and duties of a miner

under the common law with those granted and imposed by a statute whereby the State has the monopoly of right to mine, and grants licences to persons to carry on mining operations. The gold law gives to the miner no surface rights other than those specially granted by the Mining Commissioner : See secs. 67 and 68 of the Act. It is impossible to carry on gold mining unless the mine can be de-watered. The gold law is silent as to what the miner must do with the water he pumps out of his mine. He is compelled to discharge it on the surface, and persons outside the mining area have a duty to receive the water. It is for the Mining Commissioner to say when a nuisance is being committed. In the case of alluvial diggings, the digger must of necessity pollute the water in the stream, but the lower riparian owner would not have any remedy against him. The underlying idea of Act 35 of 1908 is that the Mining Commissioner is placed in charge of a proclaimed field, vested with certain powers and duties. Amongst these duties is that of protecting the lower riparian owner. That is the reason for the regulations promulgated under the gold law. Regulations 22 and 23 confer the only rights of complaint a lower riparian owner has if his water is fouled."

The above statement by Advocate Barry (later to become a judge) clearly sets out the overriding rights of a mining company at the time of the case (1932) in relation to the common law rights of individuals using water from a stream which also contains mining effluent.

The case was heard before Mr Justice Tindall and it lasted 32 days from May 4 to September 9, 1932, with judgement being given on October 14, 1932.

The details of the case as reported in the law reports are as follows:

"Action for perpetual interdict and damages.

Defendant was a mining company, carrying on operations on the farm Luipaardsvlei No. 8. The Rietvlei Spruit (hereafter called 'the spruit') had one of its sources on this farm, and flowed down through the farm Rietvlei and thence to other farms lower down. The plaintiff owned undivided shares in portions A, remainder of J, G, K, and a portion named Eendracht, and the remaining extent of the farm Rietvlei. Plaintiff alleged that he and his co-owners (eight of whom had ceded their claims to him) had suffered by reason of the fact that defendant had discharged, and was daily discharging into the spruit, and on to the said portions of Rietvlei, water, slimes and sands containing poisonous, injurious and other deleterious matter. It was alleged that thus the defendant had polluted and was polluting the spruit, and had deprived and was depriving the plaintiff and the other co-owners of the use of the water therefrom for household purposes, for the purposes of watering their animals and for irrigation purposes; further, that the defendant has thus damaged the land of the plaintiff and the cedents in that the soil and the vegetation of the water lands and vleis on the said portions had become poisoned, silted up, covered with sand and slimes, and unfertile and useless for agricultural and grazing purposes. The plaintiff alleged that the said acts of the defendant were wrongful, in violation of his rights of ownership and those of his co-owners, in contravention of secs. 22 and 23 of the regulations framed under Act 35 of 1908, and in contravention of sec. 7 of the regulations framed under Act 12 of 1911.

The length of the course of the spruit to the Rietvlei boundary was about two and a half miles, and from this boundary to Eendracht, the lowest of the portions concerned, was four miles.

Mining waste in huge quantities had in the past found its way down the spruit, damaging the land, and fouling the water. For many years mining operations had been carried on by various persons and companies on Luipaardsvlei No. 8, and the defendant contended that the pollution, or most of it, was the result of erosion from other properties, and of the operations of others. Plaintiff contended that there had been no appreciable pollution or deposit of deleterious matter until after 1925, in which year defendant admittedly breached a dam in the spruit, known as the Lancaster dam. In the past various persons and companies carrying on mining activities had constructed six dams in all. The walls of three of these dams had been breached for many years. In the case of the fourth, known as the Luipaardsvlei dam, though the wall of this dam was intact, the spillway had been eroded almost to the level of the bed of the stream. The fifth dam was the Lancaster dam which was on a water right granted to a predecessor of defendant, who had ceased mining operations about 1914, the water right lapsing about 1921. The distance from the wall of this dam to the Rietvlei boundary was one and a half miles. This dam contained a great quantity of slimes.

Since 1925, the waste material, after the completion of the process of gold extraction, had come away in two forms, known respectively as slimes and sand. The waste known as slimes was deposited in what was known as a 'slimes dam,' which was not a dam in the ordinary sense of the term, but an area into which the water containing slimes from the recovery works was run. The water was then drained off, leaving a layer of slimes, the various layers settling in course of time into a more or less cohesive mass of fine waste material. The waste known as sands on the other hand, came dry out of the reduction plant, and was simply dumped in a loose heap known as a 'sand dump'. The Lancaster dam was not a slimes dam, but an ordinary water dam in the spruit; and, situated as it was across the valley, it caught up a great quantity of slimes contained in water which flowed down a creek into it from the defendant's mine, and in storm water which found its way into that dam. In June, 1925, the defendant applied to the Mining Commissioner for permission to de-water the Lancaster water dam, the letter stating that the defendant believed

that soakage from the dam found its way into underground workings of the defendant, that the water in the dam was not likely to be required for mining purposes, and that the dam wall was a menace in case it should break away. On 4th July, 1925, the Mining Commissioner intimated that there would be no objection 'to your company de-watering the dam', but he pointed out that the water in the dam was believed to be extremely acid, and stated that the defendant must accept all risk of damage caused by the flow of water over any agricultural or other occupied land. Subsequently, in the latter half of 1925, the defendant de-watered the dam and the means it adopted was to breach the dam by cutting through the dam wall in the line of the stream bed. About a year after the breach of the dam, the first complaint was made to the Mining Commissioner that slimes were being deposited on Rietvlei. As a result, the Mining Commissioner investigated, and called upon defendant to abate the nuisance, intimating that he was acting in terms of regulation 23, framed under Act 35 of 1908. In January, 1927, defendant repudiated liability for slimes coming from the Lancaster dam, but the Mining Commissioner merely repeated the notice to abate. By this time a considerable quantity of slimes had been deposited on the farm Rietvlei. In February, 1927, defendant intimated that it was willing to erect a partial closing of the breach in the wall, and did so, but the work was not efficiently done, and in the same year a storm carried the work away, and the gap, which had existed ever since, recurred.

At all material times there were in the neighbourhood three mines producing slimes, each of which might have been a possible source of contamination – defendant's mine, and those of the Randfontein Estates and Gold Mining Co., and West Rand Consolidated Gold Mining Co. Some of the water from the Randfontein Estates Mine contained an appreciable amount of brown sediment, but contained no sulphocyanide or ferrocyanide, and nothing suggesting sewage contamination, nor was it acid. The remaining portion of the water from the Randfontein Estates had carried slimes, but this source was found by His Lordship to be of minor importance. The West Rand Co. had two furrows leading ultimately into the spruit, the water that ran in these furrows being drained from the slimes dam on the West Rand Mine. Slimes had been deposited in large quantities on the land abutting on these furrows, and there was no doubt that the water discharged into the spruit from them was foul and not potable by human beings. Samples when analysed disclosed the presence of sulphocyanide. The water for which defendant was responsible consisted of water drained from its current slimes dams by means of a contrivance known as a 'penstock', seepage from underneath its old slimes dams no longer in use, water from its existing slimes dams, water from its native compound, and mine water containing sediment from underground, known as sludge. These waters entered the spruit, along which they passed into the Lancaster dam. The water in its course through the Lancaster dam would be bound to pick up more slimes as that dam contained a thick bed of slimes, for which mining activities other than those of defendant were mainly responsible. The land adjacent to the spruit in Rietvlei was at the time of the trial 'smothered with slimes' over a considerable area; in places the deposit was at least three feet deep. Owing to the provisions of sec. 6 (e) of the Prescription Act (No. 26 of 1908), plaintiff limited his claim to damages sustained not earlier than three years before the date of issue of summons – i.e., 17th July 1931.

The following were His Lordship's findings on the facts, relevant to this report (tabulated by the reporter):

(1) Before mining commenced on Luipaardsvlei No. 8, the spruit had its origin in a number of small springs forming a vlei, which extended for a distance on that farm, and then developed into a running stream; and the natural water which flowed along the spruit to where the Lancaster dam was subsequently built was public water, forming the source of a public stream, within the meaning of the Irrigation Act (No. 8 of 1912).

(2) A considerable part of one of the slimes dams (known as No. 7) erected by defendant was built over the head of a creek, which was one of the sources of the spruit – a circumstance which must have been a source of weakness to a structure such as a slimes dam.

(3) The sludge, which was discharged into the creek at very short, possibly daily, intervals, ultimately reached Rietvlei, one-third of this liquid sludge being deleterious sediment.

(4) The nature of the combined stream from all sources discharged by the defendant down the creek into the spruit, before it became mixed with water for which the defendant was not responsible (excluding the sludge dealt with in para. 3) was very acid; it contained an abnormally high concentration of dissolved matter, was quite useless for any purpose, harmful to drink, unsuitable for consumption by animals, and would, and did, have a harmful effect on agricultural land.

(5) Before the breaching of the Lancaster dam in 1925, the appearance of the water in the spruit when it reached Rietvlei was clear, except after rain. But even then it could not have been good drinking water for human beings, or for domestic purposes. Before the breach, it would, however, have been suitable for cattle, and only an inconsiderable amount of mine waste could have been carried on to Rietvlei.

(6) Some of the silting up took place before 1928, and damage in respect of this was irrecoverable by plaintiff. Most of the silting on portions A, K,

G, and remainder of J, took place after 1928.

(7) The damage caused to plaintiff and his co-owners was due to the negligent manner in which the defendant, the Randfontein Estates Co., and the West Rand Co., discharged waste water into the spruit, each acting independently of each other."

The judgement finally handed down by Judge Tindall was as follows:

"A. An order interdicting the defendant (1) from discharging slimes or other mine refuse or water containing slimes or containing such refuse or containing matter injurious to human beings, to animals, to the soil or to plant life into the said Rietvlei spruit or on to the remaining extent, portions A, remainder of J, G, K and Eendracht of the farm Rietvlei; (2) from allowing slimes or other mine refuse or such water to run into the said spruit or on to the said land. This order shall not apply to so-called normal erosion from the defendant's two slimes dams in use at present at points 8 and 9 on Exhibit A or from slimes dams established by the defendant in the future, that is, erosion by rain from such slimes dams which still occurs after reasonable precautions have been taken to try to prevent such erosion.

B. An order directing the defendant to take steps to prevent any pollution of the said stream or damage to the said portions being caused by reason of the breach by the defendant of the Lancaster water dam.

C. The operation of the said orders is suspended for two years from the date of this judgement after which period the defendant will, if it can show good grounds, have liberty to approach the Court for a further suspension, the suspension to be without prejudice to the plaintiff's right to recover any further damage sustained between the date of this judgement and the date of compliance with the said orders.

D. Judgement against the defendant for £317 15s.

E. Costs against the defendant.

F. Qualifying fees are allowed for the witnesses van Hees, Lazar, Lucas and Whittome, but not for the witness Warden."

This judgement certainly indicated that in the future (i.e. after October 14, 1932) mining companies would have to exercise more care and attention to such matters as the disposal of slimes and sand, underground water pumped to the surface, penstock water from slimes dams, effluent from mine compounds, etc. and Mining Commissioners would have to use circumspection far greater than before in regard to these matters as well as requests from mines for alterations which might prove inimical to other users of the water of a stream or river.

It was a step towards the protection of riparian users of stream water (e.g. farmers) from fouling by mining operations. However, it left open the matter of run-off from established slimes dams and sand dumps which are known to be foci of fouling of the water environment due to the presence of pyrites (FeS_2) which in the presence of moisture and certain bacteria gives rise to ferrous sulphate and sulphuric acid.

III. USE OF WATER AND DISCHARGE OF WASTEWATERS ARISING FROM SUCH USE: THE NEED FOR CENTRAL CONTROL

McLachlan[1], in a masterly review of the history of the Southern African Branch of the Institute of Sewage Purification on the 21st anniversary of its founding in Johannesburg, has chronicled developments leading up to the *status quo* arrived at in 1956 by the promulgation of the Water Act (Act 54 of 1956).

The South African Branch,* as it was called at its inception, was founded on May 4, 1937, on a petition to the Council of the Institute of Sewage Purification, London. Of the original signatories numbering twelve all but five are alive now (1983).

McLachlan states that, "the inaugural meeting of the Branch was held on the evening of the same day as the petition; Harold Wilson was elected Chairman and K A Murray Hon. Secretary/Treasurer. It is understandable that much of the Committee's time in the next few years was occupied with constitutional matters, applications and qualifications for membership and the like. The technical activities of the Branch were confined to visits to sewage treatment works along the Reef and Pretoria, and to discussions of papers presented to the parent body".

He has singled out Dr E J Hamlin (then City Engineer of Johannesburg who was not a signatory to the original petition) and Harold Wilson (who were both Members of the London body) whose help, inspiration, guidance and liaison with the mother body steered the Branch on the right and successful course it has followed.

Standards of Purity for Sewage Effluents

It will be noted from the foregoing Sections I on Sewage Effluents and II on Mining Effluents that by 1939/40 the need for a Central Authority to lay down standards of purity for effluents had become a matter of compelling interest and concern.

In May 1939 the Branch made its first attempt to influence the direction of public concern in matters of sewage treatment, rivers pollution prevention and cognate matters. The Secretary for Public Works had invited the Branch to submit recommendations for standards of purity for sewage effluents for inclusion in Regulations under the Public Health Act of 1919.

McLachlan[1] states with regret, that this matter was pursued for many years but with little effect on official mind in the Department of Health. It was a

*Later changed to the Southern African Branch as it then contained, *inter alia*, members from neighbouring territories notably the then Rhodesia (now Zimbabwe).

case, he states, of "flogging a dead horse".*

First Appearance of Central Authority, 1942

In dealing with the need for a Central Authority McLachlan[1] states: "Our memorandum, drafted by Harold Wilson (as were all our representations of public issues) and supported by Mr de Waal, Dr Hamlin and Dr Murray, was offered to the heads of those government departments which we thought ought to be concerned, but we heard nothing further".

A Witwatersrand Drainage Board

Again quoting McLachlan[1], – "Dr K A Murray had first given voice to the need for a competent controlling authority on sewage matters, and in his Chairman's Address for 1942 had suggested a Drainage Board for the Witwatersrand might prove a good example for demonstrating the advantages of a National Drainage Board. There were present several prominent Reef Councillors, Medical representatives from the Union Health Department, from the South African Railways and from Mining groups, and Medical Officers of Health and City and Town Engineers from the Reef and Pretoria Local Authorities . . ." "The unanimous support encouraged the Branch in the strength of the case which would be made for a regional scheme as a first step in a national scheme. The support of organized chemical industry was also forecast, as without some form of regulation and control, rapidly expanding industry might become sufficiently powerful to oppose desirable legislation aimed at rivers pollution prevention, as being hampering to industry's profitable activities".

The Central Authority Becomes a Reality – The National Health Services Commission, 1943

Towards the close of its acceptance, Dr Nelson, Medical Officer of Health for Pretoria suggested to the National Health Services Commission that the views of the South African Branch of the Institute of Sewage Purification should be heard. The Commission agreed to receive a memorandum from the Branch: a deputation comprising Mr H M de Waal (Chairman), Dr E J Hamlin and Messrs. H Wilson and J A McLachlan supported the evidence and received a very satisfactory hearing from the Commission. The main purpose of the memorandum McLachlan reiterates "was to stress the need for a Central Authority, competently constituted, which would be empowered to regularize the means taken by local authorities and industry for the purification of sewage and polluted waters . . ."

McLachlan states, further, "The National Health Services Commission did not, of course, give us the Central Authority we asked for, but we had another opportunity of mounting our 'hobby horse' in 1945 when the Union Health Department set up a 'Departmental Committee of Enquiry' to investigate the bacterial and chemical pollution of water supplies. The same deputation presented the same memorandum (suitably amended) with the same result as before".

South African Council for Scientific and Industrial Research

In the latter part of 1945 the Government established the CSIR whereat the Branch, supported by the Rand Water Board, The SA Chemical Institute and the Association of Reef and Pretoria Medical Officers of Health submitted a memorandum to the CSIR. A profitable interview took place with the newly appointed first President of the CSIR, Dr B F J Schonland, in October 1945.

Arising out of this the Water Treatment Division of the CSIR, attached to the National Chemical Research Laboratory, came into being with Dr H Wilson in charge – followed some four years later by Dr G J Stander. Initially, facilities were provided at the University of the Witwatersrand, Johannesburg.

This development was really in line with developments which had taken place earlier in Great Britain where the Water Pollution Research Board was formed under the aegis of the Minister of Health and the Department of Scientific and Industrial Research which, prior to establishing its own laboratories, had groups of investigators working at such centres as the Sir William Ramsay and Ralph Foster Laboratories of University College, London; Teddington (where ion-exchange resins were discovered by Adams and Holmes); Mersey Docks and Harbour Board Offices, Liverpool (where investigations on the influence of sewage discharges on the mud deposits in the estuary of the River Mersey were carried out); Birmingham, Tame and Rea District Drainage Board, Birmingham (where, *inter alia*, large-scale investigation of alternating double filtration was investigated).

The South African Council for Scientific and Industrial Research and the South African Bureau of Standards were both established in 1946.

McLachlan states with some justification, "However it came about it must be nearly historically correct to say that the inspiration derived from the Branch, launched the Bureau on its first job!" – i.e.

*It will be recalled from Section I – Sewage Effluents – in dealing with the case of Vucinovich vs. Johannesburg City Council that Sir Edward Thornton had laid down that 100 acres of suitable land should be available to broad-irrigate one million gallons of settled sewage per day and that no sewage or effluent from such irrigated land must be allowed to enter a watercourse. This policy of the Union Department of Health was rigidly followed by subsequent Secretaries of Health! Today, this method of disposal of sewage in a country with limited water supplies can only be regarded as a wasteful procedure.

Tackling the neglected subject of standards for waters and the best methods for determining the necessary analytical values.

A memorandum was drafted by Dr Harold Wilson to the "Standards for Effluents", etc. committee and in a matter of some two years the Bureau's joint committee issued its first draft in 1949 to be followed in October 1950 by its publication, "Standards for the Quality of Effluents discharging from Municipal, Industrial, Mining and Private Enterprises". And so, *per ardua* over a period of approximately nine years a certain modicum of achievement had been attained!

Water Laws Enquiry Commission, 1950

The SA Branch of the Institute of Sewage Purification, now a much stronger and respected body, made a determined effort and submitted copies of a memorandum which contained all relevant matter compounded from previous memoranda to the Commission which gave representatives a verbal hearing in August 1950. The Draft Bill entitled "Water Laws Amending Bill" was discussed by the Branch in 1954 and a comprehensive memorandum presented thereafter to the Select Committee.

In due course the Water Act (Act 54 of 1956) saw the light of day!

Though it dealt with many matters other than quality criteria and pollution control such as matters of more concern to farmers e.g. water abstraction, water use (by industrialists), riparian rights, Government Water Control Areas, etc. etc. Notwithstanding attention was, in fact, given to matters of effluent quality and pollution control as set out in sections 21, 22, 23, 26 and 170 and due recognition was accorded the quality criteria laid down later by the SA Bureau of Standards.

In 1958 the Water Treatment Unit of the CSIR, under the able control of its Director, Dr G J Stander became the National Institute for Water Research in its own self-contained building forming part of the CSIR complex at Scientia, Pretoria.

The Institute was now well-equipped and able to carry out research which in the early days was done by some of the larger local authorities – notably Johannesburg, Pretoria and Germiston.

Although the creation of a Central Authority, in the manner originally contemplated by members of the "Institute", (now the "Institute of Water Pollution Control") has not come about – the fact that the Department of Water Affairs, which itself evolved from the old Department of Irrigation could, up to fairly recently, be regarded as an acceptable surrogate Central Authority. However, with the recent rationalization within the Civil Service we have witnessed the coalescence of the Department of Water Affairs, Forestry and the Environmental Affairs Branch of the Department of Planning and the Environment. What is more, the Minister controlling this combination of interests is also concerned with fisheries being designated the Minister of Environment Affairs and Fisheries. So, in point of fact the new Department of Environment Affairs* does in fact, constitute the Central Authority.

As far as drainage boards are concerned we find that a number of water boards have been created and these boards have powers to control effluent disposal in their respective drainage areas. They constitute regional water and sewage authorities linked to the Departement of Water Affairs.

The Rand Water Board

In Chapter II, Section 4(2) of the Water Act (Act 54 of 1956) it is stated that –

"Nothing in this Act contained shall be construed as affecting or derogating from any rights, powers, duties or functions vested in, conferred upon or assigned to the Rand Water Board under any law".

The Rand Water Board was constituted by the Rand Water Board Incorporation Ordinance, 1903 (Transvaal) to supply water within the limits of supply as defined in that Ordinance.

The constitution, powers, rights and duties of the board have from time to time been altered and added to by subsequent Ordinances and Acts of the Union Parliament all of which, together with the Rand Water Board Incorporation Ordinance of 1903 (Transvaal) it became expedient that the Rand Water Board Statutes 1903 – 1049 be consolidated.

This was assented to on 1st May, 1950 under the signature of the Governor-General.

However, this consolidation (Act No. 17 of 1950) was amended later by Act 29 of 1964. The Board was given (*inter alia*) powers to impound water in the Vaal River. This gave the Board the right to maintain the barrage and to impound and store behind the barrage a stated volume of water and to abstract a specified quantity of water each month: a limit was placed on the average daily amount which could be distributed by pipeline to users of the water such as the municipalities, mines and railways.

The transmission of water by the Board to users was subject to the priviso that "the board shall at all times discharge or permit to flow over or through the barrage such quantity of water as has been determined by the Extraordinary Water Court constituted in terms of section *fourteen* of the Act of 1914 as being the normal flow which shall be passed through the storage works for the use of riparian owners below the barrage".

In terms of Act 17 of 1950 the Board consisted of thirty-four members of whom one was appointed by and was also removable by the Governor-General. Sixteen members were appointed by the Transvaal Chamber of Mines, one by the Railway Administra-

*Now reverted to the title of "Water Affairs".

tion, five by the City Council of Johannesburg, one by the City Council of Pretoria, and one by each of the following Town Councils: Benoni, Boksburg, Brakpan, Germiston, Krugersdorp, Nigel, Randfontein, Roodepoort-Maraisburg, Springs and Vereeniging.

At present, the Minister of Water Affairs of the Republic has power to appoint a Chairman and Members of the Board and the State President has power to extend the areas of distribution/transmission of Rand Water Board water. At present Rand Water Board water is pumped as far afield as Rustenburg and well into the Orange Free State.

The Rand Water Board co-operates with the Department of Water Affairs in the prevention of pollution of its impoundment from areas some 50 to 60 kilometres from the intakes to its water treatment works.

In recent years the Minister has appointed as Chairman an experienced engineering executive of the Department of Water Affairs.

REFERENCE

1. McLachlan, The Institute of Sewage Purification (South African Branch), "A review of the history of the branch on the occasion of its twenty-first birthday". 23 September to 3rd October 1958.

Chapter 12 ANALYTICAL METHODS

1. METHODS OF ANALYSIS OF WASTEWATERS AND PURIFIED EFFLUENTS

"The efficiency of any process of sewage purification is measured by the difference between the impurities in the liquid before and after the process in question."

Gilbert J Fowler*

The choice of an analytical method must necessarily be conditioned by the objective of a particular investigation, project or process. A quantitative evaluation of the elements present in a mineral has pertinent significance when examined by a mineralogist. But, for an ever-changing mixture of organic and inorganic substances, as we have in sewage, such ultimate quantitative evaluations are of little assistance in following the changes which take place in sewage flow-liquors within a sewage purification works.

This being so, analytical methods have been developed which afford information, collectively, that indicate the extent of transformations occurring under aerobic and anaerobic conditions and, at the same time, act as finite measures of water quality.

Also, it will be realized that uniform procedures should be followed in carrying out any particular determination and the recording of results.

Following on Part V of the Fourth Report of the Royal Commission on Sewage Disposal, a committee appointed under the aegis of the Ministry of Health in Britain reported on *"Methods of Analysis as Applied to Sewage and Sewage Effluents"*. – This report was principally the work of Dr G McGowan.

"Methods of Analysis as Applied to Sewage and Sewage Effluents" which is published by H.M. Stationery Office, London, first appeared in 1929 and was reprinted in 1953. This booklet gives details of methods of analysis used in sewage works practice. On the other hand a report of the committee of the American Public Health Association (APHA) charged with the extension of standard procedures to all methods involved in the analysis of water, in 1905, became the first edition of *"Standard Methods of Water Analysis"*. Successive revised editions of this publication appeared until 1925 when the sixth edition published under the joint auspices of the APHA and the American Water Works Association (AWWA) appeared under the new title of *"Standard Methods for the Examination of Water and Sewage"*.

In 1935 the Federation of Sewage Works Associations published *"Standard Methods of Sewage Analysis"*. Merging of these two publications took place in 1947 with the publication (under the joint editorial board of the three associations) of the tenth edition entitled *"Standard Methods for the Examination of Water, Sewage, and Industrial Wastes"*.

"Standard Methods", through vicissitudes of changing title and content is now in its 16th Edition (1985) under the style and title of *"Standard Methods for the Examination of Water and Wastewater"* and is published by the APHA, AWWA and the Water Pollution Control Federation.

This publication is the most comprehensive reference obtainable at present.†

South African Bureau of Standards: Standard Test Methods

SABS Standard Test Methods must be used in all cases where compliance with permit conditions is involved or in any legal cases involving the quality of effluent and the pollution of rivers. Copies of the Standard Methods may be obtained on application to the South African Bureau of Standards at 1, Dr Lategan Road, Groenkloof, Pretoria or Private Bag X191, Pretoria, 0001.

Note: The *"Operaters Handbook"* published by the SA Branch of the Institute of Sewage Purification contains details of certain basic tests.

The following is a list of SABS standard test methods:

Water Analysis: SABS Standard Test Methods

Ammonia – free and saline	217
Arsenic	200
Bacteriological – faecal coliform, etc.	221

"Sewage Works Analyses", London, P S King and Son, New York, John Wiley and Sons, 1902, p. 1.

†A companion publication entitled *"Simplified Laboratory Procedures for Wastewater Examination"* deals with analytical procedures essential to day-to-day operation of wastewater treatment plants.

Boron	1053
Cadmium	201
Calcium hardness	216
Chemical oxygen demand	1048
Chloride	202
Chlorine – residual	1052
Chromium – total	1054
Chromium VI	206
Colour	198
Conductivity	1057
Copper	203
Cyanide	204
Fluoride	205
Hardness – total	215
Iron	207
Lead	208
Magnesium	1071
Manganese	209
*Methylene blue active substances (MBAS)	199
Mercury	1059
Nitrate plus nitrite	210
Nitrite	219
Oil and grease	1051
"Oxygen absorbed"	220
Oxygen demand (chemical)	1048
Oxygen dissolved	1047
pH	11
Phenolic compounds	211
Phosphate – ortho	1055
Selenium	1058
Sodium	1050
*Solids – dissolved	213
Solids – suspended	1049
Sulphate	212
Sulphide	1056
Turbidity	197
Zinc	214

*No longer in any specification.

For maintaining the efficient running of a sewage purification works the use of recommended methods such as those contained in the latest edition of *"Standard Methods for the Examination of Water and Wastewater"* or the SABS *"Standard Test Methods"* may be used but it is not incumbent on sewage works managers and chemists to use such methods save in the case of final effluent where the SABS standard tests must be used when submitting results to the Department of Water Affairs; or where analyses are of legal concern SABS methods, where possible, should be adhered to.

Automation and Instrumental Analysis

A great deal of progress has been made in the fields of automation and instrumental analysis and these have found application in water and wastewater technology.

A variety of automatic samplers are available for the sampling of sewage effluents and industrial effluents. Furthermore, sensors, based on ion-selective electrodes are available for a variety of determinands (e.g. F, Ca, NO_3, B, I, Br, Cl, CN, Cu, Pb, Cd, SO_4, PO_4, CNS).

Automatic pH meters, dissolved oxygen meters, conductivity and temperature recorders have been in use for some time. However, continuous monitoring systems require planned, regular maintenance and unless maintenance is thoroughly and regularly executed the results may be valueless. However, a significant development has been the production of water quality monitors incorporating means for automatic sensor cleaning and autocalibration. Cleaning is effected using ultrasonic cleaning units which are arranged to operate at pre-set time intervals.

Laboratory Analyses: Notwithstanding these developments, to ensure accuracy at all times, it is necessary to use laboratory methods of analysis. But, the importance of correct sampling cannot be overemphasized! In fact, no matter how accurately sewage liquors are analysed the results of analysis may prove of little or no account if samples are unrepresentative.

In interpreting results the following must be borne in mind:

(1) Samples are truly representative;
(2) A long period of time must not elapse between the time of sampling and the time of analysis, particularly at temperatures above that at the point of sampling.

Basic Analytical Parameters

pH Value: Hydrogen ion concentrations (H^+) are an essential factor in many biochemical processes. The acidity of a solution can be expressed in terms of normality or of gram equivalents. However, this practice was improved on for convenient instant assessment by S P L Sørensen, a Danish biochemist, who introduced the concept of Hydrogen Ion Exponent (pH) which may be defined as the negative logarithm of the hydrogen ion concentration, thus, –

$$pH = -\log_{10}[H^+] = \log_{10}\frac{1}{[H^+]}$$

$$H = 10^{-pH}$$

Likewise for hydroxyl ion concentrations $[OH^-]$ we have

$$p(OH) = -\log_{10}[OH^-]$$

Thus for concentrations from 1 gram equivalent of hydrogen ion $[H^+]$ per litre to 1 gram equivalent hydroxyl ion $[OH^-]$ per litre the degrees of acidity or alkalinity can be expressed on a pH scale from 0 to

14, where pH 7 represents neutrality; pH less than 7,0 acid; and pH greater than 7,0, alkaline. The ionic product of pure water $K_w = [H^+] \times [OH^-] \simeq 1 \times 10^{-14}$ And so pH + pOH = 14.

Note: More accurately the ionic concentrations should be expressed in activities (a).

Two methods of pH measurement can be used for sewage liquors and effluents, viz:

(1) Electrometric methods whereby the electromotive force created between a standard reference electrode (e.g. saturated calomel electrode) and a second electrode or probe placed in the sample under investigation (e.g. glass, antimony, hydrogen, quinhydrone) is measured.
(2) Colorimetric methods using indicators.

Note: The antimony electrode, if allowed to stand in septic sewage for some time becomes coated with sulphide and ceases to function satisfactorily.

The glass electrode is favoured by most analysts. Proprietary instruments are marketed for this purpose which give dial or digital pH recordings.

It should be noted that ordinary glass electrodes function satisfactorily within the range pH 0 to pH 9. At pH values beyond 10 errors may be encountered depending on the type of glass, temperature and composition of the solution.

The colorimetric method of determining the pH value is not suitable for unbuffered solutions, or colloidal solutions where interaction of the colloidal particles with the indicator takes place. High salt concentrations give rise to a so-called "salt error". Colorimetric methods should only be used on clear samples after filtration through laboratory filter paper.

Total Solids: This involves pouring a measured volume of sample into a tared evaporating basin (platinum, silica or porcelain), evaporating to dryness, first on a water bath and then in a steam-heated drying oven. Before weighing the basin should be allowed to come to constant weight in a desiccator.

The difference between the two weighings gives the "total solids" in the volume of sample taken.

Volatile Solids: The amount of volatile matter (e.g. in sludge) can then be determined by placing the basin containing the dried solids in a muffle furnace at c. 700°C and igniting the contents – cooling to constant weight in a desiccator and re-weighing. The solids loss-on-ignition represents the volatile solids.

**Total Dissolved Solids:* The procedure is the same as for "total solids" save that the aliquot taken shall have had all suspended matter previously removed by filtration through an asbestos-packed Gooch crucible, an ultrafilter or subjection to centrifugation at 2 000 g.

Suspended Solids: This involves separating the suspended solids from the aqueous solution by filtration or centrifugal techniques and determining the weight of the dried solids directly or by difference.

Phase separation methods may include the Gooch crucible method; the use of finer-grade glass-fibre filters (e.g. Whatman types GF/C and GF/F) or polymeric filters (e.g. Millipore, Gelman, Nucleopore, Sartorius); the use of ultrafiltration techniques; centrifugation techniques.

A "rough and ready" routine method consists in weighing a dry (Whatman No. 3) filter paper, filtering a measured aliquot through the filter paper – drying the filter paper at 110°C – and re-weighing; the difference giving the weight of suspended solids in the known volume of sample.

Free and Saline Ammonia: Refer to SABS 217 method.

A commonly used method consists in adding a few drops of a saturated sodium carbonate (Na_2CO_3) solution to a diluted sample (20 to 100 mℓ sample added to c. 500 mℓ NH_3-free water) in a distillation flask; distilling and collecting 250 mℓ distillate.

Nessler Reagent solution is then added and the intensity of colour compared with a standard NH_4Cl solution using a Nessler tube, comparator (colorimeter) or spectrophotometer.

Nessler Reagent:
(1) 70 g KI in 200 mℓ distilled water (NH_3-free).
(2) Saturated solution of $HgCl_2$ (mercuric chloride).
(3) 960 mℓ of 25 per cent (w/v) NaOH.

Place 70 g KI in a glass container (e.g. a Winchester) and add 200 mℓ (ammonia-free) distilled water. Pour in enough saturated $HgCl_2$ solution to leave a faint excess. Add the 960 mℓ of 25 per cent NaOH and then more $HgCl_2$ solution to give a yellow precipitate. Dilute to 2 ℓ. Allow the container to stand for a day or two before using the clear solution.

Freshwater Biological Society Method: A method found useful by members of this association is described by Mackereth, Heron and Talling in *"Water Analysis: Some Revised Methods for Limnologists"*, 1978. The method is based on the fact that ammonia reacts with phenol and hypochlorite in an alkaline solution to form indophenol blue: the reaction is catalysed by nitroprusside. The resultant absorbance is proportional to the ammonia present, and is measured spectrophotometrically at 635 nm.

Oxygen Absorbed from Acid Permanganate at 26,7°C: Refer to SABS 220. To 50 mℓ of N/80 $KMnO_4$ solution and 10 mℓ of 25 per cent (v/v)

*In the case of purified sewage effluents this has been replaced by the "conductivity method" which is a rapid and reasonably precise method that does not consume any of the sample. The SABS 1057 method should be used.

H_2SO_4 an appropriate aliquot of the sample is added and the whole allowed to stand for 4 h when KI (10 per cent (w/v) solution) in adequate amount is added and the iodine liberated by the excess $KMnO_4$ is then titrated with N/40 $Na_2S_2O_3$ using starch (1 per cent, w/v) as an indicator.

It is desirable to arrange that about 50 per cent of the $KMnO_4$ available is used up (before addition of the KI) thus to ensure that there is an excess of $KMnO_4$ present.

Note: A procedural variation of this determination is referred to as the Permanganate value (or PV value).

Chemical Oxygen Demand (COD): Refer to SABS 1048 or *"Standard Methods for the Examination of Water and Wastewater."*

This is carried out by refluxing 50 mℓ of sample or an aliquot diluted to 50 mℓ to which has been added 25 mℓ of 0,25 N potassium dichromate ($K_2Cr_2O_7$) solution and, thereafter, 75 mℓ conc. H_2SO_4 carefully added thereto, in portions, with mixing.

A 300 mℓ round-bottom flask with ground glass neck and (ground-glass-fitting) glass upright condenser is used and refluxing carried out for 2 h, after which the contents are swilled from the glassware apparatus into a 500 mℓ Erlenmeyer flask, diluted to 350 mℓ and the excess $K_2Cr_2O_7$ titrated with standard ferrous ammonium sulphate [$FeSO_4(NH_4)_2SO_4.6H_2O$] solution using ferroin (2 to 3 drops) as an indicator.

Chloride: Refer to SABS 202. The method consists in titrating a measured volume of the sample with standard silver nitrate ($AgNO_3$) solution using potassium chromate (K_2CrO_4) as indicator.

If the $AgNO_3$ solution contains 4,79 g pure $AgNO_3$ then 1 mℓ ≡ 1 mg Cl.

Note: This estimation is only applicable to neutral solutions.

Nitrite: Refer to SABS 219. Two commonly used methods are the "Griess-Ilosvay Method" and the "Meta-phenylene diamine Method"

Griess-Ilosvay Method: Solutions required are –

(i) Standard sodium nitrite solution containing 3 g $NaNO_2$/ℓ (1 mℓ ≡ 0,6 mg N);

(ii) Sulphanilic acid solution, made as follows:

sulphanilic acid	4 g
glacial acetic acid	60 mℓ
water (distilled)	1 140 mℓ

(iii) α Naphthylamine acetate solution, made as follows:

α naphthylamine	0,7 g
glacial acetic acid	70 mℓ
water (distilled)	1 130 mℓ

Dissolve the α naphthylamine in the conc. acetic acid first and then add the distilled water.

The solutions (ii) and (iii) are stock solutions and require to be mixed 1:1 by volume when required for estimating NO_2.

Samples of effluents for analysis should be decolorized, when necessary, with char and then filtered. A suitable quantity of sample is taken and made up to 100 mℓ. 2 mℓ of Griess-Ilosvay Reagent [i.e. 1:1 mixture of solutions (ii) and (iii)] are added to each 100 mℓ sample and to 100 mℓ of the standard sodium nitrite solution. (A suitable standard should contain less than 0,08 mg N present as NO_2 per 100 mℓ otherwise a brown precipitate will be formed instead of the usual pink colour. A convenient standard contains from 0,03 to 0,06 mg N as NO_2 per 100 mℓ. This is made by diluting 1 mℓ of the standard nitrite solution to 100 mℓ and then taking an aliquot of this and making up to 98 mℓ.)

After addition of the Griess-Illosvay Reagent the samples and the standard are allowed to stand for 10 to 20 minutes until a permanent colour has developed. Comparison is then made with the standard using Nessler tubes or a colorimeter.

Meta-phenylene diamine Method: Solutions required are –

(i) Standard sodium nitrite solution containing 3 g $NaNO_2$/ℓ (1 mℓ = 0,6 mg N);

(ii) Sulphuric acid, 1:3 (v/v) H_2SO_4:H_2O

(iii) Meta-phenylene diamine

m-phenylene diamine	1 g
water (distilled)	200 mℓ
H_2SO_4 (conc.)	2 mℓ

Dissolve 1 g m-phenylene diamine in 200 mℓ distilled water. Add 2 ml concentrated H_2SO_4 and a slight quantity of phosphate-free char, then filter.

Procedure: The procedure is similar to that of the Griess-Ilosvay Method. The comparison can be made in Nessler cylinders or using a colorimeter.

Note: As a colorimetric method it will be found that the Griess-Ilosvay Method is slightly more sensitive than the m-phenylene diamine method: however, the latter method has a greater range.

A convenient standard is one of the same strength as that used for the Griess-Ilosvay Method. Take 1 mℓ standard $NaNO_2$ solution, make up to 100 mℓ as in a Griess-Ilosvay Method. Take 10 mℓ of this and make up to 98 mℓ in a measuring cylinder. Samples of effluents should be decolorized with char, filtered and made up to 100 mℓ. 1 mℓ of sulphuric acid is added to the standard $NaNO_2$ solution and to each sample. Then 1 mℓ m-phenylene diamine solution is added to the standard and the samples – all of which are allowed to stand for 10 to 20 minutes. Comparisons of colour intensities are then made with the standard.

Note: It will be found that the Griess-Ilosvay Method becomes unsatisfactory in certain instances (e.g. with certain activated sludge effluents): in such cases it will be found advisable to use the m-phenylene diamine method.

Nitrate: Sprengel or Phenol-Sulphonic Acid Method:

The solutions required are as follows:

(i) Phenol-sulphonic acid

Phenol ..... 18 g
Distilled water ..... 9 mℓ
H_2SO_4 (conc.) ..... 111 mℓ

To 111 mℓ concentrated sulphuric acid add 19 g melted phenol. Digest on a water bath for 3 to 4 h and then add 9 mℓ water.

Standard potassium nitrate containing 0,7221 g KNO_3/ℓ. This is kept as a stock solution.

(iii) Sodium hydroxide, 20 per cent (w/v) solution.

(iv) Standard silver sulphate solution: Dissolve 4,397 g silver sulphate (free of nitrate) in 1 ℓ distilled water.

1 mℓ ≡ 0,001 g Cl

Procedure: If the sample contains more than 30 mg Cl it should be neutralized with N/10 H_2SO_4 and sufficient silver sulphate (Ag_2SO_4) solution added to precipitate the chloride and the precipitate (AgCl) removed by filtration.

From 10 to 50 mℓ of sample, (after adding char and filtration if such is necessary to clarify the sample) are evaporated to dryness in a 100 mℓ glass beaker. When cold, 1 mℓ phenol-sulphonic acid and 1 mℓ distilled water are added and brought into intimate contact with the contents of the beaker. The beaker is then heated on a water bath for a few minutes, diluted with about 20 mℓ distilled water and about 10 mℓ of the sodium hydroxide (NaOH) solution added (i.e. sufficient alkali is added to produce maximum yellow colour).

A standard is made by evaporating 5 mℓ of the standard KNO_3 solution to dryness and treating it in a similar manner to the sample. Standard and sample are made up to 100 mℓ with distilled water.

If a precipitate (e.g. iron hydroxide) is formed on the addition of NaOH the samples should be filtered and the filter paper washed to avoid any loss of colour by adsorption on the filter paper.

Colour intensity comparisons are made in Nessler cylinders or using a colorimeter.

This is a direct method for determining nitrate.

Other Methods for Nitrite and Nitrate: Methods are available for determining nitrate and nitrite together, e.g. Crum's nitrometer method; the method due to Gladstone and Tribe – by reduction to ammonia with a copper-zinc couple.

However, a more recent method for the determination of nitrate alone is that due to Elliott and Porter* in which nitrate is reduced to nitrite by means of spongy cadmium and the nitrite determined spectrophotometrically using a modified Griess-Ilosvay Method.

Dissolved Oxygen: A number of methods are available for determining dissolved oxygen. These include titrimetric methods and electrometric methods using electrode probes.

Winkler Method as Modified by Rideal and Stewart: This is a reliable test and finds application in the 5-day BOD test.

This method is based on the oxidation in alkaline solution of Mn^{2+} by oxygen to the higher Mn^{4+} oxide. After acidification iodine is liberated from potassium iodine and this liberated iodine is in equivalent amount to that of the dissolved oxygen. The iodine is determined by titration with thiosulphate.

The solutions required are as follows:

(i) Concentrated sulphuric acid.

(ii) N/10 Potassium permanganate, i.e. containing 3,16 g $KMnO_4/\ell$.

(iii) 2 per cent (w/v) of the crystallized salt

$$\begin{matrix} COOK \\ | \\ COOK \end{matrix} \cdot 2H_2O \text{ in water}$$

(iv) Manganous chloride, 33 per cent (w/v) $MnCl_2$ in distilled water.

(v) Alkaline potassium iodide, a mixed solution of potassium hydroxide and potassium iodide containing 70 per cent (w/v) KOH and 10 per cent KI i.e. dissolve 700 g KOH and 100 g KI in 1 ℓ of distilled water. (NaOH may be used in place of KOH, the corresponding amounts of salts per litre being 500 g NaOH and 100 g KI.)

(vi) Concentrated hydrochloric acid, free from chlorine. (This may be substituted by sulphuric acid.)

(vii) N/40 Sodium thiosulphate, containing 6,2 g $Na_2S_2O_3.5H_2O$ and 1 g Na_2CO_3 or 10 ml N NaOH/ℓ.

(viii) Starch solution, 1 per cent (w/v) in water (distilled).

Procedure: A narrow-necked bottle of c. 350 mℓ capacity provided with a well-fitting glass stopper is used for the test, the volume of the bottle being noted.

The bottle is gently filled with the sample to overflowing and the stopper gently inserted (with a swirling motion) and the dissolved oxygen determined as follows:

Add 0,9 mℓ sulphuric acid followed by sufficient potassium permanganate (usually 1 to 2 mℓ) to ensure a slight excess of the latter. After re-inserting the stopper, mix – by turning the stoppered bottle over (by hand) a few times – then allow the bottle to stand for 20 min. (The function of the permanganate is to oxidize any nitrite present to nitrate.)

After 20 min have elapsed the excess permanganate is destroyed by adding 1 mℓ of the oxalate solution, the bottle being re-stopped and the contents mixed by rotary hand movement.

After decolorization, 1 mℓ of manganous chloride is run in from a pipette at the bottom of the bottle: in using the pipette care must be taken to prevent the admission of air to the contents of the bottle when

*Analyst, London, 1971, **96**, 522.

withdrawing the pipette. Immediately thereafter 4 mℓ of the mixed (KOH + KI) solution is added by means of a dropping pipette to ensure quick addition below the surface.

The stopper is again inserted and the contents of the bottle mixed by turning the bottle over once or twice, allowed to stand for a few minutes, turned over again and allowed to stand for a further period. (This procedure ensures adequate settlement of the hydroxides of manganese.)

5 mℓ of hydrochloric acid are now added to the contents of the bottle, the stopper re-inserted and the bottle set aside (out of the light) for 5 min, with occasional rotation.

After the rejection of the top 20 mℓ the remaining contents of the bottle are titrated with N/40 sodium thiosulphate solution using the starch solution as indicator. The dissolved oxygen is taken as being derived from 330 mℓ (350 – 20) sample.

The "oxygen equivalent" being known the amount of dissolved oxygen can be calculated. The weight of iodine equivalent to 1 mℓ thiosulphate multiplied by 0,06303 gives the "oxygen equivalent" in grams. The sodium thiosulphate requires regular standardization with iodine.

Miller Method: This is a rapid determination.

Procedure: To 50 mℓ of the sample in a 100 mℓ Nessler cylinder 5 mℓ of alkaline tartrate solution* and 1 drop of phenosafranine indicator are added and the surface covered with 3 mℓ paraffin. Standard ferrous sulphate solution is then run in – small amounts at a time (e.g. 1 mℓ) – from a graduated pipette or burette provided with a special delivery attachment for adding solution below the paraffin layer. Stirring should take place with each addition of ferrous sulphate until the colour fades; after which the additions of ferrous sulphate are progressively reduced until the colour is finally discharged.

For the quantities indicated, the ferrous sulphate used in mℓ gives the mℓ dissolved oxygen. (However, the ferrous sulphate solution should be standardized with oxygen saturated distilled water.)

Electrode Probe Method: The oxygen-temperature probe can be used *in situ* or as a laboratory instrument. Some instruments based on the platinum-silver electrode system require an external polarizing potential, generate a relatively small current, and require at least daily standardization.

A galvanic cell due to Mackereth† which requires no external polarizing potential and generates a relatively large current, is stable over long periods. The housing incorporates a thermistor, by which the temperature of the aqueous sample or water body can be measured.

The device consists of a galvanic cell protected from the external environment by a membrane which is basically only permeable to gases. The cell consists of a perforated cylindrical silver electrode inside which is a large porous annular lead electrode. The two electrodes, together with the thermistor, are mounted on a plastic body and the cell is isolated from the external aqueous environment by a polyethylene membrane covering the silver electrode. The electrolyte in the cell is a saturated aqueous solution of potassium hydrogen carbonate which may be incorporated as an agar gel.

The electrode processes are as follows:
At the silver electrode, with oxygen present,

$$^1/_2\ O_2 + H_2O + 2\bar{e} \longrightarrow 2\ OH^-$$

At the lead electrode we have –

$$Pb \longrightarrow Pb^{2+} + 2\bar{e}$$

The Pb^{2+} ions react with the OH^- ions to produce $Pb(OH)_2$. The overall cell process results in the precipitation of $Pb(OH)_2$ on the Pb-electrode, thus –

$$^1/_2\ O_2 + Pb + H_2O \longrightarrow Pb(OH)_2$$

When the silver and lead electrodes are connected through a circuit of low resistance incorporating a current measuring instrument the rate of electron flow from the lead electrode to the silver electrode will be shown to be related to the oxygen supplied to the silver electrode.

Therefore, such a cell can be used for determining dissolved oxygen concentration.

Note: When not in use the cell must be kept in a deoxygenated state e.g. by addition of Na_2SO_3 solution or by sealing the system from contact with oxygen or air. The membrane requires replacing from time to time.

The temperature coefficient of the oxygen concentration is stated to be c.6 per cent per °C.

Ortho-phosphate: It is recommended that the SABS 1055 method be followed.

A suitable method is based on the fact that in acid solution phosphate reacts with ammonium molybdate $(NH_4)_6\ Mo_7O_{24}.4H_2O$ solution to produce molybdo-phosphoric acid which, on reduction, (e.g. with activated stannous chloride) yields the intensely coloured molybdenum blue complex which can be evaluated spectrophotometrically.

Residual Chlorine: Refer to SABS method 1052. The more commonly used methods are colorimetric ones based on the use of orthotolidine which produces a yellow colour with chlorine. The colour produced is then compared with empirical standards prepared from chromate-dichromate or iodine solutions.

*Alkaline tartrate: 346 g Rochelle salt ($KNaC_4H_4O_6 - 4H_2O$) and 100 g NaOH per litre.

†Mackereth, F.J.H., J. Scient. Instrum., 1964, **41**, 38.

Volatile Acids in Sludge: The term volatile fatty acids is applied to the first 6 lower molecular weight (water soluble) fatty acids. These may be determined in a suitable aliquot of sludge (raw or digested) e.g. 50 mℓ, diluting to 200 mℓ and steam-distilling off a distillate of 150 mℓ and titrating this with standard NaOH solution using phenolphthalein as indicator. The acidity is expressed as mg/ℓ volatile acids as acetic acid (CH_3COOH).

Methods for Assessing Bacteriological Pollution

Refer to the following publications:

(i) SABS 241, *"Specification for Water for Domestic Supplies"*.
(ii) Department of Health and Social Security – Report No. 71, *"The Bacteriological Examination of Water Supplies"*, London, H.M. Stationery Office, 1977.
(iii) *"International Standards for Drinking Water"*, World Health Organization, Geneva, 1971.

Coliform Organisms and E. coli: Bacteria commonly used as indicators of faecal contamination are the coliform group of organisms as a whole and, in particular *Escherichia coli*. Coliform organisms may be regarded as gram-negative, oxidase-negative, non-sporing rods capable of growing aerobically on an agar medium containing bile salts and able to ferment lactose within 48 h at 37°C with the production of both acid and gas.

E. coli is a coliform organism, which is capable of fermenting lactose with the production of acid and gas at both 37°C and at 44°C in less than 48 h.

The enumeration of coliform organisms can be carried out by two methods, viz. –

(1) The multiple tube method.
(2) The membrane filtration method.

In the former method measured volumes of the samples (e.g. sewage effluent) are added to test tubes or bottles containing a suitable medium (e.g. MacConkey broth). Each container is provided with a Durham's tube. After incubation the formation of acid is noted by the colour of the broth (imparted to the broth by the indicator) and gas by the gas formed in the Durham's tubes.

The second method involves filtering a measured volume of the sample through a membrane filter. The bacteria retained on the surface of the membrane are enumerated by incubating the membrane face upwards on a suitable medium and counting the colonies which develop on the surface of the medium during an incubating period of 18 h.

This method is subject to statistical variations. Replicate counts on the same sample do not give the same results.

MacConkey Broth – Single-strength Medium

Bile salts*	5 g
Peptone	20 g
Lactose	10 g
NaCl	5 g
Bromocresol purple (1% ethanolic solution)	1 mℓ
Distilled water	1 000 mℓ

Mix all the ingredients except the lactose and the indicator (bromocresol purple), steam to dissolve and store at 4°C overnight. Filter while still cold, add the lactose and allow to dissolve. Adjust the pH value of the mixture to 7,4. Add the bromocresol purple and distribute in 5 mℓ volumes into 150 mm × 16 mm test-tubes.

Double-strength MacConkey Broth is prepared in the same way using double the quantities of ingredients per 1 000 mℓ. It is distributed in 10 mℓ volumes into 150 mm × 19 mm test-tubes and in 50 mℓ volumes into screw-capped bottles of at least 142 mℓ capacity. Each test-tube or bottle should contain a Durham fermentation tube of suitable size. Sterilize in an autoclave† at 115°C for 15 min (at least).

Faecal streptococci

On occasions it may be considered desirable to supplement the examinations for coliform organisms and *E. coli* in potable water (or discharges leading to public water supply impoundments). In such cases resort may be had to an examination for faecal streptococci.

Faecal streptococci may be detected and enumerated as follows:

Inoculate multiple aliquots of the sample into tubes of single or double strength glucose azide broth, and incubate at 45°C for 48 h; all tubes showing acidity at this temperature for this incubation period contain faecal streptococci.

Glucose Azide Medium (after Hannay and Norton)

Peptone	10 g
NaCl	5 g
K_2HPO_4 (potassium hydrogen phosphate)	5 g
KH_2PO_4 (potassium dihydrogen phosphate)	2 g
Glucose	5 g
Yeast	3 g
Sodium azide (NaN_3)	0,25 g
Bromocresol purple (1,6% ethanolic solution)	2 mℓ
Distilled water	1 000 mℓ

Steam to dissolve all the ingredients; the pH value of the medium should be 6,6 to 6,8 and no adjustment should be necessary. Distribute in test-tubes in 5 mℓ volumes and sterilize in an autoclave at 121°C

*The term "bile salts" includes sodium taurocholate and sodium tauroglycocholate.
†A large pressure cooker is also suitable for the purpose.

for 15 min. For use with inocula of 10 or 50 mℓ aliquots, double this concentration is prepared and distributed in 10 to 50 mℓ volumes.

Collection, Transport and Storage of Samples

Scrupulous care requires to be exercised in taking samples for bacteriological examination to ensure that such samples are truly representative and that no external contamination has taken place during sampling and subsequently.

Sterilized glass bottles with ground-glass stoppers (or metal screw caps) should be used: the stoppers and necks of bottles should be protected by satisfactory covers of paper, parchment or thin aluminium foil.

If the samples contain or are likely to contain traces of chlorine, chloramine, or ozone it is necessary to add to the sampling bottles before sterilization, a sufficient quantity of sodium thiosulphate ($Na_2S_2O_3.5H_2O$) to neutralize these substances. In this connexion it should be noted that 0,1 mℓ of a 3 per cent (w/v) solution of sodium thiosulphate in a 170 mℓ bottle has no significant effect on the coliform or *E. coli* content of unchlorinated water during 6 h storage. This amount of sodium thiosulphate is sufficient to neutralize at least 5 mg/ℓ of residual chlorine.

Samples should be examined as soon as possible after sampling.

The period which elapses between the times of sampling and examination should never exceed 24 h. Even when kept in ice or ice-salt mixtures the maximum time-lapse should not exceed 6 h.

Interpretation of the Results of Analysis

"Strength" of Sewage: Adeney* considered that a classification of the substances which may occur in polluted water may be based on their behaviour towards the dissolved oxygen of the water, as follows:

(1) Directly oxidizable substances.
(2) Indirectly oxidizable substances.

These latter, be stated, may be further subdivided, according to their fermentative properties into

(a) Carbon oxidizable substances, that is, most known organic substances, except antiseptics.
(b) Nitrogen fermentable substances, that is, the waste products from first stage fermentation and ammonium compounds.

The "strength" of sewage came to be regarded in terms of the oxygen required to oxidize the carbonaceous and ammoniacal matter biochemically.

However, the "long aeration" method of Adeney was time consuming and more rapid test methods were sought.

McGowan,† in a "Memorandum as to the best method of expressing or measuring 'strength' of sewage as affecting purification" states, as follows:

"We are satisfied that 'strength', as affecting purification, can at the present time be best expressed and measured in terms of the amount of oxygen required for the complete, or practically complete, oxidation of its organic matter".

McGowan states further, "Although the 4 hours 'oxygen absorbed' test cannot be taken as measuring accurately the carbonaceous 'stength' of a sewage, our experience leads us to consider it (using a large excess of strong acid permanganate) a good rough guide for arriving at the degree of oxidizability of domestic sewages and tank liquors, apart from the cellulose and fat which these contain and also apart from the ammonia and organic nitrogen".

McGowan put forward the following formula (after modification of his originally reported one), viz. –

Strength of sewages = (Ammon. N + Organic N) × 4,5 + (Oxygen Absorbed in 4 hours × 6,0).

However, as he rightly points out, "the foregoing method of arriving at 'strength' of sewage has no claim to anything like absolute accuracy".

McGowan, Frye and Kershaw in the 8th Report of the Royal Commission on Sewage Disposal, Volume II – Appendix, reported on *"Standards and Tests for Sewage and Sewage Effluents Discharging into Rivers and Streams"*.

They dealt with the following determinations:
Ammoniacal nitrogen
Albuminoid nitrogen
Total organic nitrogen
Oxygen absorbed from permanganate in 4 h
The incubator test
Dissolved oxygen absorption (5 days at 18,3°C)
Suspended solids
Nitrous and nitric nitrogen
Chlorine
Solids in solution
Hardness

They have concluded by stating that, "of the test usually applied in the examination of sewage liquors and effluent, the determination of the dissolved oxygen absorption in 5 days at 18,3°C (65°F) affords, on the whole, a better index than any other single test of the effect which such liquors or effluents will exert on the water of a stream. For this reason we consider that, taken in conjunction with the determination of suspended solids, it constitutes the best practical test for purposes of a standard for effluents".

The 5-day dissolved oxygen absorption test, now referred to as the 5-day BOD test, has had a vastly extended use as a parameter not merely of effluent

*Royal Commission on Sewage Disposal, 5th Report Appendix VI, p. 108.
†Royal Commission on Sewage Disposal, 5th Report Appendix IV, pp. 1-9.

quality but also as a "load" factor to assess the performance of purification plant units.

However, no single test can determine the "strength" of a sewage liquor and any formula incorporating well-known tests will have limited application even for domestic sewage.

We can obtain, of course, a bird's-eye picture of the overall nature of a sewage and a conception of its likely biochemical breakdown by carrying out an array of tests such as those which have been canvassed, each with a particular objective in view.

Significance of Individual Tests

pH Value: This finds application in the following circumstances:

(1) The anaerobic digestion of sludge where the pH value of the digesting sludge should be within the range 6,5 to 7,5 (preferably 7,0 to 7,2).
(2) The activated sludge process where the mixed liquor should have a value close to pH 7,0 (the pH value of the influent, of course, will vary).
(3) Sewer protection: (i) Where industrial effluents are discharged into concrete sewers the pH values of such effluents should be near 7,0 – in order to prevent corrosion below the water-line; (ii) in long outfall sewers the sewage may become septic (acid) and where ventilation is inadequate the H_2S (resulting from the acid fermentation) and oxygen present will result in the formation of H_2SO_4 (bacteriologically) above the water-line. The H_2SO_4 will attack the free lime in the cement resulting in the formation of calcium sulphate crystals which leads to rupture of the hard internal surface skin of the sewer and so leads to catastrophic corrosion of the sewer above the water-line.
(4) For effluent discharging into a river (e.g. the final effluent from a sewage purification plant or an industrial effluent) the pH-range must conform with the following:

    (i) For "General Standard" catchment areas 5,5 to 9,5;
    (ii) For "Special Standard" catchment areas 5,5 to 7,5.

Total Solids and Volatile Solids: These two determinations afford information on the organic content of raw and digested sludge.

Total Dissolved Solids: This serves as a parameter for controlling the increase in dissolved solids above that of the conveyance water as follows:

(i) For "Special Standard" areas increase $\not>$ 15 per cent;
(ii) For "General Standard" areas increase $\not>$ 500 mg/ℓ.

Note: In South Africa, due to rainfall conditions and the nature of the Republic's rivers, it is essential that escalation of the dissolved solids content of rivers feeding water impoundments should not occur.

Suspended Solids: This indicates the amount of colloidal or finely divided matter in an effluent. The following limits should not be exceeded:

(i) For "Special Standard" catchment areas, 10 mg/ℓ;
(ii) For "General Standard" catchment areas, 25 mg/ℓ.

Free and Saline Ammonia: Urine is an important constituent of sewage (refer to Chapter 3, Section 2, "The Chemical Composition of Sewage and the Transformation of the Constituents during Treatment"). Urine contains urea and sodium chloride. Urea readily decomposes to produce ammonia. Other amino compounds are present and one of the functions of sewage purification is the biochemical oxidation of nitrogenous matter. The elimination – by transformation – of all free and saline ammonia, therefore, is a desirable objective. The limits promulgated are 1,0 mg/ℓ and 10 mg/ℓ respectively for "Special" and "General" Standard catchment areas.

Chloride: Control of industrial effluents should be exercised to ensure that the chloride content is not allowed to increase beyond the normal domestic sewage value for a particular sewage.

Note: At one time, chloride was used as a "strength" parameter for domestic sewage.

"Oxygen Absorbed" or Permanganate Value: This test, in these two procedural forms has been widely used to indicate the amount of oxidizable carbonaceous material in sewage. The "4 hours oxygen absorbed" test does not give absolute values but for a purified effluent the value should be low ("Special Standard", 5 mg/ℓ; "General Standard", 10 mg/ℓ).

Chemical Oxygen Demand (COD): It is considered that this test has better application than the "Oxygen Absorbed" test for cases where industrial wastes are present in the sewage. A limit of 75 mg/ℓ ("General Standard") has been set for effluent in "General Standard" catchment areas and 30 mg/ℓ for "Special Standard" areas.

Nitrite and Nitrate: The oxidation of ammonia to nitrite is carried out by *Nitrosomonas* and related nitrifying bacteria. The subsequent oxidation of nitrite to nitrate is carried out mainly by *Nitrobacter*.

The reduction of nitrate can also occur due to the catalysing influence of certain facultative anaerobes including *E. coli* and certain denitrifying species of *Pseudomonas*.

The nitrification process in biofilters and activated sludge plants can be followed by determining free and saline ammonia and nitrite throughout the plants. Low NH_3 and NO_2 values in a final effluent are indicative of satisfactory nitrification.

However, nitrate together with phosphate can cause eutrophication of impoundments. Also, high nitrate (> 45 mg/ℓ as NO_3; 10 mg/ℓ as N) presents a health hazard for infants since after reduction to nitrite methaemoglobinaemia could result. The "Special Standard" requirement is 1,5 mg/ℓ (as N).

Dissolved Oxygen: An adequate amount of dissolved oxygen is required by fish and other aquatic organisms. A complete change in the flora and fauna of a river can result from the discharge into it of effluent which reduces the dissolved oxygen content of the river water. For this reason the dissolved oxygen in a final effluent should be at least 75 per cent saturated at the temperature and pressure persisting.

Ortho-phosphate: Due to the significant part played by phosphate in the triggering-off of eutrophication it became necessary, in a number of sensitive catchment areas, to control the level of reactive phosphate in effluents. As from 1 August 1985 the amount of ortho-phosphate in an effluent discharging into such catchment must not exceed 1 mg/ℓ as P.

Residual Chlorine: To protect the flora and fauna in a river it is necessary to limit the amount of chlorine, after the necessary contact period, before discharge to 0,1 mg/ℓ (as Cl) for "General Standard" catchment areas and to nil for "Special Standard" areas.

Volatile Acids in Sludge: In sludge digestion the volatile acid should be within the range 250 – 1 000 mg/ℓ as CH_3OOH and should not be allowed to exceed 2 000 mg/ℓ. Adjustment may be effected by the addition of lime.

E. coli: E. coli should be absent in 100 mℓ of sample – but, in certain circumstances, e.g. discharge to sea, this requirement may be relaxed.

Note: The promulgated requirement (Government Notice No. R.991 of 18 May 1984) states that for both "Special" and "General" Standard catchment areas, "The waste water or effluent shall contain no typical (faecal) coli per 100 mℓ."

2. IONIC SPECIES IN EFFLUENTS INIMICAL TO THE ENVIRONMENT IN REGARD TO: FARMING, TOXICITY TO FISH, ANIMALS AND HUMAN BEINGS

"Out of this nettle, danger, we pluck this flower, safety"

King Henry IV, Part I, Act 2, Scene 3

(i) FARMING

Aspects of farming which are influenced by the quality of water include the effects of water constituents on:
(a) the soil;
(b) plant growth, and
(c) stock watering.

(a) The Soil

Soil constitutes a four-component system of mineral particles resulting from the weathering of rocks; organic matter derived from plant and animal residues; soil solution, and air. The main constituent (except in the case of peat) is the mineral one. Additionally present in the soil matrix are a variety of micro-organisms and small animals.

The mineral particles in soil are classified as follows:

- *International Scheme (International Soc. Soil Science)*

Fraction	*Range of diameters of particles in mm*
Coarse sand	2,0 – 0,2
Fine sand	0,2 – 0,02
Silt	0,02 – 0,002
Clay	less than 0,002

- *US Department of Agriculture Scheme*

*Name of Separate**	*Diameter (range) mm*
Very coarse sand	2,0 – 1,0
Coarse sand	1,0 – 0,5
Medium sand	0,5 – 0,25
Fine sand	0,25 – 0,10
Very fine sand	0,10 – 0,05
Silt	0,05 – 0,002
Clay	Below 0,002

*Soil separates are the individual size groups of mineral particles (US Department of Agriculture, Soil Survey Manual, Agricultural Handbook No. 18).

Soils have been categorized as sand, loam, silt or clay and, intermediately as sandy loam, silt loam, or clay loam according to the relative per cent of size fractions found by mechanical analysis.

Clay particles are negatively charged and display colloidal behaviour and cation exchange properties.

Much of the colloidal clay in most soils is present as a film around the larger soil particles: it is also associated with organic material in the soil. Flocculation of clay particles results in granules compounded of sand, silt and organic matter to give the soil an overall crumb or granular structure which is desirable for good aeration and moisture retention. For this reason "calcium soils" are the most suitable for agricultural purposes since the presence of calcium ions improves the tilth of the soil.

However, in the presence of univalent cations such as sodium (Na^+), the clay fraction of the soil disperses causing the soil to lose its granular structure and so its agricultural utility is correspondingly impaired.

Base Exchange: Base (cation) exchange in soils was discovered by Thompson[1] and Way,[2] two English investigators. H S Thompson, an English landowner, engaged the services of a York analyst named Spence to investigate the loss of ammonia from manure heaps. Spence found that on causing a solution of ammonium sulphate to percolate through a column of soil, the effluent from the column contained no ammonium salts but to his surprise a considerable amount of calcium sulphate was present in the effluent. His discovery was reported to the Royal Agricultural Society in 1850 and was confirmed by J T Way, an agricultural chemist during the period 1850 to 1854, who concluded *inter alia* –

(1) The exchange (using an ammonium salt) releases an equivalent amount of calcium from the soil.
(2) The process is caused mainly by the clay fraction of the soil.
(3) Prior heat treatment reduced the absorptive power of the soil.
(4) Certain bases are more readily exchanged than others.
(5) Potassium, sodium and magnesium salts are absorbed (exchanged) in the same way as ammonium but calcium passes through into the filtrate.
(6) The absorption of ammonium increases with increase of concentration of the solution used.
(7) The process is rapid but differs from a true physical adsorption.
(8) Synthetic calcium silicate does not exhibit base exchange but a dried alumino-silicate gel has pronounced exchange capacity.

Therefore, Way would seem to have pictured base exchange as the conversion of an insoluble alumino-silicic acid from one salt form to another – i.e. ion exchange as we know it today.

The cation-exchange capacity of a soil is compounded of the cation-exchange capacity of the organic and the clay fractions and is expressed as milli-equivalents per 100 grams dry weight of soil.

The following are a number of clay and humus cation-exchange capacities:

	Cation-exchange capacity m equiv/100 g
Humus (organic fraction)	100 – 300
Montmorillonite	90 – 110
Illite	30 – 40
Kaolinite	3 – 15

Ion replacement in cation exchange follows a replacement order. Hydrogen (H^+) heads the order, followed sequentially by the following cations: barium, strontium, calcium, magnesium, potassium, sodium and lithium.

In dilute solutions the order of ion exchange affinities follows the Hofmeister lyotropic series, viz:

Li Na K Mg Ca Sr Ba Al ----- H

Therefore, if effluent containing high concentrations of sodium salts is used for irrigation, the Ca^{2+} ions will be washed out of the soil and will be replaced by Na^+ ions – so leading to dispersion of the clay and impairing the permeability of such soil.

Land flooded by sea water is ruined agriculturally – but with subsequent applications of lime its utility may be restored.

If the clay particles holding the exchangeable bases are regarded as micelles carrying a negative charge, the process of base exchange occurring with a saline effluent may be represented as follows:

$$\boxed{\text{Clay micelle}}\begin{matrix}\text{Ca}\\ \text{K}\end{matrix} + 2\,\text{NaCl} \longrightarrow \boxed{\text{Clay micelle}}\begin{matrix}\text{Na}\\ \text{Na}\\ \text{Na}\end{matrix} + \text{CaCl}_2 + \text{K}$$

Dealing with cation-exchange material, Duncan and Lister[3] state, that in minerals, ion exchange is most marked in the aluminosilicates containing cross-linked sheets of SiO_2 tetrahedra, e.g. zeolites, montmorillonite, and other clay minerals, ultramarines, glauconites and the chabazites. Felspars and kaolinite also show the phenomenon but to a lesser degree. A common feature of such minerals is an open structure permitting the free flow of ions in and out of the lattice, and there are indications that a large crystal volume per oxygen atom is associated with a large exchange capacity.

In the soil, organic material is also present in the form of humic acids and proteins. The humic acids possess cation-exchanging properties (cf. previous table) and proteins may exchange either cations or anions.

(b) Plant Growth

Crop production is also conditioned by the quality of the water used for irrigation. Adverse results can arise due to salinity, permeability, toxicity, etc.

If the amount of salts in solution in the irrigation water is excessive, accumulation of salts will take place in the root zone leading to difficulty of water uptake of the crop, thereby causing early wilting.

Train[4] has pointed out that the irrigation use of water is not only dependent upon the osmotic effect of dissolved solids, but also on the ratio of the various cations present. He has represented the hazard as indicated in the following table:

Dissolved Solids Hazard for Irrigation Water (mg/ℓ)

Water from which no detrimental effects will usually be noticed	500
Water which can have detrimental effects on sensitive crops	500 – 1000
Water that may have adverse effects on many crops and requires careful management practices	1000 – 2000
Water that can be used for tolerant plants on permeable soils with careful management practices	2000 – 5000

Permeability of the soil is influenced by three factors, viz. sodium content of the irrigation water in relation to calcium and magnesium; bicarbonate and carbonate content; the total salt concentration. These factors are dealt with in Chapter 14 under SAR (Sodium Adsorption Ratio).

Toxicity occurs within the crop itself as a consequence of the uptake of certain constituents from the irrigation water. Constituents of concern include sodium, chloride and boron.

Boron: Boron occurs as calcium or sodium borate salts. Boron is an essential element for the growth of plants. However, it has been found that sensitive crops (e.g. citrus) show toxic effects when irrigated with water containing 1 000 $\mu g/\ell$ (as B). It is considered that the limit which should not be exceeded is 750 $\mu g/\ell$ for long-period irrigation of sensitive crops.[4]

Chloride: Small dressings of chlorides appear to increase the yield and improve the texture of the tobacco leaf without affecting its burning qualities. However, larger dressings, which still increase the yield, lower the quality.[5]

Salinity: Maas and Hoffman,[6] quoting Bernstein,[7] state that the predominate soluble ions in saline soils and waters are sodium, calcium, magnesium, bicarbonate, chloride and sulphate. Except where ratios of these ions are extreme, most plants respond to salinity as a function of the total salt concentration. Nevertheless, some herbaceous plants and most woody species are susceptible to specific ion toxicities. For example, many fruit and berry crops are susceptible to chloride and sodium injury. Boron, an essential element for plant growth, is often found in saline soils at concentrations toxic to many plants.

pH Value: To avoid undesirable effects in irrigation waters, the pH range 4,5 – 9,0 should not be exceeded.

Arsenic: For the irrigation of crops the concentration of arsenic in the water should not exceed 100 $\mu g/\ell$. (This has significance where herbicides containing arsenic are used.)

Beryllium: The concentration of beryllium in irrigation waters should not exceed 100 $\mu g/\ell$ (as Be). Beryllium can inhibit photosynthesis in terrestrial plants and toxicity towards some varieties of citrus seedlings as well as inhibiting the growth of tomatoes, peas, soybeans, lettuce and lucerne.

Lead: Lead nitrate has been found to be toxic to the following, in the concentrations listed, viz – In experiments with oats and tomato plants it was found that death occurred at a concentration of 50 mg/ℓ and with beans 30 mg/ℓ. Root growth is reduced at a concentration of 10 mg/ℓ. However, these Pb concentrations are above those likely to occur in soils but could occur in effluents.

Nickel: Nickel in concentrations at or below 100 $\mu g/\ell$ in irrigation water should not be harmful to plants.

Phenol: 50 mg/ℓ should not interfere with irrigation.

Trace elements: Elements essential for plant nutrition – the so-called minor or trace elements – include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, calcium, magnesium and iron.[8] However, Meyer and Anderson[9] have pointed out that in addition to the ten elements cited by Robinson[8] that claims for the inclusion of further elements considered essential have been made. These include arsenic, aluminium, barium, boron, bromine, caesium, chromium, chlorine, cobalt, copper, iodine, lithium, manganese, nickel, selenium, silicon, strontium, tin, titanium, vanadium and zinc. These authors point out that at least two elements in this list, boron and manganese, must be added to Robinson's[8] list of ten elements. Of the "further" elements quoted in the additional list Meyer and Anderson[9] state that, "With few exceptions all of them, in fact, are toxic in any appreciable concentration".

The toxicity of any element varies greatly depending on its ionic concentration. This is strikingly shown by the salts of the "heavy metals" such as iron, copper, mercury, etc. Even essential elements such as magnesium, calcium and potassium may exert slight toxic effects in certain circumstances.

Iron: Iron salts in appreciable concentrations are toxic to plants. Ferrous salts are more toxic than ferric salts. (In fact, ferrous sulphate has been used as a weed-killer.)

Manganese: Except in very low concentrations manganese salts are distinctly toxic to plants. (At concentrations as low as 1 mg/ℓ in soils of pH 6.)

Zinc: When present in appreciable concentrations zinc ions are highly toxic.

Aluminium: Except in very dilute solution aluminium is distinctly toxic to plants.

(c) Stock Watering

Permissible mineral concentrations in drinking water for cattle have been given by the Department of Agriculture[10] as follows:

	mg/ℓ
Total Dissolved Solids	5 000
Element or ionic species	
Calcium	1 000
Magnesium	500
Sodium	2 000
Sulphate	1 000
Chloride	3 000
Fluoride	6

Train[4] has assembled information collected from various reliable sources in regard to water criteria for a large number of purposes, including toxicity, etc. to livestock, viz.

Iron: Iron at exceedingly high concentrations has been reported to be toxic to livestock and to interfere with the metabolism of phosphorus.

Lead: Lead is a toxic metal that tends to accumulate in the tissues of man and animals. The toxicity of lead in water is affected by the pH value of such water, its hardness, organic matter and other metals present. The water solubility of lead ranges from 500 μg/ℓ in soft water to 3 μg/ℓ in hard water.

Manganese: Manganese does not appear to be a problem in water consumed by livestock.

Mercury: It is considered that the mercury content of drinking water for livestock should not exceed 0,05 μg/ℓ.

Phenol: Concentrations up to 1 000 mg/ℓ should not interfere with stock watering.

Selenium: Animals can beneficially metabolize selenium in amounts of 0,01 to 0,10 mg/kg of food ingested.

Boron: It is reported that a dairy cow fed 16 to 20 g per day of boric acid for 40 days showed no ill effects.

Nitrate poisoning: Reference should be made to Chapter 14 under the heading "Drinking Water for Cattle".

(ii) TOXICITY TO FISH

The following are the recommended criteria* levels for a water quality that will provide for the protection and propagation of fish:

Alkalinity: 20 mg/ℓ or more as $CaCO_3$ for freshwater aquatic life.

Ammonia: 0,02 mg/ℓ (as unionized ammonia) for freshwater aquatic life.

In water an equilibrium is established –

$$\underset{\text{Ammonia (gas)}}{NH_3} + \underset{\text{Water}}{H_2O} \rightleftharpoons \underset{\text{Unionized ammonia}}{NH_3.H_2O} \rightleftharpoons \underset{\text{Ammonium ion}}{NH_4^+} + \underset{\text{Hydroxyl ion}}{OH^-}$$

Toxicity is due to the unionized NH_3 and is dependent on the pH value of the water as well as the concentration of total ammonia ($NH_3 + NH_4^+$) as is illustrated by the table below.

Barium: For both freshwater and marine environments toxicity is considered likely to occur in concentrations in excess of 50 mg/ℓ.

Beryllium: For the protection of aquatic life the following limits should not be exceeded:

*Environmental Protection Agency, Washington, 1979, Office of Water Planning and Standards, EPA.

†Thurston, R.V. *et al.*, 1979, *"Aqueous ammonia equilibrium calculations"*, Fisheries Bioassay Laboratory Technical Report No. 74-1, Montana State University, Boseman.

Per cent Unionized Ammonia in Aqueous Ammonia Solutions†

Temperature/ °C	pH Value								
	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10,0
5	0,013	0,040	0,12	0,39	1,2	3,8	11	28	56
10	0,019	0,059	0,19	0,59	1,8	5,6	16	37	65
15	0,027	0,087	0,27	0,86	2,7	8,0	21	46	73
20	0,040	0,13	0,40	1,2	3,8	11	28	56	80
25	0,057	0,18	0,57	1,8	5,4	15	36	64	85
30	0,080	0,25	0,80	2,5	7,5	20	45	72	89

11 $\mu g/\ell$ for aquatic life in soft fresh water;
1 100 $\mu g/\ell$ for aquatic life in hard fresh water.

Boron: The minimum dose for minnows exposed to boric acid at 20°C for 6 h was reported to be 18 000 to 19 000 mg/ℓ in distilled water and 19 000 to 19 500 mg/ℓ in hard water.

Cadmium: Limiting values: 0,4 $\mu g/\ell$ in soft water and 1,2 $\mu g/\ell$ in hard water for salmonid fishes; 5,0 $\mu g/\ell$ for marine fish.

It should be noted that edible marine organisms can accumulate cadmium in their body systems – A concentration factor of 1 000 for cadmium in fish muscle having been reported.

Chlorine: Total residual chlorine should not exceed 2,0 $\mu g/\ell$ for salmonid fish.

Chromium: Limit which should not be exceeded: 100 $\mu g/\ell$ for freshwater aquatic life.

Fish appear to be relatively tolerant of chromium. The toxicity varies with species, oxidation state of chromium and pH value.

Copper: The toxicity of copper to aquatic life is dependent on the alkalinity of the water as copper ions are complexed by the anions present, which, in turn, affect toxicity. In the United States, concentrations of copper below 25 $\mu g/\ell$ are not rapidly fatal to most common fish species.

Cyanide: 5,0 $\mu g/\ell$ is the limit for freshwater and marine aquatic life. Cyanide is acutely toxic to most fishes at concentrations ranging from 50 to 200 $\mu g/\ell$.

Iron: Limit: 1,0 mg/ℓ for freshwater aquatic life. The smothering effects of iron precipitates may be detrimental to fish eggs and to bottom-dwelling fish food organisms.

Lead: In general the salmonids are most sensitive to lead in soft water, but the influence of the pH value of the water and other factors on the solubility and form of the lead preclude the recommendation of a freshwater criterion based on acute toxicity alone. Lead accumulates in the tissues.

Manganese: The tolerance values range from 1,5 mg/ℓ to over 1 000 mg/ℓ for freshwater aquatic life. However, permanganates have been reported to kill fish in 8 to 18 h at concentrations of 2,2 to 4,1 mg/ℓ.

Mercury: Limits: 0,05 $\mu g/\ell$ for freshwater aquatic life; 0,10 $\mu g/\ell$ for marine aquatic life.

Nickel: Limit: 0,10 of the 96-h LC_{50}* for freshwater and marine aquatic life.

Nitrates, Nitrites:

(1) Nitrate nitrogen at or below 90 mg/ℓ is unlikely to give rise to adverse effects on warm water fish.
(2) Nitrite nitrogen at or below 5 mg/ℓ should not affect most warm water fish.
(3) Nitrite nitrogen at or below 0,06 mg/ℓ should not affect salmonid fishes.

pH Values: Limiting pH ranges: 6,5 – 9,0 for freshwater aquatic life; 6,5 – 8,5 for marine aquatic life.

Phenol: Limits: 200 $\mu g/\ell$ for fish and aquatic life; 1 $\mu g/\ell$ phenol threshold fish tainting concentration.

Phenolic compounds can affect freshwater fish adversely by direct toxicity to the fish, *per se*, and to the fish food organisms and also by tainting the fish flesh.

Phthalate Esters: Limit: 3 $\mu g/\ell$ for freshwater aquatic life.

Polychlorinated Biphenyls (PCB's): Limit: 0,001 $\mu g/\ell$ for freshwater and marine aquatic life.

Selenium: Threshold: For marine and freshwater aquatic life, 0,01 of the 96-h LC_{50} as determined by bioassay using a sensitive resident species.

Silver: Threshold: For marine and freshwater aquatic life, 0,01 of the LC_{50} as determined by bioassay using a sensitive resident species.

Total Dissolved Solids and Salinity: Fish, of all species, must tolerate a range of dissolved solids concentrations in order to survive. Freshwater fish can survive a concentration of 10 000 mg/ℓ dissolved solids.

Estuarine fish species are tolerant of salinity changes ranging from fresh – to brackish – to seawater.

Hydrogen Sulphide: Limit: 2 $\mu g/\ell$ undissociated H_2S for fish and other aquatic life, in fresh and marine water.

Zinc: Threshold: For freshwater aquatic life, 0,01 of the 96-h LC_{50} as determined by bioassay using a sensitive resident species.

(iii) ANIMALS – TOXICITY

With regard to the toxicity of certain ions in water towards animals reference should be made (in this chapter) to "Stock Watering".

*LC_{50}: The concentration of toxicant that is lethal to 50 per cent of the organisms tested under the test conditions in a specified time.

(iv) HUMAN BEINGS – TOXICANTS

Reference should be made to Chapter 14 – *"Water Quality Criteria for Various Uses"*, 1(a), 1(b); 2 *et. seq.*

Addendum

Nitrates and Nitrites:[11] In normal healthy individuals nitrates and nitrites are absorbed from the intestinal tract and excreted by the kidneys. However, in infants up to 6 months from birth (particularly the first 3 months) and in very young animals the imbibation of nitrates can be fatal.

Normally nitrites may be produced microbiologically from nitrates by micro-organisms in the gastro-intestinal tract: the resulting nitrites react with haemoglobin in the blood to form methaemoglobin.

In the case of adults the methaemoglobin formed is rapidly coverted by enzyme action to oxyhaemoglobin. However, in the case of very young infants and animals this enzyme mechanism is not completely developed and so the clinical condition known as methaemoglobinaemia results.

In this connexion it should be noted that nitrates are found in vegetables, particularly spinach. Cases of methaemoglobinaemia, some resulting in death, have taken place arising from the consumption of spinach – the spinach was fed to the young infants in the form of a pureé. It should be noted, also, that on standing, nitrates in certain foods have been found to be converted to nitrites thereby aggravating conditions.

Further Water Quality Criteria for Human Consumption

Barium: 1 mg/ℓ.

Beryllium: The toxic hazard is from the inhalation of fumes and dusts emanating from processing and fabrication operations. However, effluents from certain metallurgical plants could contain beryllium.

Beryllium is toxic by most routes of administration but its oral toxicity differs greatly from that by other routes. The sulphate, while highly toxic by all other routes at a single dose level, is practically non-toxic by mouth at a level several thousandfold greater by multiple dose.

Nickel: Nickel is considered relatively non-toxic to man.

Total Dissolved Solids and Salinity: Limit: 250 mg/ℓ for chlorides and sulphates.

*Criteria for Pesticides and Herbicides in the Aquatic Environment**

Aldrin and Dieldrin: 0,003 μg/ℓ for freshwater and marine aquatic life. Dieldrin is a highly persistent chemical which accumulates in aquatic organisms which are used for human food. It is also considered a potential human carcinogen. Aldrin is converted metabolically to dieldrin by aquatic organisms.

Chlordane: 0,01 μg/ℓ for freshwater aquatic life; 0,004 μg/ℓ for marine aquatic life.

Chlordane is a highly persistent chemical which accumulates in aquatic organisms used for human food. It is considered to be a potential human carcinogen.

DDT: 0,001 μg/ℓ for freshwater and marine aquatic life.

The persistence, bioaccumulation potential, and carcinogenicity of DDT caution human exposure to a minimum.

The Environmental Protection Agency has suspended the production and use of DDT.

Dimeton: 0,1 μg/ℓ for freshwater and marine aquatic life.

Endosulfan: 0,003 μg/ℓ for freshwater aquatic life; 0,001 μg/ℓ for marine aquatic life.

Endrin: 0,2 μg/ℓ for domestic water supply; 0,004 μg/ℓ for freshwater and marine aquatic life.

Guthion: 0,01 μg/ℓ for freshwater and marine aquatic life.

Heptachlor: 0,001 μg/ℓ for freshwater and marine aquatic life.

The persistence, bioaccumulation potential and the carcinogenicity of heptachlor cautions human exposure to a minimum.

It has been shown that oysters can accumulate heptachlor almost 18 000 times and bluegill as much as 1 840 times.

Lindane: 4,0 μg/ℓ for domestic water supply; 0,01 μg/ℓ for freshwater aquatic life; 0,004 μg/ℓ for marine aquatic life.

Malathion: 0,1 μg/ℓ for freshwater and marine aquatic life.

Methoxychlor: 100 μg/ℓ for domestic water supply; 0,03 μg/ℓ for freshwater and marine aquatic life.

Mirex: 0,001 μg/ℓ for freshwater and marine aquatic life.

Parathion: 0,04 μg/ℓ for freshwater and marine aquatic life.

*Abstracted from the recordings of Train.[4]

Toxaphene: 5 $\mu g/\ell$ for domestic water supply; 0,005 $\mu g/\ell$ for freshwater and marine aquatic life.

Chlorphenoxy Herbicides

2,4-D: 100 $\mu g/\ell$ for domestic water supply;
2,4,5-TP: 10 $\mu g/\ell$ for domestic water supply;
2,4-D(2,4-dichlorophenoxy acetic acid) and 2,4,5-TP (silvex) 2-(2,4,5-dichlorophenoxy propionic acid) are widely used herbicides.

REFERENCES

1. Thompson, H.S. J. Royal Agr. Soc., 1850, **11**, 68.
2. Way, J.T. J. Royal Agr. Soc., 1850, **11**, 313; 1852, **13**, 123.
3. Duncan, J.F. and Lister, B.A.J. Quarterly Reviews, The Chemical Society, London, 1948, Vol II, No. 4, p. 308.
4. Train, R.E. *"Quality Criteria for Water"* US Environmental Protection Agency, Washington DC, Castle House Publications Ltd. 1979.
5. Russell, Sir E.J. and Russell, E.W. *"Soil Conditions and Plant Growth"*, Eighth Ed, Longmans Green & Co, London, 1956, p. 46.
6. Maas, E.V. and Hoffman, G.J. *"Crop Salt Tolerance: Evaluation of Existing Data"*, Proc. Internat. Salinity Conf., Lubbock, Texas, 16-20 August 1976.
7. Bernstein, L. Amer. J. Bot., 1961, **48**, 909.
8. Robinson, G.W. *"The Soil"*, Revised Ed, (originally due to Sir A.D. Hall), John Murray, London, 1949, pp. 229-230.
9. Meyer, B.S. and Anderson, D.B. *"Plant Physiology"*, D van Nostrand Company Inc., Toronto, New York, London, 1950, p. 419 *et seq.*
10. Information supplied by the Director General, Department of Agriculture and Fisheries (South Africa), 1982.
11. *"Nitrates, Nitrites and N-Nitroso Compounds"*, Environmental Health Criteria 5, World Health Organization, Geneva, 1978.

Chapter 13 RIVER WATER USAGE: ADVERSE EFFECTS CAUSED BY SEWAGE EFFLUENT, INDUSTRIAL SEEPAGE, RUNOFF AND ATMOSPHERIC DISCHARGES

1 EUTROPHICATION

"As countries are settled, more and more problems arise having to do with the prodigious growth of algae in places where they are not wanted"

Josephine E Tilden*

An Exposition of the Problem



From a eutrophied impoundment.

The enrichment of the water of lakes, dams and rivers by nutrients can lead to the inordinate growth of algae and aquatic plant species. This process is referred to as eutrophication.

Algae utilize carbon dioxide, nitrate and phosphate and their metabolism also uses a number of elements in trace amounts: these include sulphur, potassium, sodium, magnesium, calcium, hydrogen, oxygen, iron, manganese, boron, molybdenum, cobalt, copper and zinc.

Three trophic states have been defined, viz. –

(1) Oligotrophic – deficient in dissolved nutrients.
(2) Mesotrophic – having a moderate amount of dissolved nutrients.
(3) Eutrophic – rich in dissolved nutrients.

The trophic status of an impoundment results from two components – (i) the cultural and (ii) the morphometric. The cultural component arises from enrichment derived from the nature of the associated catchment and the human activities within such catchment. The morphometric component is related to the size, shape and depth of the impoundment basin as is instanced by the fact that a large deep impoundment is less likely to become eutrophic than a small shallow one.

Impoundments, generally – in temperate climates – undergo an annual cycle of thermal stratification and destratification. Features of a lake or dam are shown in the drawing on page 162.

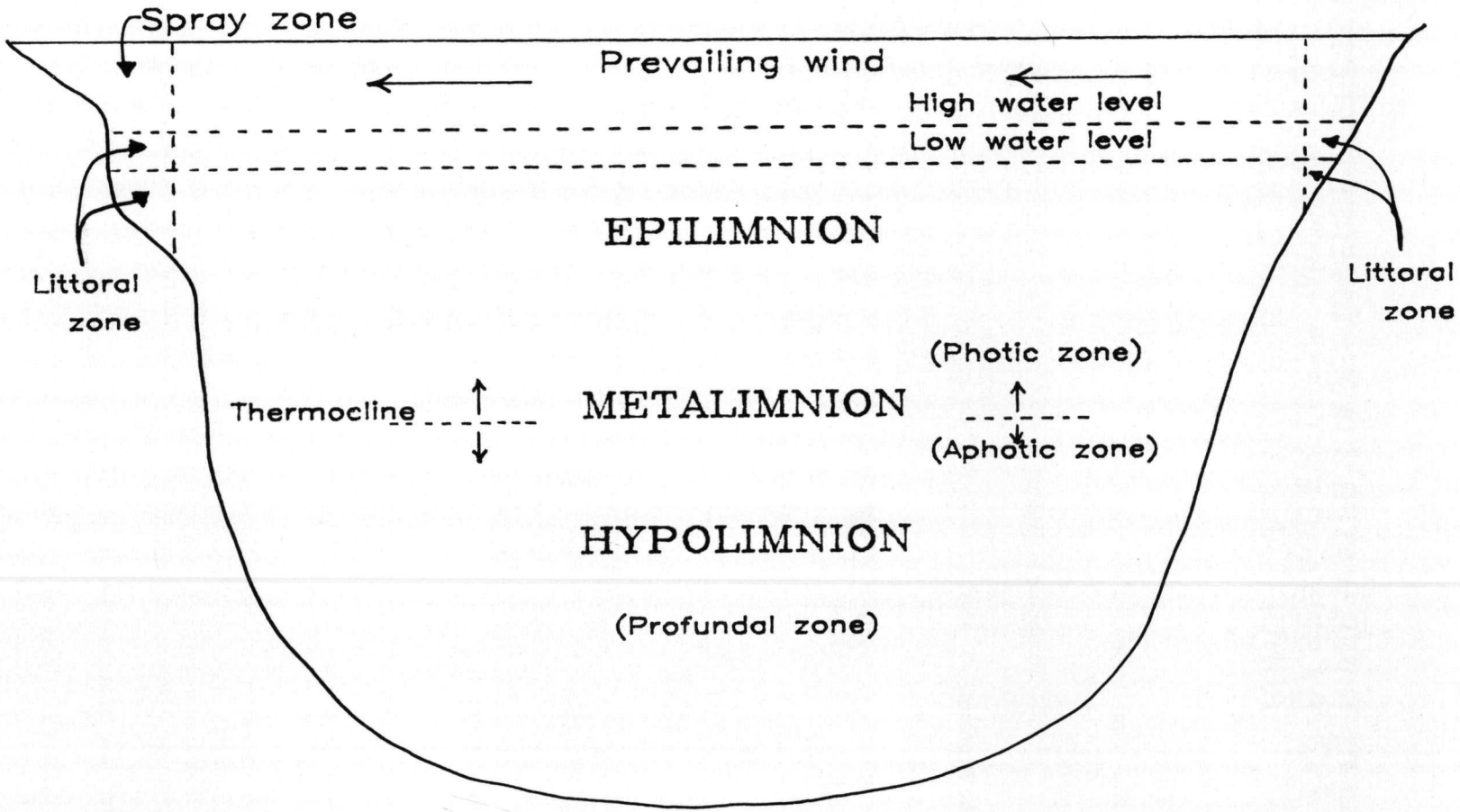
The upper warm layer, known as the epilimnion, has a uniform temperature throughout and is regarded as an isothermal layer; below the epilimnion the temperature drops through the metalimnion which contains the thermocline or zone of steepest temperature gradient. Below this is the hypolimnion where the temperatures are again uniform with depth; this is a cool zone containing profundal water.

Human activities within a catchment give rise to enrichment from point sources such as sewage effluent discharges and diffuse sources which include run-off from agricultural land, seepage from residue dams and dumps and enrichment from the atmosphere due to industrial emissions.

Nutrient additions to an impoundment can arise from conditions, factors or occurrences such as the following:

(1) Pollution from adjoining swamps.
(2) Rainfall run-off subsequent to forest or grass fires.
(3) The presence of decaying organic matter.
(4) Surface run-off and discharges from towns, cities and their associated industries.
(5) Variations of water levels.
(6) The inherent constituents and adsorbed nutrients of silt and sediments.
(7) Atmospheric deposition.

*"*The Algae and Their Life Relations"*, The University of Minnesota Press, Minneapolis, Minnesota, 1935, p. 472.



Features of a lake or dam

Algae Responsible for Surface Blooms: Scott[1] has stated that planktonic blue-green algae belonging to the genus *Microcystis* are mostly responsible for the development of massive surface blooms in eutrophic waters. This investigator states, further, that in the Transvaal three different types or forms are prominent bloom formers. These have been identified as *M. aeruginosa forma flos-aquae*, *M. aeruginosa forma aeruginosa* (both identified in the Hartbeespoort Dam) and *M. wesenbergii* (present in the Rietvlei Dam, South East of Pretoria).

Subsequently Scott has reported[2] that *M. aeruginosa* can grow at a fast rate over a range of light intensities, giving it a competitive advantage over other algae.

Algal Growth Potential (AGP): The algal growth potential is measured by algal bioassay wherein determination is made of the maximum cell concentration (in mg/ℓ) which a suitable test alga can produce in a sample of water. The water sample being tested should be autoclaved at 121°C for not less than 15 min before use.

Algae which have been regarded as suitable and have been used by investigators have included *Selenastrum capricornutum*,[3,4] *Selenastrum gracile*[5] and *Chlorella pyrenoidosa*.[6,7]

Shelef and Halperin[5] consider that *Selenastrum gracile* constitutes a proper indicator organism for assay purposes because of the following characteristics:

- Broad nutrient response;
- Adaptation to laboratory conditions;
- Distinctive shape, uniform size and clear division

Ranking of impoundments according to their algal growth potential (AGP) (After Toerien *et al.*[3], 1975)

Rank No.	Impoundment	AGP (mg ℓ^{-1})	Rank No.	Impoundment	AGP (mg ℓ^{-1})	Rank No.	Impoundment	AGP (mg ℓ^{-1})
1	Gubu	4,3	34	Nagle	16,5	66	Chelmsford*	44,9
2	Paul Sauer	4,4	35	Churchill	16,8	67	Gamkapoort*	45,4
3	Njelele	4,4	36	Douglas Weir	17,2	68	Bellair	45,5
4	Magoebaskloof	4,6	37	Wagendrift	17,3	69	Leeuw Gamka	46,6
5	Bulshoek	4,7	38	Jericho	18,1	70	Erfenis	48,6
6	Groendal	4,9	39	Maden	18,5	71	Maselspoort*	49,1
7	Korinte Vet	5,1	40	Vergelegen*	18,6	72	Allemanskraal	53,1
8	Ebenezer	5,2	41	Henley	18,9	73	Malelane Weir*	53,5
9	Albasini	5,7	42	Rustfontein	20,5	74	Kromellenbogen	55,0
10	Buffeljagts	6,1	43	Glen Alpine	20,6	75	Tonteldoos*	55,1
11	Rooikrantz	7,3	44	Krugersdrift	23,6	76	Verwoerd*	56,2
12	Vlugkraal	8,1	45	Nwanedzi	23,7	77	Koppies*	57,9
13	Midmar	8,7	46	Westoe	24,0	78	Kosterrivier	58,4
14	Settlers	9,3	47	Buffelspoort	25,0	79	Lindleyspoort	60,0
15	Calitzdorp	9,7	48	Klein Maricopoort	25,3	80	Da Gama*	60,6
16	Kalkfontein	10,0	49	Howisonspoort	25,7	81	Marico Bosveld*	64,9
17	Craigieburn	10,4	50	Mkuzi Weir	26,9	82	Laing	70,1
18	Phalaborwa	10,5	51	Stompdrift	27,4	83	Rooikraal*	74,0
19	J.G. Strydom	11,1	52	Brandvlei (Lake		84	Beervlei*	77,0
20	Klipkopje	11,1		Marais)	28,7	85	Vaalharts Weir*	84,6
21	Ohrigstad	12,3	53	Loskop	29,5	86	Wolmaransstad*	86,2
22	Pongola Weir	12,3	54	Kafferskraal*	32,1	87	Floriskraal*	94,1
23	Gamka	12,6	55	Bloemhof*	32,3	88	Doornpoort*	103,0
24	Clanwilliam*	12,9	56	Rust der Winter	32,5	89	Vaaldam*	104,2
25	Loerie	13,0	57	Mockes*	32,8	90	Loxton*	128,6
26	Stettynskloof	13,0	58	Smithfield*	34,4	91	Armenia	136,4
27	Primkop	13,6	59	Bronkhorstspruit*	34,5	92	Egmont*	146,6
28	Kamanassie	14,5	60	Hluhluwe	35,5	93	Shongweni*	265,0
29	Katrivier	14,5	61	Klaserie	36,1	94	Vaal Barrage*	300,0
30	Nahoon	14,5	62	Wemmershoek*	36,9	95	Johan Neser*	452,2
31	Buffelskloof	15,5	63	Nooitgedacht	37,3	96	Roodeplaat*	491,4
32	Steenbras	16,4	64	Bethulie*	42,1	97	Hartbeespoort*	549,1
33	Premiermyn	16,4	65	Boegoeberg	42,5	98	Rietvlei*	660,4

*Denotes impoundment with N as primary growth-limiting nutrient.
CSIR Special Report WAT 48, 1977.

which facilitate quantitative evaluation;
- Non-attachment to glass;
- Ubiquity in natural bodies of water.

Toerien,[8] and Steyn, Toerien and Visser[4] have reported on the eutrophication levels of a number of South African impoundments according to their algal growth potential (cf. table on previous page).

Growth-Limiting Nutrients: The nutrient which is present in the least amount relative to the growth needs of an aquatic alga or macrophyte is referred to as the primary growth-limiting nutrient. If the concentration of the primary growth-limiting nutrient be increased an increase in growth will take place until the secondary growth-limiting nutrient is exhausted. Therefore, the problem of eutrophication would appear to resolve itself into a determination of the growth-limiting nutrient in the water-body concerned, and having established this, to take measures to reduce the concentration of such nutrient to a level which will be inadequate to support the metabolism of the algae and macrophytes which would otherwise become viable.

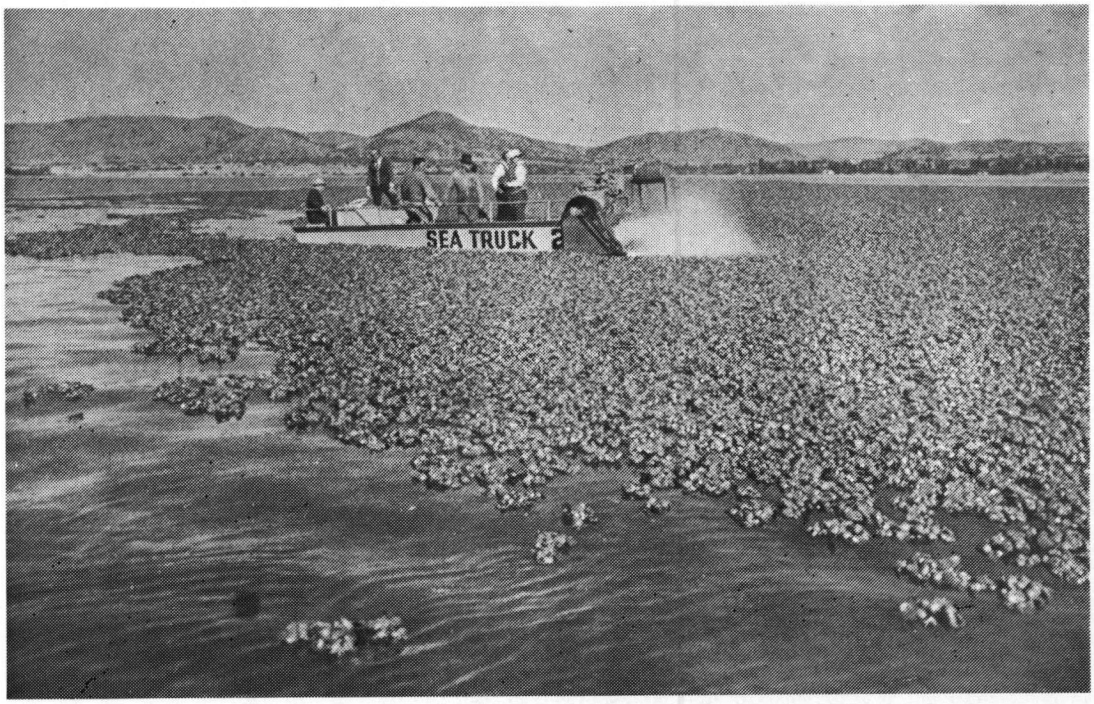
Preventing the Occurrence of Eutrophication: To prevent the onset of eutrophication in an impoundment it is desirable to carry out long-term surveillance to establish any change in the trophic status from oligotrophic – to mesotrophic – to eutrophic and to take steps to prevent eutrophic conditions from becoming established by limiting aquatic fertility.

Whilst it is possible to limit the amount of phosphate* and nitrate† from point sources such as sewage purification works and industrial (both surface and atmospheric) discharges, it is not an easy task to control nutrient additions to an impoundment from diffuse sources.

Allaying the Effects of Eutrophication: The following are some of the techniques which have been suggested:

(1) The nutrient status of phosphate may be metastasized by the addition of chemicals such as alum, ferric salts and calcium salts when the phosphate precipitates and becomes sealed-in with the sediments.
(2) Impoundment management wherein during the stratification period during summer bottom waters are caused to discharge from an impoundment instead of water being allowed to flow over the spillway.
(3) Forced aeration of the bottom waters or the hypolimnion.
(4) Where growth [e.g. of water hyacinth (*Eichhornia crassipes*), *Potamogeton*, etc.] is excessive the necessary harvesting of the aquatic plants.
(5) Chemical control: The use of chemical herbicides has been successfully applied to destroy water hyacinth in the Hartbeespoort Dam.
(6) Dredging of sediments which contain nutrients.

*It should be noted that the form in which phosphate is directly available for algal growth is the orthophosphate.
†Most algae can use nitrogen in the form of nitrate, ammonia, nitrite or urea. However, certain blue-green algae are capable of fixing gaseous nitrogen.



Removal of Water Hyacinth from an Impoundment.

Guidelines for the Control of Eutrophication in South Africa: The report of Toerien[8] published by the NIWR has been followed by that of Walmsley and Butty.[9] This should be consulted by those grappling with the problems of eutrophication.

Algae which cause problems in South Africa are stated[9] to be as indicated in the following table:

Algae	Problem
Melosira	Filter blockage
Microcystis	Filter blockage, taste and odour, toxicity, scum formation
Oscillatoria	Filter blockage, taste and odour, scum formation
Anabaena	Filter blockage, toxicity, scum formation
Euglena	Filter blockage
Chlamydomonas	Filter blockage, filter penetration
Dinobryon	Taste and odour
Prymnesium	Toxicity to fish
Green unicellulor algae	Filter penetration
Small diatoms	Filter penetration

Assessing the Trophic Status of an Impoundment: Observations of significant import in indicating the trophic status during summer stratification have been outlined by Walmsley and Butty[9] as indicated in the following table:

Eutrophication is an on-going process in an impoundment. This being so, it is possible to monitor the process by the following means:

(1) Limnological – by noting the production of various plants and animals present in different locations within the water-body.
(2) Chlorophyll evaluations in the surface layers.*
(3) Vertical haul biomass evaluations.†
(4) Chemical – by evaluations of nitrate, orthophosphate as well as other significant parameters.

Limnological considerations: Data used to denote eutrophication trends are as follows:

Visual: Changes in colour of the water. Appearance of algal blooms and macrophyte growth.

Chemical: Content of nitrogen, oxygen, phosphorus and hydrogen sulphide; conductivity; pH value and sediment characteristics.

Biological: Algae – species composition in water and sediments; standing crop estimate; primary productivity; phosphatase activity; algal growth potential.
Macrophytes – rooted and floating community biomass.
Zooplankton, Zoobenthos } standing crop and species composition.
Fish – standing crop.

*Samples are collected by means of a 5 metre × 20 mm (I.D.) plastic hosepipe.
†Using a net (approximate mesh size 100 μm) lowered to the bottom of the water-body and hauled to the surface.

Pointers Denoting Trophic Status during Summer Stratification

Characteristics	Comments
pH value of surface water	if > 8,4 then possibly eutrophic
Dissolved oxygen at surface, Dissolved oxygen at bottom	if surface supersaturated and bottom anaerobic, then eutrophic
Orthophophate at surface, Orthophosphate at bottom	if > 0,025 mg/dm^3 and accumulation observed in the bottom then eutrophic
Ammonia at surface, Ammonia at bottom	if accumulation in the bottom waters then meso- or eutrophic
Algal growth potential	if > 25 mg/dm^3 then meso- or eutrophic
Chlorophyll content at surface	if > 10 μg/dm^3 then meso- or eutrophic if > 20 μg/dm^3 then eutrophic
Iron and manganese at bottom	if accumulation in bottom water then meso- or eutrophic
H_2S in bottom waters	if present then meso- or eutrophic

Chlorophyll Evaluations Signalling Trophic Status
(from 5 m hosepipe samples)*

Trophic status	Chlorophyll concentrations $\mu g/dm^3$
Oligotrophic	< 3
Mesotrophic	3 – 9
Eutrophic	> 9

Trophic Status from Vertical Haul Wet Biomass Evaluations*

Trophic status	Biomass g/m^3
Oligotrophic	< 0,5
Mesotrophic	0,5 – 1,0
Eutrophic	> 1,0

*According to Walmsley and Butty[9]

Trophic Status and Plant Nutrient Concentrations

Nitrogen and phosphorus-containing compounds are the significant constituents in a water-body giving rise to eutrophication. Phosphorus is the more important in regulating plant growth in impoundments since it has been found that even in the absence of nitrogen-containing ionic species in the water but with phosphate present, algal growth occurs due to nitrogen-fixing algae. On the other hand, when nitrogen compounds are present and phosphate absent algal growth does not occur.

Therefore, the importance of preventing the import into an impoundment of nutrients, more particularly phosphate, cannot be gainsayed.

Abating the Problem

The Removal of Nutrients from Cultural Sources

Import foci and diffuse sources of nutrients include the following:

(i) Sewage purification works.
(ii) Industrial discharges
  (a) into sewerage systems or rivers;
  (b) into the atmosphere.
(iii) Seepage and run-off from land in the catchment including silt.

(i) *Sewage Purification Works*

In earlier chapters methods used for purifying sewage have been dealt with. As these give rise to effluents containing nitrate and phosphate such effluent discharges into rivers represent point sources for the enrichment of impoundments thereby contributing to or exacerbating eutrophication.

Due to the extent of eutrophication which had taken place in a number of large dams, the Minister of Water Affairs, in an effort to alleviate conditions, extant or likely to occur, prescribed – in terms of the Water Act – that the effluents from sewage purification works in certain "sensitive" areas should not contain orthophosphate in excess of 1,0 mg/ℓ as P.

A period of five year's grace was allowed to enable local authorities and others operating sewage purification works in the prescribed areas to effect the necessary changes in the quality of their effluents.

A general awareness of the necessity to reduce the content of nitrate and phosphate in effluents resulted. The National Institute for Water Research under contract to the Water Research Commission initiated research on the causes, consequences and control of eutrophication. The programme of research aimed at preventing eutrophication of impoundments not already enriched and rehabilitating eutrophied ones.

From a study[10] of 21 South African impoundments it was established that when phosphate was the limiting nutrient, trophic status was related to orthophosphate loading rate.

Thereupon, the necessity to attenuate the phosphate content of effluents became abundantly clear.

Towards this end the Water Research Commission has sponsored research and investigational work on the removal of nutrients from sewage effluents as follows:

- At the University of Cape Town under the direction of Professor G v R Marais.
- Large-scale plant investigations at Johannesburg's Goudkoppies Activated Sludge Plant.
- Pilot plant investigations by the National Institute for Water Research at Pretoria's Daspoort Sewage Purification Works.

The overall results of this work have been published by the Water Research Commission in the form of a collaborative document prepared by the University of Cape Town, the City Council of Johannesburg and the National Institute for Water Research (Daspoort Investigations). This extensive, in-depth document is titled – *"Theory, design and operation of nutrient removal activated sludge processes"*.

The initial work on the removal of nitrate and phosphate from sewage effluents resulted in the development of the Bardenpho Process which was patented world-wide. This was later superseded by the so-called Phoredox Process. The Phoredox Process (which may be regarded as a 5-stage Bardenpho Process) is an activated sludge method with the following reaction zone sequences, viz. –

(1) Anaerobic → (2) Primary anoxic → (3) Aerobic → (4) Secondary anoxic → Reaeration.

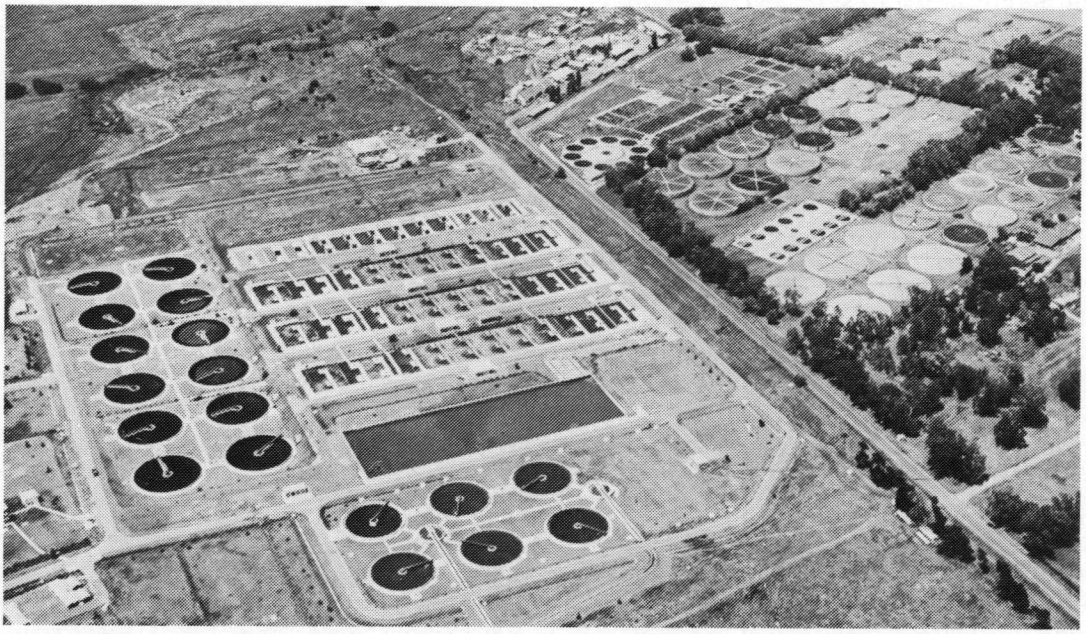
Where "anaerobic" refers to a zone free of oxidized nitrogen compounds (e.g. nitrate, NO_3) and dissolved oxygen; "anoxic" refers to a zone contain-

ing nitrate but no dissolved oxygen and "aerobic" is an aerated zone.

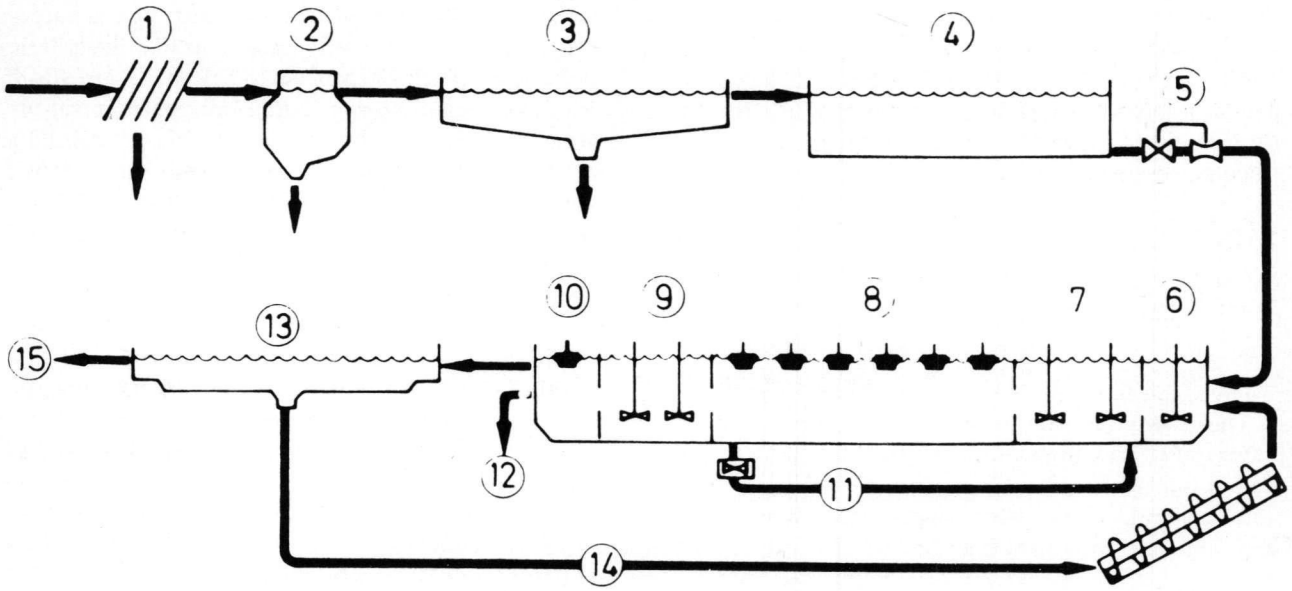
The process has been described by Simpkins and Gerber[11] in a publication prepared by the National Institute for Water Research for the Water Research Commission.

A significant amount of interest and effort has been generated in the problem which investigators have sought to solve by various permutations of anoxic and aeration zones and their extent subsequent to an initial anaerobic zone. The significance of sludge age has also been investigated. However, sight must not be lost of the fact that for an idealized operating regime the flow of substrate to the initial anaerobic zone should be controlled which calls for prior balancing of the flow and taking care of flood conditions during rainstorm periods of flow.

A diagrammatic layout of the Goudkoppies Sewage Purification Works of the Johannesburg City Council as given by Pitman[12] is as follows:



Goudkoppies – 5-Stage Bardenpho Plant for N and P removal alongside older Klipspruit Biofilter Plant



1 SCREENING
2 GRIT REMOVAL
3 PRIMARY SEDIMENTATION
4 FLOW BALANCING
5 FLOW CONTROL
6 ANAEROBIC ZONE
7 FIRST ANOXIC ZONE
8 MAIN AERATION ZONE
9 SECOND ANOXIC ZONE
10 REAERATION ZONE
11 MIXED LIQUOR RECYCLE
12 WASTE ACTIVATED SLUDGE
13 CLARIFICATION AND SLUDGE THICKENING
14 ACTIVATED SLUDGE RETURN
15 EFFLUENT

An aerial photograph of the Goudkoppies activated sludge plant illustrates the nature and size of the undertaking (cf. photograph on page 167).

The plant has a design capacity of 150 Mℓ/d arranged in a set of 50 Mℓ/d modules incorporating the 5-stage Phoredox layout. The final effluent produced is stated to contain 5 mg N/ℓ and 0,5 mg P/ℓ.

Comment: Adequately trained and experienced operators are necessary for the control of nutrient-removal activated sludge plants. Such operators require to be backed-up by suitable laboratory facilities manned by proficient staff.

For the larger local authorities and industries with the necessary technical back-up removal of nutrients via the modified activated sludge route is a reasonable possibility.

However, for agencies which have biological filtration, plants already operating, the removal of nutrients from effluents presents a problem of another kind. Boksburg, for instance, which has an economically well-designed and well-operated biofiltration plant has sought to overcome this problem by treatment with chemicals. If such a method results in increasing the salinity of an effluent then the effort might prove self-defeating by resulting in increasing the salinity of the receiving water – in this case, a headwater of the Vaal Barrage – thus emphasizing the need for careful control of chemical dosing by competent chemical staff and plant operators.

Chemicals used for the removal of phosphate include lime, aluminium salts (e.g. in the form of sulphate, chloride and sodium aluminate) and iron salts (e.g. ferric chloride, ferrous and ferric sulphate): waste pickle liquor has also found application, as well as acid mine drainage.

Wiechers and van Vuuren[13] have dealt with chemical methods for phosphate removal in a review of means for nutrient removal from municipal effluents.

2 INCREASE IN SALINITY

"Water, water everywhere
Nor any drop to drink"
Samuel Taylor Coleridge 1772 – 1834
"The Ancient Mariner"

The quality of water in a river is conditioned by the nature of its catchment area and the human activities within the catchment.

In general, river water quality is a summation deriving from the following factors:

(1) Precipitation.
(2) Surface runoff.
(3) Seepage.
(4) Point-source discharges.
(5) Diffuse-source discharges.

(1) Precipitation

This can be divided into (i) wet precipitation and (ii) dry precipitation. Measurements of precipitation are usually made by using an open collector which may be emptied at regular time intervals. The moisture collected will include both wet and dry components.

Wet precipitation is considered as being due to "rain-out" and "washout" processes. Rain-out involves the solution of aerosol particles which function as condensation nuclei for raindrops whilst washout is due to the solution on impact of atmospheric particles by raindrops while falling below the clouds.

Dry fall-out derives from the deposition of atmospheric particles of relatively large size (greater than 20 μm).

The composition of precipitation will depend upon whether the location is inland or borders on the sea. Inland situations will be influenced by dust and industrial stack emissions and the corresponding precipitation will contain significant amounts of Ca, NH_4, NO_3, NO_2, HCO_3 and SO_4 ions. Coastal situations will receive precipitation containing noticeable amounts of Na, Cl, Mg and K ions derived from oceanic water.

(2) Surface Runoff

Precipitation falling on a drainage area represents the contact water source which, in a natural environment, then changes in composition due to integrated interactions with the soils, vegetation, rocks, minerals and litter, in the catchment.

In built-up areas the quality of water is further altered by sewage effluent and industrial discharges – the latter being both aquatic and atmospheric discharges as well as seepage and runoff from waste residue dams and dumps. Additionally urban runoff causes pollution. (Refer to Chapter 15 – *"Handling and Disposal of Effluent Arising from Mining and Mineral Recovery Operations"* and Chapter 16 – *"The Disposal of Solid, Toxic and Hazardous Wastes"*.)

Agricultural and forested areas may give rise to diffuse-source pollution.

Precipitation, in measure, penetrates the soil and a portion seeps out to enter the river whilst a portion joins the groundwater regime.

The three components of water entering a river as runoff are –

- Surface runoff;
- Through-flow or inter-flow;
- Base-flow or groundwater.

Surface runoff over a sloping section of a catchment may infiltrate and later join the river as through-flow. In doing so its chemical composition will be altered from what it was originally as precipitation or as true runoff.

The water which moves downward through the soil

joins the groundwater which constitutes the body of sub-surface water – below the water table – and saturates the pores of the associated rock and its overburden in the so-called "zone of saturation".

(3) Seepage

Normally, in a natural environment, free from toxic deposits, seepage will add to the number and amount of ionic species originally present in the precipitation – but not deleteriously. However, seepage from mine waste (slimes) dams and dumps is a source of concern due to the sulphate content of these emissions, and in some cases, ferrous sulphate and free sulphuric acid as well where acid mine drainage is involved. (Refer to Chapter 15 – *"The Mining Industry: Handling and Disposal of Effluent Arising from Mining and Mineral Recovery Operations"*.)

(4) Point-source Discharges

Point-source discharges are many and varied. They include effluents from sewage purification works which if they are from the works of a local authority may also contain the end products of industrial wastes originally present in admixture with the sewage.

They also include a large variety of industrial effluents which may contain both organic and inorganic matter. Major industries giving rise to polluting effluents are dealt with in Chapter 15 (cf.).

(5) Diffuse-source Discharges

Pollution can arise from ill-defined sources. The discharges or emissions from such sources are referred to as diffuse discharges and may be due to the following mechanisms:

- Runoff and seepage from agricultural land;
- Urban runoff;
- Runoff and seepage from forested areas;
- Runoff and seepage from mining areas;
- Atmospheric emissions from factories and power stations.

Increase in Salinity of Water Supplies

Not only is excessive salinity a health hazard but increasing salinity of a water supply can give rise to considerable economic losses to be shouldered by users of hot-water installations and steam-raising plants. Apart from these considerations the use of hard water gives rise to the increased use of softening agents and detergents. High salinity will increase corrosion of metal pipes and home and industrial utility equipment where saline water comes in contact with metallic parts.

Heynike[14] has directed attention to this problem by consideration of the likely economic effects of rising salinity on the water supply from the Vaal River Barrage and the adverse effects resulting for users in the Pretoria, Witwatersrand, Vereeniging, Sasolburg (PWVS) complex.

Heynike's economic survey is based on a study of the consequences of an increase in the total dissolved solids content of the Vaal River Barrage water from the present value (in 1976 – 1981) of c. 300 mg/ℓ to (i) 500 mg/ℓ and (ii) 800 mg/ℓ by the year 2000.

He has systematically considered the effects of salinity changes on the following:

- Private dwellings and flats;
- The Rand Water Board's operations;
- Water supply and distribution systems of local authorities;
- Industrial undertakings;
- Power stations.

His survey has led him to estimate that the total increased costs per annum for the PWVS community for water qualities (TDS) of 800 and 500 mg/ℓ would be R139 $\times$ 10^6 and R77,5 $\times$ 10^6, respectively.

His findings indicate that in order to prevent detriment to the PWVS community means should be sought to prevent an inordinate rise in the salinity of the Vaal Barrage water.

Consideration has been given to desalination by physico-chemical methods to be used by the supplier and the users of Rand Water Board water. The isolation in evaporation dams of mining effluents has also been canvassed and, in measure, implemented.

Desalination methods which have been used with success for certain situations have included the following:

- Multi-stage flash distillation;
- Ion exchange;
- Reverse osmosis;
- Electrodialysis.

However, the application of any one of these methods to large volumes of water such as those handled by the Rand Water Board for the vast PWVS complex introduces an economic factor of considerable magnitude.

The alternative to desalination is dilution with good quality water. Mileikowsky[15] developed a one-dimensional cell-type numerical model to simulate daily salinity fluctuations in the Vaal Barrage.

Midgley[16] has stated that by means of the mathematical model devised by the Hydrological Research Unit of the University of the Witwatersrand at the request of the Water Research Commission, a wide range of options could be tested for ameliorating conditions. He stated that good quality water from Vaaldam could be blended into Barrage water to provide water of satisfactory quality at all times.

Midgley[16] considers that only 40 per cent of South

Africa's exploitable water is being used and of this quantity three quarters is for irrigation. He believes in the transfer of water from areas with surplus sources to the "central core region" – the PWV triangle area – as well as to other regions of intense water requirement deriving from their development. He favours the principle of inter basin transfer within Southern Africa in the hope that this is emotionally and politically possible.

Comment

The occurrence of droughts in South Africa brings home the need to conserve water and the onus on everyone that water supplies must not be used wastefully.

Effect should be given to any reasonable means of reducing demand without affecting quality and productivity in industry and agriculture and without aggravating the *modus vivendi* of the public.

These may include –

(1) The use of lesser intensive methods of irrigation in agriculture.
(2) The hierarchical use of water (cf. Chapter 14).
(3) The use of dry methods of cooling (e.g. in power stations).
(4) The use of dry processes, where possible (e.g. in the mining industry).

In order to ensure the unhindered development of major centres of activity recourse should be had to supplementation with good quality water from surplus water resources in other regions.

This will avoid an undue increase in total dissolved solids brought about by recycling and evaporation as evidenced in the case of the Vaal River Barrage which provides water for the PWVS complex.

REFERENCES

1. Scott, W.E. *S. Afr. J. Sci.*, 1974, **70**, 179.
2. Scott, W.E. "Observations on the ecology, growth and physiology of Microcystis aeruginosa in the laboratory and in the field"; paper presented at CSIR Conference on "Health Aspects of Water Supplies", Pretoria, 15 November 1979.
3. Toerien, D.F. and Steyn, D.J. Verh. Internat. Verein. Limnol., 1975, **19**, 1947-1956.
4. Steyn, D.J. Toerien, D.F. and Visser, J.H. *Water SA*, 1976, **2**(2), 53.
5. Shelef, G. and Halperin, R. "Wastewater Nutrients and Algae Growth Potential", Proc. Jerusalem Internat. Conf. on Water Quality and Pollution Research, June 1969.
6. Bierman, V.J. Jr., Verhoff, F.H., Poulson, T.L. and Tenney, M.W. "Multi-Nutrient Dynamic Models of Algal Growth and Species Competition in Eutrophic Lakes" – Contribution to "Modeling the Eutrophication Process", Ann Arbor Science Publishers Inc., Ann Arbor, Michigan, USA.
7. Falco, J.W. and Sanders, W.M. III, "A Physical Model for Simulation of Aquatic Ecosystems" – Contribution to "Modeling the Eutrophication Process", Ann Arbor Science Publishers Inc., Ann Arbor, Michigan, USA.
8. Toerien, D.F. CSIR Special Report WAT 48, 1977. "A Review of Eutrophication and Guidelines for its Control in South Africa".
9. Walmsley, R.D. and Butty, M. "Guidelines for the Control of Eutrophication in South Africa", W.R.C. Report.
10. "Limnology of Some South African Impoundments", A collaborative report by the Water Research Commission and the National Institute for Water Research, 1980.
11. Simpkins, M.J.N.P. and Gerber, A. "Technical Guide on Biological Nutrient Removal: The Phoredox Process", National Institute for Water Research, Pretoria, 1981.
12. Pitman, A.R. "Theory, Design and Operation of Nutrient Removal Activated Sludge Processes", Water Research Commission, Pretoria, 1984.
13. Wiechers, H.N.S. and van Vuuren, L.R.J. "A Review of Applied Technology for Nutrient Removal from Municipal Effluents", A Technology Transfer Seminar held at the CSIR Conference Centre, Pretoria, 17 May 1979, report issued by the Water Research Commission, Pretoria.
14. Heynike, J.J.C. "The Economic Effects of the Mineral Content Present in the Vaal River Barrage on the Community of the PWVS Complex" – (A Desk Study) – Final Report, Water Research Commission, June, 1981.
15. Mileikowsky, R.N. "A Mathematical Model for Simulating Daily Salinity Fluctuations in the Vaal Barrage", Report No. 4/80, Hydrological Research Unit, University of the Witwatersrand, Johannesburg, March, 1980.
16. Midgley, D. "Towards a Rational Water Policy for South Africa", *Optima*, 1985, **33**(2), 60.

Chapter 14 THE HIERARCHICAL USE OF WATER IN SOUTH AFRICA: PORTENTS FOR THE FUTURE

"Teach thy necessity to reason thus;
There is no virtue like necessity."

William Shakespeare
(King Richard II, Act 1, Scene 4)

Available Water Supplies and Estimated Future Usage

In 1910 the consumption of water by all sectors of the population was stated to be of the order of 3 000 million cubic metres per year which represented 14 per cent of the usable potential resources. At this stage 96 per cent of the water used was employed for irrigation and stock watering.[1] By 1965 the total consumption of water had increased to 9 150 million cubic metres per annum – some 43,5 per cent of the potential assured supply.

According to the "Report of the Commission of Enquiry into Water Matters" published by Government Authority in 1970, it was stated that by 1965 the consumption of water in the Republic of South Africa for irrigation and stock watering had reached 20 985 million cubic metres per day or 83,5 per cent of the total water throughout the country. Assuming the then current methods of utilization, it was estimated that by the year 2 000 the total usage of water for irrigation would reach 34 780 million cubic metres per day of which 32 280 million cubic metres per day would have to be provided from permanently developed surface resources.

By contrast, it was estimated that by the year 2 000 the use of water for urban and industrial purposes would reach 45 460 million cubic metres per day. This presupposed that a growth rate of water consumption for these two purposes would be maintained at 7 per cent which had been the case since 1965.

It will be seen from the above quantities and estimates that by the year 2000 the total water needs of the Republic will be of the order of 80 240 million cubic metres per day.

Also, it will be noted that industrial and urban water demand will have overtaken agricultural demand.

The Commission goes on to state that the assumed yields of water in the Republic are estimated at only 60 460 million* cubic metres per day with a potential maximum of 75 010 million cubic metres per day.

Therefore, the likelihood of demand overtaking ordinary natural supply would seem to be close at hand.

The Commission has enumerated possible solutions to the problem of balancing supply and demand, viz. – "First," it states, "we must strive for improved methods of development and utilization of our natural water sources. Secondly, we must raise the efficiency of current use of developed supplies; the most obvious methods lie in the re-use of effluents and improved efficiency in the use of water for irrigation. Finally we must seek ways of creating new sources of water; probably the desalination of sea water would make the biggest contribution . . ."

Underground Water Resources: In 1974 the Republic's ground-water resources were stated to contribute only 5,5 per cent of the overall resources.[2] The total consumption of ground water was estimated to be, as follows:

	$m^3 \times 10^6$/year
Irrigation	636
Stock watering	50
Domestic, municipal and industrial purposes	150
	836 Total

It has been postulated[2] that the probable safe yield of underground water is of the order of 1 350 million cubic metres per annum.

Wastewater Reuse: In examining South Africa's water supply problem Hart and van Vuuren[3] state, "The challenges posed by this situation have forced the acceptance of the inevitable fact that water supply and wastewater reuse, and control of pollution are inseparable components in a broad water conservation plan for every metropolitan area, as well as for the country as a whole".

*"Water 75" estimates that the annual volume of water entering rivers and streams is of the order of 52 000 million cubic metres or a mere 9 per cent of the total average yearly rainfall (mean rainfall 475 mm). However, this does not constitute an assured amount. It is considered that only 40 per cent of 21 000 million cubic metres per annum of the surface run-off can be relied on for use. The potential yield of storage dams is reduced due to evaporation losses varying from less than 10 to 60 per cent, and, on average, 27 per cent. There are also losses due to seepage and losses over spillways during periods of abnormal flooding.

They have listed the daily volumes of effluent available from some major South African towns and industries, viz. – sewage effluent (total): 1 233 500 cubic metres per day; power station cooling: 107 700 cubic metres per day; industrial: 87 200 cubic metres per day and have dealt with reuse methods practised and investigated, e.g. the reclamation of potable water from purified sewage effluent by the Stander Method; irrigation with purified sewage effluent; irrigation of industrial effluents such as those from the pulp and paper and chemical industries; the use of purified sewage effluent for cooling purposes in power generating stations; slurrying at cement factories and gold mines, washing at diamond mines, in ash conveying, etc.

Dealing with the direct reuse of purified sewage effluent a critical elaboration of the advanced purification plant at Windhoek is given. The authors have also illustrated indirect use where purified sewage effluent is discharged into watercourses feeding water impoundments such as the Hartbeespoort, Rietvlei and Bon Accord Dams. They have concluded their case histories and statistics by stating that "there appears to be much scope for a broader application of wastewater reuse in South Africa".

Recycling of water within a factory has not been dealt with by Hart and van Vuuren[3] – their interests being concerned primarily with the reuse of final effluents from municipal wastewater treatment plants and certain industrial effluents.

Water Reclamation

The foregoing emphasizes the need for wastewater reclamation. Therefore, consideration has to be given to the purification of sewage and industrial effluents by methods which will yield water of a quality sufficient for use by industry and in agriculture for irrigation and stock watering and, at the same time, avoid any adverse effects on the water in rivers and impounding dams such as eutrophication from the presence of certain constituents in sewage and industrial effluents such as phosphate and nitrate, particularly the former, which serve as nutrients for biological growths such as algae and water hyacinth; mineral salts such as sulphates in gold mine and coal mine effluents which mitigate against the re-use of water as well as sodium chloride and other sodium-containing salts in high concentration in certain effluents, notably those from tanneries processing salted hides and skins. Further, in many cases, the overall organic pollution concomitant with low dissolved oxygen content is important as this may have an adverse effect on fish life.

The Water Act

The Water Amendment Act (No. 96 of 1984) constitutes a statutory enactment, dealing *inter alia*, with the control, conservation and re-use of water for domestic, agricultural, urban and industrial purposes.

The use of water for agricultural purposes is subject to the user's riparian rights or allocation by a Water Court. In so far as it concerns the use of water for industrial purposes – which includes the use for sewage disposal – the Water Act is based on the tenet that water withdrawn or originating from a river must be purified to Regional Standards which have been prescribed by Government Notice No. 991 of May 18, 1984 and returned to the river of origin.

Where this is not possible the Minister of Water Affairs may issue a permit stating the quantity of water allowed a particular user, the conditions of usage and methods of disposal which have to be fulfilled.

The General Standard* sets out certain chemical, physical and bacteriological requirements with which an effluent must conform. This is the most generally applicable standard and, at present, serves as the *sine qua non* for discharge of effluents into most rivers; though more stringent requirements, particularly in respect of phosphate, have been added in order to ameliorate eutrophication which reached disturbing prominence in a number of the country's water impoundments – in particular the Hartbeespoort and Bon Accord Dams.

The Special Standard is applicable to certain catchment areas draining into rivers or their tributaries at any point between the source of the river or tributary and the place specified in a schedule, where 66 catchments are specified. Many of these specified rivers constitute so-called trout streams in areas free from industrialized living and activity.

Up to the present, the policy of the Department of Water Affairs has been to enforce the General Standard as far as possible and to disallow discharges of effluent into streams or rivers in Special Standard areas where it is realized that the achievement of an effluent of the required purity is beyond the financial and technical capability of the applicant.

In practising an hierarchical system of water usage by an industrial undertaking, it is well to remember that the final effluent discharged by such undertaking into a watercourse must conform with gazetted requirements: where the final effluent is discharged into a sewerage system of a local authority such effluent must conform with the industrial effluents acceptance by-laws of the relevant local authority. Where effluent is used for irrigation the threshold limits for constituents (ionic species, total dissolved solids, pH value, etc.) in the effluent should not be exceeded for the particular crop and soil being irrigated.

Agricultural, Industrial and Urban Use of Water

In terms of the Water Act (Act 54 of 1956) as

*Refer to Appendix for details.

amended by Act No. 96 of 1984, the various uses of water are defined as follows:

"*Use for agricultural purposes* in relation to water, means use for the irrigation of land, and includes use by a riparian owner or any other person who has gained a right to the use of water for the irrigation of land, for domestic purposes or for the purpose of waterborne sanitation or for the watering of stock or gardens." (Act 54 of 1956.)

"*Use for industrial purposes*, in relation to water means use of water (including effluent supplied by a person other than the user) for or in connection with –

(a) the manufacture, alteration, processing, treatment, repair, decoration, painting, spraypainting, electroplating, corrosion prevention, cooling, dyeing, washing, polishing, cleaning, finishing or breaking up of any article or part thereof, whether that article or part is a solid, liquid, vapour or gas or a combination thereof;
(b) the generation of power;
(c) railway purposes;
(d) the mining or winning or washing of sand, gravel or stone;
(e) an intensive animal feeding system or the breeding of fish or any mollusc;
(f) the slaughtering of livestock;
(g) any sewerage system or work or any water care work;
(h) the conveyance of any substance; or
(i) printing or photographic work,

and includes use for domestic purposes or for the watering of stock or of streets and gardens in so far as such use may be incidental to use for industrial purposes." (Water Amendment Act, No. 96 of 1984.)

"*Use for urban purposes*, in relation to water, means use in any area under the jurisdiction of a local authority or approved authority, council, board or body for purposes of which water is ordinarily used by a local authority or by the inhabitants of such an area, including use for domestic purposes or for the purpose of waterborne sanitation or for the watering of gardens, watering or cleaning of streets or for industrial purposes." (Basically in accord with Act No. 54 of 1956.)

The Problem of Intractable and Toxic Wastes

It will be appreciated that where industries with intractable or toxic wastes are established in a particular area, it would be unwise to allow such effluents to be discharged into the municipal sewers, since this would place a great restriction on the use of purified effluent discharged from the sewage purification works from the point of view of producing an effluent of the requisite quality for discharge into a river, for re-use by industry or for irrigation of such sewage effluent – or yet again such industrial effluent could cause complete malfunctioning of the sewage purification works.

The philosophy behind the re-use of effluents must also be conditioned by the realization that re-cycling of water containing mineral salts leads to increased concentration of such salts in the water to a stage where the water can no longer be used industrially or it is rendered unfit for discharge into a river.

Mining effluents containing sulphate in solution, at present, place a great mineral burden on the Rand Water Board's water supply in the Pretoria, Witwatersrand, Vereeniging, Sasolburg complex.

Motivating Industrialists: It might be found possible to encourage industrialists to use less water and re-cycle effluents more effectively by financial inducement related, in a realistic way, to their particular efforts and achievements in reducing water consumption and pollutional load.

Likewise, it would seem necessary to introduce legislation enforcing local authorities to provide services *per se* or through competent agencies for collecting and disposing of intractable and poisonous sludges, as well as any liquid or solid wastes which may give rise to pollution of water supplies if not correctly disposed of.

Industrialists using large volumes of water for cooling purposes (e.g. for electric power generating stations) should be encouraged to use alternative methods of cooling such as air cooling. In many industries (e.g. mining and mineral recovery) dry methods should be used where practicable.

Problems Created in the Chemical Industry

Chemists and chemical engineers have made many contributions to present-day civilized living but chemical manufacturing processes give rise to pollution problems. However, in many cases, the chemical acumen of chemical manufacturers has been put to good effect towards solving both atmospheric and water pollution problems, particularly where there is an economic incentive to produce saleable by-products from intractable or dangerous wastes which would otherwise pollute the environment.

However, unlike many of the more prosaic and standardized processing industries, the chemical industry is constantly beset by economic hazards of plant obsolescence brought on by the necessity to innovate to keep pace with the needs of the community, necessitous changes of feedstocks, the introduction of newly discovered, cheaper or more efficacious chemical processes, the ingenuity of competitors and company mergers.

In this respect "a chemical company must progress or go to the wall!"

This being so, the chemical industry cannot be regarded as static but rather vital and subject to change within comparatively short periods of time. Nevertheless, there should always be forward planning in regard to the use of water – its economical use – and the disposal of effluents and waste products, since neglect of these important aspects of planning and development might redound to the discredit of the company's public image, prove restrictive and affect the viability of an enterprise.

Equitable Use of Water

Due to the limited amount of water available in the Republic it would seem desirable to enforce an hierarchical system of re-use.

As the cost of supplying water becomes progressively higher such a system will become one of penetrating importance.

The primary use of water is to sustain life in all its forms. But, it will be conceded that waters of different qualities may be used for different purposes. For example, the quenching of coke and ash, the flushing of toilets and the allaying of dust do not require the use of high quality water – but water distributed for drinking purposes, which forms part of domestic use, should conform with the World Health Organization's "International Standards for Drinking Water" or SABS 241-1984 for South Africa (cf. later).

User Echelons: The hierarchy of water-use categories may be enunciated as:

(1) Domestic;
(2) Industrial, and,
(3) Agricultural (including all types of irrigation such as farm lands, plantations, sports fields, golf courses, parks and other amenity areas).

Normally, it will be conceded, that urbanized communities should have first claim on pure wholesome water for domestic purposes whereas lower quality categories may be used by industry and agriculture.

This hierarchical use is illustrated by the fact that sewage from a community, after purification at a sewage purification works, may be used for cooling purposes, more particularly by power stations and the water from this secondary use may be used further (e.g. for irrigation).

The hierarchical use of water should be applied wherever possible – matching the process to the quality of the water. High quality water which has been used for one process should be passed on for reuse within a factory or plant or to another industry or undertaking requiring water of a lesser quality and so on. The final effluent (depending on its constituents) might then be used for such end-uses as irrigation, ash quenching, slurrying etc.

Use Echelons within a Factory: Phase separations should be practised within a factory and these could include the following unit processes, viz.

- Filtration,
- Coagulation,
- Hydrocycloning,
- Centrifugation,
- Ultrafiltration,
- Ion-exchange,
- Electrophoresis,
- Flotation,
- Electrodialysis,
- Desalination by various techniques such as reverse osmosis,
- Adsorption,
- Climbing film distillation, and,
  other forms of evaporation with recovery of concentrate and distillate water.

All these processes can be usefully employed (according to circumstances) for recovering water for reuse in a factory. Closed loop re-cycling should be practised (e.g. in the textile industry) in a factory when possible.

Reuse of Water for Irrigation

Elgabaly[4] has drawn attention to problems of soils and salinity, and salinity and waterlogging in the Near East.

He has stated that the factors affecting the suitability of water for irrigation are as follows:

(1) Total salt content and ionic composition of the water;
(2) Physical, mineralogical and chemical composition of the soil;
(3) Crop tolerance to salinity and specific ion effects;
(4) Climate, particularly evapotranspiration and rainfall;
(5) Management of irrigation (method, leaching requirements, etc.).

Davis and de Wiest[5] have given a classification of water based on total dissolved solids content, viz.

Types of Water

Name	Total Dissolved Solids (mg/ℓ)
Fresh water	0 – 1 000
Brackish water	1 000 – 10 000
Salty water	10 000 – 100 000
Brine	>100 000

More particularly, the US Salinity Laboratory grouping is given as follows:

Class of Water	Electrical Conductivity micro mhos/cm	Salt g/ℓ
Low salinity	250	0,2
Medium salinity	250 – 750	0,2 – 0,5
High salinity	750 – 2 250	0,5 – 1,5
Very high salinity	2 250 – 5 000	1,5 – 3,0

Tolerance of Crops to Salt: The relative tolerance of crop plants to salts as given by the US Department of Agriculture are shown in the following table:

Low tolerance	Medium tolerance	High tolerance
Pear	Grape	Date palm
Apple	Olive	Beet
Orange	Fig	Asparagus
Almond	Pomegranate	Spinach
Apricot	Tomato	Bermuda grass
Peach	Cabbage	Barley
Lemon	Cauliflower	Cotton
Avocado	Lettuce	
Radish	Corn	
Celery	Carrot	
Green beans	Onion	
Clover	Alfalfa (Lucerne)	
	Wheat	
	Rye	
	Oats	
	Sunflower	

Undue amounts of sodium (Na) ions in irrigation water can reduce soil permeability and cause some hardening of the soil due to the replacement of calcium (Ca) and Magnesium (Mg) ions by sodium (Na) ions of the soil clay particles.

The Sodium Adsorption Ratio (SAR) is expressed as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

where Na, Ca and Mg are each expressed in milli-equivalents per litre.

According to Ayers and Westcot[6] "For SAR values greater than 6 to 9, the irrigation water could be expected to cause a permeability problem on the shrinking-swelling types of soil".

Permeability problems are also related to the carbonate (CO_3) and bicarbonate (HCO_3) content of the irrigation water. During drying of the soil, CO_3 and HCO_3 react with the Ca and Mg ions in the soil to precipitate as $Ca - MgCO_3$, thus proportionally increasing the Na hazard. This effect is evaluated by the Residual Carbonate (RSC) method.[7]

The concepts of SAR and RSC have been refined by the use of the so-called "adjusted Sodium Adsorption Ratio (adj. SAR), viz. –

$$\text{adj. SAR} = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}\,[1+(8{,}4-pHc)]$$

pHc is a theoretical calculated value of pH of the irrigation water in contact with lime and in equilibrium with soil CO_2.

Values of pHc above 8,4 indicate a tendency to dissolve lime from the soil through which the water moves; values below 8,4 indicate a tendency to precipitate lime from the water applied.

The adj. SAR is considered to more correctly predict the potential for soil permeability than SAR and RSC evaluations.

Hart and van Vuuren[3] have indicated the mineral quality requirements of water for agricultural purposes to be as follows (see Table below):

Agricultural Use	Total Dissolved Solids mg/ℓ	Remarks
Crops	< 500	Satisfactory for all crops.
	500 – 1 000	Water can have a detrimental effect on sensitive crops; additional water may be required for leaching.
	1 000 – 2 000	Water that may have adverse effects on many crops and thus requires careful application practice.
	2 000 – 5 000	Water that can be used for tolerant plants on permeable soils with careful management practice.
Livestock	2 500* – 5 000†	*Threshold value at which poultry or sensitive animals might show slight effects from prolonged use. †Animals in lactation or production might show definite adverse reaction.

Soils: Robinson[8] states that most crops will grow in soil containing 0,25 per cent salt. However, it is pointed out that where rainfall is insufficient to produce percolation into the underground water, salts tend to accumulate in the subsoil and may come to the surface by capillary rise to cause entire sterility.

Water Quality Criteria for Various Uses

Drinking Water

1(a) *World Health Organization – International Standards**

Substance and characteristics affecting acceptability: concentrations of constituents expressed in mg/ℓ.

Substance or characteristic	Highest desirable level	Maximum permissible level
Colour (° Hazen)	5	50
Turbidity (Formazin units)	5	25
Odour	unobjectionable	unobjectionable
Taste	unobjectionable	unobjectionable
Total solids	500	1 500
pH value (range)	7,0 – 8,5	6,5 – 9,2
Anionic detergents	0,2	1,0
Mineral oil	0,01	0,30
Phenolic compounds (as phenol)	0,001	0,002
Total hardness (as $CaCO_3$)	100	500
Calcium (as Ca)	75	200
Chloride (as Cl)	200	600
Copper (as Cu)	0,05	1,5
Iron (total as Fe)	0,1	1,0
Magnesium (as Mg)	30 (up to 150 where SO_4 is low)	150
Manganese (as Mn)	0,05	0,5
Sulphate (as SO_4)	200	400
Zinc (as Zn)	5,0	15
Nitrate (as NO_3)	45	45
Fluoride (as F)†	0,6 – 0,9	0,8 – 1,7
Arsenic (as As)		0,05
Cadmium (as Cd)		0,01
Cyanide (as CN)		0,05
Lead (as Pb)		0,1
Mercury (as Hg)		0,001
Selenium (as Se)		0,01
Chromium (Hexavalent, as Cr)		0,05
Polynuclear aromatic hydrocarbons		0,0002

International Standards continued

Substance or characteristic	Highest desirable level	Maximum permissible level
Gross alpha radioactivity (in pc/ℓ)		3
Gross beta radioactivity (in pc/ℓ)		30

1(b) *Limits for Fluoride in Drinking Water*

Annual average maximum daily air temperature	Fluoride limits	
	Lower	Upper
0 – 12	0,9	1,7
12,1 – 14,6	0,8	1,5
14,7 – 17,6	0,8	1,3
17,7 – 21,4	0,7	1,2
21,5 – 26,2	0,7	1,0
26,3 – 32,6	0,6	0,8

1(c) *Bacteriological Requirements (for Water in a Distribution System)*

(i) Throughout any year coliform organisms should be absent per 100 mℓ in 95 per cent of the samples taken.
(ii) No sample should contain *E. coli* in 100 mℓ.
(iii) No sample should contain more than 10 coliform organisms per 100 mℓ.
(iv) Coliform organisms should not be detectable in 100 mℓ of any two consecutive samples.

2 *South African Bureau of Standards Specification for Water for Domestic Supplies (SABS 241 – 1984)*

This specification lays down the minimum physical, chemical and bacteriological requirements for the purity (as delivered to the consumer) of water for domestic supplies.

Water for domestic supplies includes water for culinary purposes and general household usage, but not necessarily for hot water systems (for which special treatment might be required to prevent problems such as scale formation or corrosion or both).

Note: Methods of sampling and analysis may be obtained from the South African Bureau of Stan-

*"International Standards for Drinking Water", 3rd Edition, World Health Organization, Geneva, 1971.
†Refer, further, to 1(b) following.

dards, Dr Lategan Road, Groenkloof, Pretoria or (Postal address: P O Box X191, Pretoria 0001).

Physical Requirements

Turbidity: (nephelometric turbidity units) – Recommended limit 1
Maximum allowable limit 5

Colour: Recommended limit – of platinum ..... 20 mg/ℓ
Maximum allowable limit – not specified.

Odour and taste: Odour and taste shall not be objectionable.

Chemical Requirements

		Min.	*Max.*
pH Value –	Recommended range of pH	6,0 –	9,0
	Allowable range of pH	5,5 –	9,5
Conductivity	Recommended limit		70 mS/m
	Maximum allowable limit		300 mS/m

Note: Both of the limits specified as "recommended" and "maximum allowable" represent water fit for human consumption and for domestic purposes.

The "recommended" limit should, if possible, be applied to all water supplied for domestic use, and the "maximum allowable" limit should never be resorted to unless no other water supply is practically available. In this case, steps should be taken to improve the quality in a reasonably short time by practical technology.

Macro-determinants

Determinant mg/ℓ	Recommended limit	Maximum allowable limit
Total hardness (as $CaCO_3$)	20 min. 300 max.	Not specified 650
Magnesium (as Mg)	70 max.	100
Sodium (as Na)	100 max.	400
Chloride (as Cl)	250 max.	600
Sulphate (as SO_4)	200 max.	600
*Nitrate + nitrite (as N)	6 max.	*10
Fluoride (as F)	1,0 max.	1,5
Zinc (as Zn)	1,0 max.	5,0

*If nitrate plus nitrite (expressed as N) is present in concentration in excess of 10 mg/ℓ, the water may be unsuitable for use by infants under 1 year of age and an alternative source of supply must be found for such infants' use.

Micro-determinants

Determinant μg/ℓ	Recommended maximum limit	Maximum allowable limit
Arsenic (as As)	100	300
Cadmium (as Cd)	10	20
Copper (as Cu)	500	1 000
Cyanide (as CN)	200	300
Iron (as Fe)	100	1 000
Lead (as Pb)	50	100
Manganese (as Mn)	50	1 000
Mercury (as Hg)	5	10
Phenolic compounds (as phenol)	5	10
Selenium (as Se)	20	50

Other Constituents

The water shall not contain any other constituents in concentrations which may render it unsuitable for use for domestic supplies. Radioactivity, if present, shall be within the limits laid down by the International Commission for Radiological Protection.

Bacteriological Requirements

Property	Recommended maximum limit	Maximum allowable limit
Total coliform bacteria count per 100 mℓ	Nil*	5
Faecal coliform bacteria count per 100 mℓ	Nil	Nil
Standard plate count per millilitre	100	Not specified

*If coliform bacteria are present in a sample a second sample taken immediately thereafter shall be free from coliform bacteria. Not more than 5 per cent of samples (from a reticulation system) tested per year shall contain coliform bacteria.

3 *Drinking Water for Cattle*

The amount of water drunk by cattle correlates with the air temperature irrespective of the humidity. The intake ranges from 27 ℓ/day at 11°C to 39 ℓ/day at 24°C.[9] The water intake can be affected by the moisture and chemical content of the food ingested.

In assessing the water consumed by stock, Wells[9] states that in England it is assumed that an animal will daily require (1 gallon) 4,5 ℓ of water per (1 cwt) 51 kg liveweight. Assuming a figure of (7 cwts) 357 kg for the mean weight of cattle, he estimated the quantity of drinking water for some 9 million cattle in England and Wales to be (63 million gallons) 286

million litres per day. In South Africa, due to the higher temperatures prevailing the daily water intake per live bodyweight is higher than the above.

The permissible concentrations of mineral ions in drinking water for cattle in South Africa are as follows:[10]

Total Dissolved Solids	1 000 mg/ℓ
Calcium	1 000 mg/ℓ
*Magnesium	500 mg/ℓ
Sodium	2 000 mg/ℓ
Sulphate	1 000 mg/ℓ
Chloride	3 000 mg/ℓ
Fluoride	6 mg/ℓ

*The magnesium content is considered to be critical and higher concentrations can give rise to major problems.

Nitrate poisoning: Nitrate poisoning in human beings and animals results from ingesting food or water containing high levels of nitrate. Garner[11] has indicated that the lethal dose for cattle is 0,6 g (NO_3) per kilogram body weight. Poisoning usually occurs in a relatively short period (e.g. an intake of 1,134 grams NO_3 per kilogram body weight over a period of 24 hours does not produce intoxication whereas as little as 0,32 gram (NO_3) per kilogram body weight caused death in 4 hours.[12]

Nitrite is considerably more poisonous than nitrate!

Further, Funke[14] has quoted the quality requirements for a number of industries, recommended

Water Quality Criteria for Various Uses
(Abstracted by Davis and de Wiest[13] from various sources)
(Numbers represent the maximum recommended concentrations in mg/ℓ)

	Drinking	General Household Use		Irrigation		Food Processing	Boiler water	
		Good	Poor	Good	Poor		High Pressure	Low Pressure
Antimony	0,05	...	...	...	...	0,05	...	...
Arsenic	0,05*	...	...	...	...	0,05	...	...
Barium	1,00*	...	...	...	...	1,00	...	...
Bicarbonate	500	150	500	200	500	300	5	50
Boron	20	...	...	0,3	3,0	...	...	...
Cadmium	0,01*	...	...	...	...	0,01	...	...
Calcium	200	40	100	...	...	80	1	40
Chloride	250	...	...	100	300	300	...	...
Chromium	0,05*	...	...	...	...	0,05	...	...
Copper	1,0	0,5	3,0	...	...	3,0	...	...
Cyanide	0,2*	...	...	...	...	0,2	...	...
Fluoride	1,5	...	...	...	...	1,5	...	...
Hydrogen sulphide	1,0	0,05	2,0	...	...	0,5	0	5
Iron	1,0	0,2	0,5	...	...	0,2	...	...
Lead	0,05*	...	...	...	...	0,05	...	...
Magnesium	125	20	100	...	...	40	1	20
Manganese	0,05	0,05	0,3	...	...	0,1	...	...
Nitrate	20	...	...	...	...	20	...	...
Phenol	0,001	...	...	...	...	0,001	...	...
Selenium	0,01*	...	...	...	...	0,01	...	...
Silica	...	10	50	...	...	50	1	30
Silver	0,05*	...	...	...	...	0,05	...	...
Sodium	200	100	300	50	300	300	...	50
Sulphate	250	100	300	200	500	...	...	...
Synthetic detergents	0,5	0,2	1,0	...	...	0,5	0	0
Total solids	1 500	300	2 000	500	3 000	1 000	100	2 000
Zinc	5	...	...	...	...	5	...	...

*Mandatory limits of the US Public Health Service for water used on interstate public transportation facilities.

by the Water Quality Control Board of California, viz. –

Maximum Permissible Concentrations in High-quality Water for Specific Industrial Uses
(All values in mg/ℓ except Colour)

	Textiles	Viscose pulp	Fine paper pulp	Plastics uncoloured
Colour (platinum)	0 – 20	5	5	2
Hardness as $CaCO_3$	0 – 20	8	100	n.s.
Alkalinity	n.s.	50	75	n.s.
Tota solids	n.s.	100	250	200
Turbidity (SiO_2)	3 – 27	5	10	2
Fe	0,1 – 1,0	0,0005 – 0,05	0,01	0,02
Mn	0,05 – 1,0	nil – 0,03	0,05	0,02
Fe + Mn	0,05 – 1,0	–	0,05	0,02

n.s. – not specified

Funke[14] has dealt systematically and effectively with measures to reduce the intake of fresh water by an industry and treatment methods to restore the reuse value of process effluents.

Under measures to reduce the intake of fresh water he has dealt, *inter alia*, with the following:

- Dry transport instead of wet transport;
- Dry separation versus wet separation;
- Dry scrubbing versus wet scrubbing;
- Dry versus wet manufacturing processes;
- Mechanical separation of water versus evaporation.

Under treatment methods to restore reuse he has included such phase separations as the following:

Screening, sedimentation, flotation, flocculation, centrifuging, filtration and cycloning.

Practical examples from industry are given. This CSIR guide by Funke should be consulted by industrialists.

Additionally, he has carried out studies, in depth, relating to water problems in a number of specific industries, viz. –

- CSIR Guide K11, Pretoria, 1969: Industrial Water and Effluent Management in the Textile Industry;
- CSIR Guide K12, Pretoria, 1970: Industrial Water and Effluent Management in the Milk Processing Industry;
- Guide 29a, Pretoria, 1973: Pollution Abatement in the Electroplating Industry.

Significant Efforts by South African Industries

Significant achievements have been reported by a number of large water users in the hierarchical use of water, notably, the iron and steel industry – Highveld Steel and Vanadium Corporation Limited and the South African Iron and Steel Corporation Limited (ISCOR); the Electricity Supply Commission (ESCOM); the chemical industry – African Explosives and Chemical Industries Limited (AECI) and Sentrachem; the cellulose fibre industry – South African Industrial Cellulose Corporation Limited (SAICCOR), South African Pulp and Paper Industries Limited (SAPPI) and the Mondi Paper Company Limited; South African Coal and Gas Company Limited (SASOL).

Van Duuren,[15] in dealing with the chemical industry, referred to a paper by Alexander[16] which dealt with a "water quality hierarchy utilization system" practised by AECI. He indicated that the Modderfontein plant of AECI uses water from four sources to augment its fresh water intake. He stated that the "cascade technique" where the effluent from one stage of a process becomes the influent to another is used successfully in the ammonia plant at the factory. The final concentrated effluent, diminished in volume, is used consumptively for quenching coke, for spraying into coal to allay dust and for wetting oxide used in the H_2S removal system.

Van Eeden[17] has asserted that the policy of ESCOM is "to use water to its full potential where possible and have no discharge of water from their power stations at all".

Raw river water is clarified and the major part concentrated 6 to 8 times in the cooling water circuit. Partial make-up is provided by purified sewage effluents. Blow-down from the cooling towers is mixed with the demineralizer or softener regenerant liquors, together with boiler and evaporator blow-down and passed to the ash system where water is used for the conveyance of pulverized fuel ash to the dumping sites where some evaporation of water takes place. The remaining ash-water is then recycled.

Van Duuren[15] states that a kilogram of flyash adsorbs about 0,6 kg of water with its associated dissolved solids. Also important are the precipitation of magnesium ions, phosphate, fluoride, silica and

the liberation of nitrogen at the high pH value (12,5) of the water. The high pH ash-return water is then used for the de-alkalizing and softening of the raw and cooling water.

The treatment method evolved by ESCOM has made it possible to increase the concentration factor of intake river water considerably. The total quantity of water used by ESCOM's power stations has been markedly attenuated by reducing blow-down and control of the ash-water system. None the less, a great deal of water is used for cooling and consideration is being given to alternative methods of cooling for new developments.

Both Highveld Steel and Vanadium Corporation at Witbank and ISCOR at its plants in Pretoria, Vanderbijlpark and Newcastle re-use purified sewage effluent and re-cycle process effluents. (Reference should be made to Chapter 15 for information concerning this industry.)

SAPPI at its three major undertakings at Springs, Ndgodwana in the Eastern Transvaal and Mandini in Natal practise re-cycling. The Springs plant owes its existence to the use of purified sewage effluent (supplied by the Municipality of Springs) as its intake water supply. At Ndgodwana the final effluent is irrigated on grassed lands for fodder and for pasturage for beef animals.

The Mondi Paper Company Limited, at its (Merebank) Durban works uses sewage effluent supplied by the Durban City Council as intake water which it purifies further for use in the production of high-quality paper. Details of the treatment used have been given by Giampietri and Voysey.[18] (Reference should be made to Chapter 15 for information concerning the cellulose fibre industry in South Africa.) The Mondi Paper Company Limited has embarked on a new major pulp manufacturing industry at Richards Bay. Regrettably, effluent is discharged into the sea as is the case with a large mill of the South African Industrial Cellulose Corporation Limited (SAICCOR) at Umkomaas. The Mondi mill at Felixton which produces paper from bagasse also discharges effluent into the sea at Port Durnford.

Notwithstanding, in these cases, internal re-use of water is practised and mainly the intractable "black liquor" is discharged into the sea – as an alternative to evaporation as practised by SAPPI at its mills at Ngodwana and Mandini. At Mandini, the final effluent – electronically fish monitored – is discharged into the River Mandini just prior to its confluence with the Tugela River – near its estuary.

At SASOL's Secunda set-up of "SASOL II" and "SASOL III" some 75 000 m^3 of raw water per day are received from the Grootdraai Dam on the Vaal River via a pump and channel system and the Bosjesspruit Dam. The water is used mainly for steam generation and cooling purposes at this unique major oil-from-coal facility.

The plants operate on the basis of zero effluent discharge.*

The contaminated process waters consist of the following:

(1) Stripped gas liquor from the coal gasifiers containing phenols and amines.
(2) Fischer-Tropsch acids from the "Synthol" synthesis process containing fatty acid and non-acid chemicals which after treatment at the "Chemical Work-up" plant contains mainly acetic acid.
(3) Oil stormwater which is passed through API skimmers.
(4) Boiler blow-down after four cycles of concentration.
(5) Equalization-ponds return-water.

All the above process waters are treated in the "Water Recovery Plant". The initial treatment is by the activated sludge process using surface aeration: effluent – after separation from the activated sludge – is subjected to the following treatment processes:

Flocculation, double media filtration (sand/anthracite), activated carbon adsorption, and ion exchange.
The surplus activated sludge is concentrated by dissolved air flotation followed by centrifugation and final incineration.

The SASOL philosophy, therefore, is one of combining all process liquors – then, after preliminary treatment of any particular process effluents, cooling, and then purifying the combined effluent biologically. After "polishing" the final biologically purified effluent by physico-chemical methods, re-using this water in the oil-from-coal plants, so ensuring zero discharge and, at the same time, maximum re-use of water.

Rudd[19] has indicated that counter-current washing techniques used in many industries have resulted in a saving in water use of up to 60 per cent. (Counter-current washing constitutes an hierarchical use of water.) He has illustrated counter-current washing with particular reference to the iron and steel industry.

Funke,[20,21] in dealing with measures to cut down the amount of water used in the textile industry, has emphasized, *inter alia*, the importance of counter-current flow in washing machines and counter-current rinsing, together with squeezing of fabrics in the removal of chemicals and adsorbed particles.

*Sewage from the town of Secunda and Langverwacht is purified in domestic sewage purification plants to conform with gazetted standards and is discharged into the adjoining spruit.

REFERENCES

1. Water 75, published by Erudita Publications (Pty) Ltd., Johannesburg, 1974, p. 15.

2. Water 75, p. 11.
3. Hart, O.O. and van Vuuren, L.R.J. *Water Re-use in South Africa*, Chapter 13, "Water Renovation and Re-use", Academic Press Inc., New York, San Francisco, London, 1977, p. 358.
4. Elgabaly, M.M. *Problems of Soils and Salinity*, "Water Management for Arid Lands and Developing Countries – Water Supply and Management", Vol 13, Pergamon Press, Oxford, 1980.
5. Davis, S.N. and de Wiest, R.J.M. Hydrogeology, John Wiley and Sons Inc., New York, London, p. 118.
6. Ayers, R.S. and Westcot, D.W. *Water Quality for Agriculture*, Proc. Internat. Salinity Conf., Texas, 1976, p. 421.
7. Eaton, F.M. *Soil Science*, 1950, **69**, 112-133.
8. Robinson, G.W. The Soil, John Murray, London, 1949, p. 233.
9. Wells, D. *The Water Requirements of Particular Stock Producing Systems*, The Role of Water in Agriculture, Pergamon Press, Oxford, 1970, p. 121.
10. Information supplied by the Director-General, Department of Agriculture and Fisheries, 1982.
11. Clarke, E.G.G. and Clarke, M.L. Garner's Veterinary Toxicology, 3rd Edition The Williams and Wilkins Co., Baltimore, Md., USA, 1967, pp. 108-118.
12. Dollahite, J.W. and Holt, E.C. *Nitrate Poisoning*, IUPAC Symposium on the Control of the Human Environment, Johannesburg, July, 1969.
13. Davis, S.N. and de Wiest, R.J.M. Ibid, p. 121.
14. Funke, J.W. *A Guide to Water Conservation and Water Reclamation in Industry*, CSIR Guide K9, Pretoria, 1969.
15. Van Duuren, F.A. The Chemical Engineer (Instn. Chem. Eng., London), 1981, p. 440.
16. Alexander, A.T. *Control of Liquid Effluent from AECI's Modderfontein Factory*, IUPAC Conference, Johannesburg, 1969.
17. Van Eeden, W.N. *J. Inst. Water Pollut. Control*, 1975, **74**(2), 211.
18. Giampietri, A. and Voysey, J.A. *J. Water Poll. Control Fed.*, 1979, 51(3), 518.
19. Rudd, R.T. *J. Water Poll. Control Fed.*, 1979, **51**(3), 453.
20. Funke, J.W. *Effluent Management in the Textile Industry: How to Cut Down Volume and Pollution Load*, South African Dyers and Finishers Association, 1st National Symposium, Port Elizabeth, 24 – 25 September 1972.
21. Funke, J.W. *Industrial Water and Effluent Management in the Textile Industry*, CSIR Guide K11, Pretoria, 1969.

Chapter 15 CONTROL OF POLLUTION FROM INDUSTRIAL EFFLUENTS (MAJOR WATER-USING INDUSTRIES)

15(1) THE MINING INDUSTRY: HANDLING AND DISPOSAL OF EFFLUENTS ARISING FROM MINING AND MINERAL RECOVERY OPERATIONS

"O Unseeing Plutus, would that thou hadst never appeared in the earth or in the sea or on the land, but that thou didst have thy habitation in Tartarus and Acheron, for out of thee arise all evil things which overtake mankind."

The antipathy of the ancient classicial poets and writers towards the mining and recovery of riches from the earth is succinctly put in the above saying attributed to Timocreon of Rhodes as reported by Georgius Agricola in *"De Re Metallica"*. (Translated from the first Latin edition of 1556 by Hoover, H L and Hoover, L H.)

This attitude of condemnation applied, more particularly, to gold, silver and iron. They regarded gold as an attractive scourge giving rise to robberies, etc. and iron as giving rise to wars!

However, in this day and age, whilst we subscribe to Ovid's thesis that the soil is there for agricultural purposes we realize that many minerals are of strategic and industrial importance – and so, lucky is the country which is well-endowed with mineral deposits of commercial value!

Historical

Copper was the first metal sought-after by the early settlers at the Cape. During the governorship of Simon van der Stel copper was found at Okiep (1682 – 1685). Coal was discovered in Natal in 1842 but deposits were not worked till more than forty years later. A colliery was started at Molteno in the Cape in 1864. In 1879 coal was discovered in the Vereeniging district. The first coal used on the Witwatersrand gold fields came from Boksburg and Springs. With the expansion of the gold fields, coal mines were opened up in Witbank and adjacent Middelburg.

Iron was first discovered in Natal in 1860.

Today the mining industry in South Africa is undoubtedly the major industry. Kurian[1] in *"The Book of Rankings"*, 1979, gives South Africa the following world rankings for a number of its mineral commodities, viz. – copper (11); silver (16); gold (1); iron ore (12); uranium reserves (2); coal reserves (10).

He states that South Africa ranks 23rd in land area and 29th in population.

He places South Africa 1st in gold production, 3rd in diamonds and 8th in coal production.

South Africa's role in world mineral reserves in 1980 is given in the 92nd Annual Report of the Chamber of Mines of South Africa, 1981.[2] Table I has been extracted from this report (cf.).

Table I
South Africa's Role in World Mineral Reserves, 1980
South Africa's (including Bophuthatswana) mineral reserves as a percentage share of Western World and World reserves.

Mineral Commodity	South Africa's Reserves (metric tons)	Western World		World	
		Rank	%	Rank	%
Manganese Ore	12 100 000 000	1	93	1	78
Platinum Group Metals (600 m depth)	27 050	1	78	1	66
Vanadium (Metal, 30 m depth)	5 200 000	1	65	1	35
Chrome Ore (300 m depth)	2 600 000 000	1	65	1	63
Gold (Metal)	16 500	1	64	1	51
Fluorspar (CaF_2 content)	33 000 000	1	45	1	34
Andalusite, Sillimanite	102 000 000	1	45	1	39

Table I continued

Mineral Commodity	South Africa's Reserves (metric tons)	Western World Rank	Western World %	World Rank	World %
Vermiculite (Crude)	73 000 000	2	29	2	28
Diamonds (carats)	71 000 000	2	23	2	21
Uranium (Metal, up to $50 lb U_3O_8)	390 000	2	14	N/A	N/A
Antimony (Metal)	400 000	2	18	3	7
Asbestos (Fibre)	8 400 000	4	8	4	5
Zirconium (Metal)	5 000 000	2	12	2	10
Phosphate (Contained concentrates)	1 790 000 000	3	9	4	9
Coal (Largely bituminous)	110 000 000 000	3	13	6	10
Zinc (Metal)	12 000 000	4	6	5	5
Lead (Metal)	6 157 000	4	5	5	4
Nickel (Metal, 600 m depth)	4 780 000	5	8	7	6
Titanium (Metal)	36 600 000	3	17	4	15
Silver (Metal)	8 700	5	6	6	4
Cobalt (Metal)	70 000	6	3	7	2
Iron Ore (30 m depth)	9 500 000 000	6	6	7	3
Copper (Metal)	6 400 000	8	2	10	1
Tin (Metal)	*	12	1	14	1

*Classified data
N/A = not available

Van Biljon[3] quotes world rankings for some of the Republic's mineral reserves as follows:

Manganese (1); platinum (1); vanadium (1); chromium (1); gold (1); calcium fluoride (1); andalusite (1); diamonds (2); antimony (3); asbestos (4); coal (6).

A more recent economic picture is given in *"South African Statistics, 1982"*.[4] (cf. Table II (a), (b), (c).)

Table II
Summary Statistics: Value of Minerals Sold
II (a)
Value of minerals sold – R Million

Year	Total	Gold	Diamonds	Coal
1980	14 793,7	10 369,6	553,0	1 495,0
1981	13 747,9	8 556,6	339,9	2 112,5

II (b)
Value of minerals sold – R Million

		Precious Minerals		Metals	
Year	Total	Gold	Other	Iron Ore	Other Metals
1980	14 993,7	*10 369,6	634,7	296,1	703,5
1981	13 747,9	*8 556,6	410	361,2	736,0

II (c)
Value of minerals sold – R Million

Year	Total	†Non-metals	‡Building Materials	Miscellaneous
1980	14 993,7	1 774,9	183,5	1 031,4
1981	13 747,9	2 426,9	217,2	1 039,9

**Note:* The price of gold (between 1950 – 1970) was about R1 583/kg (max.). This rose to R15 500/kg (max.) in 1980 but has since dropped considerably.
†Non-metallic minerals include diamonds, emerald crystals, tiger's eye, andalusite, asbestos, barytes, sillimanite, talc.
‡Building materials include fire and flint clay, granite, gypsum, silcrete, silica, shale, slate, vermiculite, wonderstone.

From the foregoing there seems little doubt that, at present, the mining industry in South Africa is a formidable one from an economic point of view.

However, the criterion, as far as the control of pollution is concerned, is the production tonnage in each case since this is related to the extent of pollution which may arise.

Production weights of minerals are given in *"South African Statistics, 1982"*,[4] viz. –

Precious Metals

Gold	655 728 kg
Silver	235 393 kg

Metallic Minerals

Beryllium	122 t
Iron ore	28 319 × 1 000 t
Antimony	9,8 × 1 000 t
Chrome ore	2 870 × 1 000 t
Copper	199,4 × 1 000 t
Lead ore	98 901 t
Lithium	N/A*
Manganese	5 040 × 1 000 t
Tantalite ore	4 t
Tin	2 811 t
Titanium	61 t
Tungsten ore	N/A*
Vanadium	N/A*
Zircon	N/A*

*Not available

Non Metallic Minerals

Diamonds	9 256 carats
Emerald crystals	502 kg
Tiger's eye	184 t
Andalusite	181,3 × 1 000 t
Asbestos	235,9 × 1 000 t
Barytes	2,1 × 1 000 t
Bentonite	44,4 × 1 000 t
Fuller's Earth	0,4 × 1 000 t
Kaolin	149,8 × 1 000 t
Coal	130 267 × 1 000 t
Corundum	0,0 × 1 000 t
Felspar	55,4 × 1 000 t
Fluorspar	334 × 1 000 t
Graphite	N/A*
Kieselguhr	0,6 × 1 000 t
Mica	2,4 × 1 000 t
Mineral pigments	1,3 × 1 000 t
Phosphates	17 712,4 × 1 000 t
Salt	525,8 × 1 000 t
Sillimanite	15,5 × 1 000 t
Talc	9,5 × 1 000 t

*Not available

Building Materials

Fire and Flint Clay	282,6 × 1 000 t
Gypsum	554,8 × 1 000 t
Lime and Limestone	23 358 × 1 000 t
Magnesite	56,6 × 1 000 t
Silcrete	9,2 × 1 000 t
Silica	1 386,8 × 1 000 t
Shale	599,5 × 1 000 t
Vermiculite	190,6 × 1 000 t
Wonderstone	5,7 × 1 000 t

As far as pollution of the water environment is concerned the mining activities and mineral processing activities which are of concern relate to the following:

Causal Pollution Agent

*Gold:**† Pyrites associated with gold (Au) giving rise to acid (H_2SO_4) mine water containing, initially, ferrous sulphate resulting from a combination of bacteriological and chemical reactions of the pyrite (FeS_2) in the presence of oxygen (air) and moisture (water).

Coal: Pyrite present in the coal – following the same course as for pyrite in gold mines resulting in acid mine water.

Fluorspar: Fluoride (F) in the process recovery waters.

Phosphate: Fluoride. In the case of apatite feedstock from the Phalaborwa deposit, fluoride (F) is present in the apatite matrix. When this apatite is processed to produce fertilizers, fluoride in the plant effluent is a problem.

For more detailed information on mineral resources the reader is referred to the comprehensive compilation, entitled *"Mineral Resources of the Republic of South Africa"*, 5th Edition, Geological Survey/Department of Mines, 1976, printed and obtainable from the Government Printer, Bosman Street, Pretoria.

In this publication[5] a contribution by the Division of the Government Mining Engineer is significant. It is indicated that at the end of 1975, the total value of mineral products of the country had increased to R40 061 577 197, of which gold accounted for approximately 66 per cent, miscellaneous (mainly uranium, platinum, nickel and osmiridium) approximately 8 per cent, coal approximately 6 per cent, diamonds approximately 6 per cent and copper approximately 4 per cent.

The importance of the gold mining industry to South Africa, therefore, cannot be gainsayed. However, in its wake the country is beset with pollution problems.

GOLD MINING

"The miner should try to obtain a mine, to which access is not difficult, in a mountainous region, gently sloping, wooded, healthy, safe and not far distant from a river or stream by means of which he may convey his mining products to be washed and smelted. This indeed, is the best position. As for the

*In the gold-bearing reefs of the Eastern Transvaal (e.g. Barberton and Lydenburg) the gold is associated with arsenopyrite, $FeAs_2 - FeS_2$). Preliminary roasting of the ore eliminates the arsenic which can be recovered.

†In the recovery of uranium by leaching of the gold residue after cyanidation, sulphuric acid and manganese dioxide (pyrolusite) are employed. Where manganese-containing effluent *per se* or seepage from evaporating dams containing such effluent can gain access to a river, the water of which forms the domestic water supply of a community, laundering problems occur due to staining of garments caused by the manganese present.

others, the nearer they approximate to this position the better they are; the further removed, the worse."

Georgius Agricola in *"De Re Metallica"* (1556).

The above highly idealized conception of Agricola is scarcely applicable to South Africa since, in many cases, water has to be pumped considerable distances to the mining area. This is the case in the Witwatersrand where water is supplied by the Rand Water Board. No river transport is available, so other forms of transport have to be used e.g. road and rail transport.

Electricity (unkown in Agricola's time) is supplied by the Electricity Supply Commission (ESCOM) operating a national grid system for the supply of electricity to the Republic. However, in the early days of mining each mine operated its own electric power generating plant and, likewise, also, did the municipalities.

Discovery of Payable Gold

The history of the discovery of gold, in retrospect, has been written of in a romantic way. Tales have been told about the early gold discoveries in California and Colorado in the United States; in Alaska; Klondike in Canada and in Australia.

As far as the Witwatersrand is concerned quite a deal of controversy has raged as to the discoverer of gold in this area of the Transvaal which has supplied a considerable amount of the world's gold. Letcher[6(a)] records that the first European to win gold on the Witwatersrand was John Henry Davis, an Englishman, who sojourned at Paardekraal (Krugersdorp) from 1852 onwards. But, as far as the discovery of payable gold is concerned, the discoverers of the auriferous conglomerates of the Witwatersrand Main Reef Series, George Harrison and George Walker, were recognized officially in 1886 as the discoverers of the Witwatersrand Goldfields.[6(b)]

Chilvers,[7] in his book *"Out of the Crucible"*, has given the palm to Fred Struben for discovering gold on the Witwatersrand. However, Charles Struben[8] (his nephew) in his book "Vein of Gold" states, "It stands on record that a resolution was passed by the Volksraad giving credit to Harry Struben (his father) as one of the discoverers of Witwatersrand Gold".

He further states, that his uncle Fred Struben "to the best of his knowledge never claimed to have discovered the 'main reef'" but records further, "but I believe without doubt that it was my father's enterprise, linked with my uncle's extraordinary valuable field work, which led directly to the discovery of the main reef . . .".

Cartwright[9] states, "But the fact is that despite Fred Struben's faith in the conglomerates they had not at that stage found them payable. The 'Confidence Reef' was near the outcrop and, like everything that had gone before it, a near miss".

He goes on to state, "In after years George Walker declared that it was he who had found the reef. But no two stories he told were alike and Harrison had vanished".

Apparently G C Oosthuizen, on whose farm in the Langlaagte area the gold discovery took place, gave Harrison a letter to take to President Kruger in Pretoria in connexion with the discovery of gold on the farm.

Harrison, according to Cartwright, signed a statement as follows: "My name is George Harrison and I come from the newly discovered goldfields Kliprivier especially from a farm owned by a certain Gert Oosthuizen. I have a long experience as an Australian golddigger and I think it is a payable goldfield".

According to Cartwright, Walker (Harrison's associate), lived until 1924 and received a pension from the Chamber of Mines but some 20 years later Ethel and James Gray[6(b)] were able to show from research they carried out in the Government Archives in Pretoria that "Harrison ought to have been given the laurel". They found that George Harrison had been awarded a discoverer's claim (Langlaagte No. 19), while George Walker received only one ordinary claim (Langlaagte No. 21). This would seem significant and tend to favour Harrison as the legal discoverer of the Main Reef, none the less Walker was the serendipitous discoverer.

Rosenthal[10] in his book *"Gold! Gold! Gold!"* states . . . "the problem for every writer is not only to identify the man who first proved that its true source was the Banket Formation, but to determine what caused him to suspect that it might be so. Never before had this conglomerate proved auriferous, yet somebody, somewhere, and at sometime carried out the fateful experiment. Though many claims are made finality eludes the historian".

He gives information about George Harrison and George Walker but also adds the names of George Honeyball, the Struben brothers and others – and, leaves the matter in the air!

Details concerning the discovery of gold on the Witwatersrand may also be had in the *"Report of the Committee of Enquiry appointed by the Commission for the Preservation of Natural and Historical Monuments, Relics and Antiques"*, published in 1941 – printed by the Government Printer, Pretoria.

The summary of the committee's findings includes a statement, "That Pieter Jacob Marais was the first person to find gold near the Witwatersrand. This was on the 8th October, 1853 in the Jukskei River". (No mention is made of John Henry Davis though Letcher's book[6(a)] is listed in the Committee's "List of Books, etc. consulted". Marais – a roving personality and a virtual "Forty Niner" of the California gold rush as well as a golddigger in Australia became the "official gold prospector" – accredited to the Volksraad on 6th December, 1853.)

With regard to Walker and Harrison, the Commit-

tee reported "That the Main Reef Group of Conglomerates was first found on G C Oosthuizen's part (Portion C) of the farm Langlaagte, shortly before the end of March, 1886. This led directly to the prospecting contract of 12th April, 1886."

"This find was accidental. It was made by George Walker, probably in association with George Harrison, but there is no record of either of these men having had assays made or milling done on the conglomerate on which they subsequently pegged contract discoverers claims."

The Committee concludes by stating that "The first battery erected specifically to work the Main Reef Group of Conglomerates was that of the Jubilee Gold Mining Company (April 1887)" and that "J B Robinson was the first to have inaugurated systematic underground development on a large and scientific scale in his effort to establish ore-reserves".

Occurrence of Gold

Gold occurs in the uncombined state as the metal. However, gold and silver form a series of solid solutions while copper, on the other hand, is soluble in gold to the extent only of approximately 20 per cent.

In addition to its occurrence as native gold, but more rarely, the element can occur in tellurides.

Pyrite (FeS_2) is the most common sulphide (mineral) in the gold-rich banket constituting approximately 1 to 3 per cent of the ore. In the so-called "Black Reef" it can exceed 3 per cent. In some cases pyrrhotite and marcasite can also be present. This presence of pyrites is of particular significance when the ore is mined and the sulphides are exposed to air and moisture.

In the banket (conglomerate) gold is seldom observed under the microscope except in the case of rich samples, hence there is some significance in the remarks of Rosenthal[10] if it were not for the fact that the early prospectors were, in fact, dealing with the rich oxidized outcrops. Pyrite (FeS_2), itself has been referred to as "fools gold" due to its somewhat "golden"-brass-like metallic lustre in certain situations.

The specific gravity of gold is on average 19,3 (19,25 to 19,37), hence in the panning of crushed conglomerate, gold will appear in the "tail" since panning is virtually a simple method of gravity separation. Pyrite, average specific gravity 5,0 (4,85 – 5,04), on the other hand, will not appear in the gold tail unless comminution of the samples has been inadequate and pyrite adheres to or occludes the gold.

Hence it would have been necessary for the early prospectors on the Witwatersrand to efficiently crush any samples of quartz outcrop found by them (specific gravity of quartz 2,50 to 2,80).

Recovery of Gold

At the start of gold mining on the Witwatersrand fine crushing of the ore was effected by means of stamps. After stamp milling, fine screening was employed to produce a pulp of c. 60 – 65 per cent minus 90 mesh (particle size 0,15 mm).

But as the gold encountered with increased depth of mining it became progressively finer, and it became necessary to employ tube mills to obtain a more finely divided product and so expose the inherent gold particles.

While mining was confined to the oxidized banket it was possible to recover the gold by simple gravity concentration methods, amalgamation and subsequent retorting of the amalgamated gold which, of course, included silver.

As mines became deeper and entered sulphide zones and also, co-incidently, as grades became poorer better methods of recovery were sought. This was brought about, by the development of the MacArthur-Forrest Cyanide Process which was discovered in Glasgow (Scotland) in 1887 by John Stewart MacArthur and the Forrest brothers.

From the foregoing it will be realized that the recovery of gold from gold ores as practised on the Witwatersrand and in the Orange Free State is a

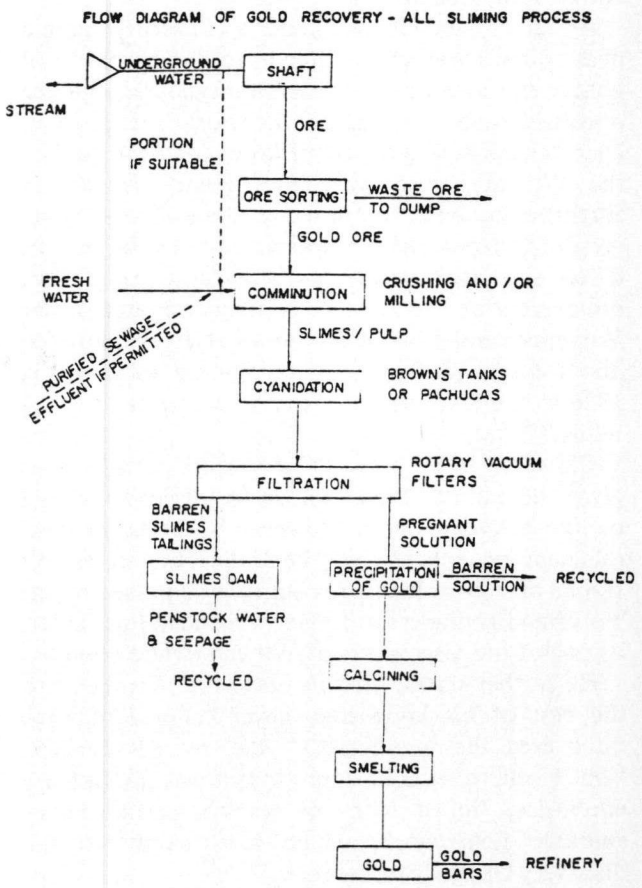


Figure 1
Flow Diagram of Gold Recovery – All Sliming Process

hydrometallurgical process requiring the use of water both in the milling and extraction stages.

For details of the methods used today reference should be made to the publications of the Chamber of Mines of South Africa, entitled *"Gold Metallurgy on the Witwatersrand"*[11(a)] and *"Gold Metallurgy in South Africa"*.[11(b)]

In the early days of mining on the Witwatersrand, tailing "dumps" consisted of sand dumps and slimes dams but with the later trend towards the all-sliming process of gold recovery only slimes dams were built. Waste rock dumps, of course, remain a natural concomitant of gold mining and gold recovery operations.

Basically the recovery process initially consists of sorting of the ore received from the mine into gold-bearing and waste rock fractions.

The gold-bearing fraction is first crushed and is further comminuted by grinding in tube mills (Refer to Figure 1).* This is followed by dissolution of the gold from the solids using the cyanide process wherein the pulp/slime in cyanide solution is aerated in special tanks (Brown's tanks) or pachucas. Separation of the dissolved gold (in the solution) from the residual solids is effected by means of rotary vacuum filters. The final stage involves the recovery of gold from the pregnant solution. This is normally done by precipitation with zinc dust. The precipitated material is then calcined and the gold smelted and poured into moulds to form gold bars. Finally, the gold bars are dispatched to the Rand Refinery for purification/refining and final export.

The final pulp from secondary tube-mill circuits, after classification, can be floated to give a flotation concentrate containing gold and pyrites. This can be applied to ores high in sulphur content. A flotation concentrate can then be used for the production of sulphuric acid, and recovery of the inherent gold in the residue-calcine from the sulphuric acid manufacturing process can be retrieved by cyanidation of the calcine.

During a period when sulphur was in short supply in the Republic a number of mines, through the aegis of the Chamber of Mines of South Africa, produced pyrites concentrates and these were supplied to sulphuric acid producers. Credit was allowed for the gold content of the pyrites supplied.

Effluent from Metallurgical Processing: Any cyanide-containing effluent which may escape from slimes dams – which can result from imbalance in the water circuitry of the hydrometallurgical processing and heavy rainfall – will naturally be a threat to the water environment. This seldom happens but can be taken care of by adjusting the pH value of the effluent to 8,2, adding sufficient chloride of lime ($CaOCl_2$) and agitating before release to the water environment.

Excess water which accumulates on top of a slimes dam is controlled by a system of penstocks which return the excess to process. With proper control no effluent should escape.

In cyanidation practice the finishing strength in the dissolution of gold is of the order of 0,02 per cent NaCN and protective alkalinity is maintained at 0,015 per cent CaO.[12]

The barren slimes disposed of on a slimes dam will separate into two phases – solids and supernatant water. This water, in due course, will have its cyanide (CN) concentration reduced due to a number of factors such as the formation of ferrocyanide, sulphocyanide and cyanate due to further interaction with the iron and sulphur-containing substances. The carbon dioxide in the air can also react to produce hyrocyanic acid gas (HCN) which is released. After 36 h retention the cyanide concentration lowers to c. 0,001 per cent.

Seepage water can be controlled by cut-off trenches arranged to divert the seepage into a sump from whence it can be recycled back to a convenient point in the plant e.g. at the tube mills.

Therefore, properly controlled slimes dams of an operating gold mine do not present a threat from the introduction of cyanide (CN^-) ions into the water environment.

Pollution Threat to the Water Environment

Probably the greatest threats to the country's rivers by the gold mining industry are as follows:

(1) Seepage and runoff from old mine sand dumps and slimes dams;

(2) Underground water from old operating mines with acid mine drainage which is pumped to the surface.

(1) *Seepage and Runoff from Old Mine Sand Dumps and Slimes Dams*

The seepage and runoff from sand dumps and slimes dams of defunct mines is a severe threat to the environment and the Chamber of Mines of South Africa has given much attention to this problem.[13(a)(b)] In association with the Department of Water Affairs practical steps have been taken in attempt to alleviate the pollution from these sources.

This has taken the form of supplying vegetative cover or shrouding of mine dumps[13(c)] and treating acid mine drainage by the "High Density Sludge" (H.D.S.) process using lime and aeration with recycling of precipitated sludge. The H.D.S. process has been mainly done on the initiative of individual gold mining companies.[14(a)(b)(c)]

Some of the older operating mines have even had to lime their underground water before pumping it to

*In a number of reduction plants "run-of-mine" milling or "autogenous grinding" has been practiced.

the surface to prevent tramline corrosion of welded steel rising mains and corrosion of pump installations, pipes and other ironwork generally.

Therefore, it is necessary to examine the nature of acid mine drainage and how it is formed.

(2) *Formation of Acid Mine Drainage*

Pyrites: Pyrites is the trade name for three minerals with a sulphur content exceeding 25 per cent, viz. –

(i) Pyrite (FeS_2) which, when pure, contains 53,4 per cent S and 46,6 per cent Fe. It has a brass-like colour and, sometimes, can have associated with it small amounts of arsenic, copper, nickel, cobalt, zinc, tin and gold.
(ii) Marcasite (FeS_2). This mineral has the same chemical composition as pyrite but is pale yellow to white in colour.
(iii) Pyrrhotite ($Fe_{11}S_{12}$)* contains 38 – 39 per cent S and is brownish-bronze in colour. The following metals may be associated with it: copper, nickel, cobalt.

It is a magnetic sulphide of iron having a Relative Attractability of 6,7 in comparison with iron (Fe) of 100 taken as standard, magnetite (Fe_3O_4) 40,2 and ilmenite ($FeTiO_3$) 24,7.

Pyrite weathers rapidly to hydrated iron oxide, goethite or limonite.

Limonite or brown haematite, an hydroxide of iron, exists in many varieties, according to the proportion of combined water. The varieties are colloidal and have no constant composition except goethite FeO(OH) which crystallizes.

The pyrites associated with the gold of the Witwatersrand conglomerates is taken to be mainly the mineral pyrite (FeS_2).

The exposure of iron sulphides to air and moisture causes them – by chemical action alone – to oxidize to ferrous sulphate ($FeSO_4$) as follows:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4$$

If, at this stage, $Ca(OH)_2$ is added $Fe(OH)_2$ (ferrous hydroxide) should precipitate from solution as a green precipitate at a pH of 5,5 (cf. Table III).

In practice this cannot happen as there are a number of on-going reactions, both chemical and bacteriological, before release of mine drainage in a mine to the environment.

Bacteriological Changes: Bacteria which are of importance in Fe and S mineral transformations are as follows:

Thiobacillus thiooxidans – oxidizes S, SO_2, $S_2O_3^{2+}$
Thiobacillus ferrooxidans – oxidizes Fe^{2+}
Ferrobacillus ferrooxidans – oxidizes Fe^{2+}
Ferrobacillus sulphoxidans – oxidizes S, Fe^{2+}

Table III
Hydroxide Precipitation pH Values from Dilute Solutions
(According to Britton H.T.S., "Hydrogen Ions")

	Precipitation pH		Precipitation pH
Magnesium	10,5	Lead	6,0
Silver	9(?)	Beryllium	5,7
Manganous	8,5 – 8,8	Ferrous	5,5
Lanthanum	8,4	Cupric	5,3
Cerous	7,4	Chromium	5,3
Mercuric	7,3	Zinc	5,2
Praseodymium	7,1	Uranic	4,2
Neodymium	7,0	Aluminium	4,1
Samarium	6,8	Thorium	3,5
Cobalt	6,8	Stannous	2(?)
Yttrium	6,8	Zirconium	2(?)
Cadmium	6,7	Ferric	2(?)
Nickel	6,7		

There are also bacteria which can reduce sulphates to hydrogen sulphide. This can take place in sewers by the process of desulphurication in the sewage below the waterline under anaerobic conditions. The H_2S released to the air above the waterline, i.e. in the presence of air and moisture, is then converted to H_2SO_4 which attacks the inner surface of concrete sewers. The H_2SO_4 reacts with calcium in the concrete, forming crystals of calcium sulphate which, in turn, rupture the hard outer skin of the internal surfaces of the sewers and the sulphuric acid reacts catastrophically with the free lime in the cement thereby destroying the sewers above the waterline.

The most widely distributed sulphate reducer according to Reinheimer[15] is *Desulphovibrio desulphuricans* and is found in the mud of lakes and ponds.

In addition to sulphate-reducing bacteria, H_2S results from the acid anaerobic fermentation of organic matter e.g. proteins in sewage.

Two general types of bacteria exist, viz. –

(1) Autotrophic bacteria which live on inorganic matter.
(2) Heterotrophic bacteria which live on organic matter.

Where the organisms are strictly of the types indicated in (1) and (2) above, they are called obligate and where they can switch substrates (i.e. they are able to use organic or inorganic material) they are regarded as facultative.

Autotrophic bacteria use CO_2 (e.g. in the atmosphere) as their source of carbon and have

*Pyrrhotite Fe_nS_{n+1} is commonly taken as $Fe_{11}S_{12}$ but can vary from Fe_5S_6 to $Fe_{16}S_{17}$.

adapted to acidic conditions and the presence of heavy metal ions at pH values of 1,5 to 3 and can exist at a pH of 1.

Chemistry of Acid Mine Water: The chemistry of acid mine drainage, dump seepage, etc. may be summarized as follows:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4 \quad \ldots (1)$$

$$4FeSO_4 + 2H_2SO_4 + O_2 \xrightarrow{\text{bacteria}} 2Fe_2(SO_4)_3 + 2H_2O \quad \ldots (2)$$

$$Fe_2(SO_4)_3 + 6H_2O \longrightarrow 2Fe(OH)_3 + 3H_2SO_4 \quad \ldots . (3)$$

Ferric sulphate, $Fe_2(SO_4)_3$, is a strong oxidizing agent and attacks the pyrite (FeS_2) to yield more ferrous sulphate ($FeSO_4$).

$$FeS_2 + Fe_2(SO_4)_3 \longrightarrow 3FeSO_4 + 2S \ldots \ldots . (4)$$

Ferric sulphate, additionally, changes into basic sulphate.

Action of Bacteria: The chemical rationale outlined by reactions (1) to (4) need clarification since bacteria play an important part in the overall changes.

Reaction (2) is considered to be the result mainly of bacterial activity.

Thiobacillus ferrooxidans oxidizes ferrous to ferric compounds in acid solutions. This acidophilic obligatory chemoautotrophic bacterium is able to oxidize ferrous compounds in acid conditions where auto-oxidation is not possible.

Thiobacillus ferrooxidans and *Thiobacillus thiooxidans* have been used for processing sulphide and uranium ores since these micro-organisms oxidize the reduced sulphur in sulphide-containing ores to sulphuric acid thereby enabling leaching out of the metals present (e.g. in so-called heap leaching and bioextractive metallurgy.

Iron Bacteria: Attention has been drawn to the fact that *Thiobacillus ferrooxidans* is capable of oxidizing ferrous to ferric compounds (cf. reaction (2)). It is an acidophilic organism and is obligatory chemoautotrophic which has adapted to acid conditions as low as pH 1. However, there are a number of iron bacteria e.g. *Leptothrix ochracea*,* *Gallionella ferruginea*, *Spirophyllum ferrugineum*, *Crenothrix polyspora*, *Cladothrix dichotoma* and *Clonothrix fusca* which have the capacity to abstract iron from waters in which they live and collect it in the form of ferric hydroxide on their surfaces. The ochre beds of ferruginous pools and streams are due to the ferric hydroxide stored by the dead iron bacteria. Iron bacteria are also responsible for the formation of bog iron ore. Also, they are responsible for the incrustation of the inner surface of water pipes in reticulation systems. However, most of these organisms are not chemoautotrophic – they are filamentous types and in most cases facultative.

Ellis[16] has stated that the most dreaded of iron-bacteria is *Crenothrix polyspora* which develops rapidly and imparts a reddish-brown colour to water in which it develops.

He has concluded that "iron bacteria are responsible for ferruginous sediment which probably form themselves by slow degrees into iron ores . . .".

Therefore, whenever iron is present in the right environment i.e. with moisture/water, mineral salts and/or organic matter present, bacteria are likely to cause transformation of iron compounds or minerals with which they come in contact.

Thermophilic Bio-oxidative Micro-organism: Brierley[17] has reported on a high temperature micro-organism which oxidizes reduced sulphur and iron in an acid (pH 2,0) medium between 45°C and 75°C. The organism was isolated from the drainage of a hot acid spring in Yellowstone National Park, USA. The organism ranges in size from 1 to 1½ micron in diameter; its morphology is unlike the Thiobacilli being pleomorphic rather than rod-shaped.

Attempts have been made to employ it in the leaching of chalcopyrite and molybdenite.

The Essence of the Pollution Problem and its Possible Circumvention

From the foregoing, the gravamen of the problem is shown to result from the very act of mining in that by sinking shafts, blasting out driveways, cross-cuts, stopes, winzes, etc. to isolate the reef and convey the gold-bearing rock in skips to the surface for recovery of the gold in the reduction plant, the previously embedded pyrite is at once exposed to air and moisture. It is not possible to exclude air from a mine, in fact, air is vital to sustain the life and well-being of the miners. Most mines "make" water which is present in underground aquifers and also seeps and percolates through underground strata to working places. Furthermore, in the process of drilling, prior to blasting, water has to be supplied to the pneumatic drills/jackhammers for lubricating purposes. Drinking water of potable quality has also to be supplied.

Therefore, underground, air and moisture are ever present!

Underground dams are present at different levels as supply impoundments and, also, to assist in stage – pumping of water to the surface.

Normally, water is caused to flow in channels alongside driveways towards the shaft to flow into a sump at the lowest point for pumping to the surface.

The amount of water pumped to the surface by some of the mines on the "West Wits Line" is considerable and involves the installation of large underground pumping stations as well as employing

*This is the most widely distributed of iron bacteria.

cementation methods to prevent flooding of the mines.

Thus the two requirements for bacterial action, viz. – moisture and oxygen, cannot be circumvented as far as access to the pyrite of these agents is concerned – only with a great deal of work would it be possible to ameliorate this by coating the hanging walls, side walls and footwalls of driveways and worked-out areas to prevent access of air and moisture to the rock surfaces, but this would be impracticable and uneconomic. Also, attempts at adding palliative chemicals to inactivate the bacteria would hardly be less futile.

Therefore, it becomes realized that the problem lies in accepting the mine drainage at the surface for treatment. None the less, it will be realized that the underground water should be pumped to the surface without delay to minimize the time of contact of the water with the pyrite.

Thus the problem appears to be identified as the treatment of acid mine drainage pumped to the surface to render it suitable for release to the environment – and coupled with this, the satisfactory construction and proper control of slimes dams and other residue dumps.

Treatment of Acid Mine Drainage

At the South West Vertical Shaft of the East Rand Proprietory Mines Limited in Boksburg, the problem was tackled originally, by adding lime to the acid mine water pumped from underground and allowing the neutralized effluent to flow into two large impoundments (in series) of a neighbouring mine from whence it flowed into the Elsburg Spruit and thence into the Natalspruit. The Natalspruit flows through an extensive stretch of reeds (*Phragmites communis*) in a vlei area on its journey south to the Vaal River.

The mine was forced to improve the quality of the effluent arising from a High Court Action instituted by a farmer in Elsburg who maintained that the water in the Elsburg Spruit adjoining his property formed the drinking water supply of his cattle which, he said, had suffered and were in poor condition due, he concluded, to the water which he stated contained run-off from the "Slop Farm" of the Germiston Municipality. However, it was shown from effluent and river surveys carried out by a firm of consulting chemists and the Municipal Chemist that the main source of pollution was underground water from the East Rand Proprietory Mines, Limited. The case was settled out of court.

In March 1967 the mine management installed a conventional lime treatment plant (cf. Figure 2) whereby underground water was neutralized with milk of lime and the mixture aerated to oxidize Fe^{2+} to Fe^{3+}. The ferric hydroxide and calcium sulphate which precipitated were settled in a clarifier. The settled sludge contained c. 2 g/ℓ of suspended solids.

The underground water was pumped from the 40th level, some 2 058 m below the surface. This method was in use until February 1975.

Subsequently, during October 1976 water from the 24th level, 1 050 m below the surface was pumped to the surface and treated by the High Density Sludge (HDS) Process. This plant treats about 33 000 m^3 of underground water per day.

Figure 3 gives an outline of the HDS Process.

The HDS Process was based on the method used by the Bethlehem Steel Corporation of the United States.

The benefit of this method is that less lime is used due to recycling of a portion of the precipitated sludge. The sludge finally disposed of is more dense and the volume much less than is the case with conventional settlement after ordinary liming and aeration.

Using the HDS Process, it was possible to improve the quality of acid mine drainage in as much as the pH value had been altered to conform with the requirements of the Water Act (Act No. 54 of 1956) as amended. The removal of H_2SO_4 and $FeSO_4$ is a considerable step forward but the concentration of sulphate (SO_4) in the water discharged into a river needs to be considerably reduced. Whether this can be achieved, at reasonable cost, by physico-chemical means such as ion exchange, reverse osmosis, ultra filtration, electrodialysis, etc., is still an open question. But the increasing of the salinity of the water in the Republic's rivers needs to be guarded against!

Rudd[18] has shown that the load of sulphate from the mines of the Witwatersrand is felt well-down the Vaal River as far as Douglas.

Tyser[19] has given the analysis of underground water from the East Rand Proprietory Mines Limited in Boksburg as follows:

pH Value	3,2
	mg/ℓ
Solids in suspension	16
Total dissolved solids	10 000
Fe^{2+}	1 400
Fe^{3+}	100
Al_2O_3	100
SO_4	6 400
CaO	600
Cl	200
Mg O	400

Bosman[20] has recorded analyses for seven mine waters. He has stated that waters containing from 6 000 to 13 000 mg/ℓ of sulphates and up to 5 000 mg/ℓ of iron have been reported. However, it is not clear whether his information refers to gold or coal mines or to both.

High Density Sludge Process (HDS Process): The High Density Sludge Process was first used by the Anglo American Corporation of South Africa

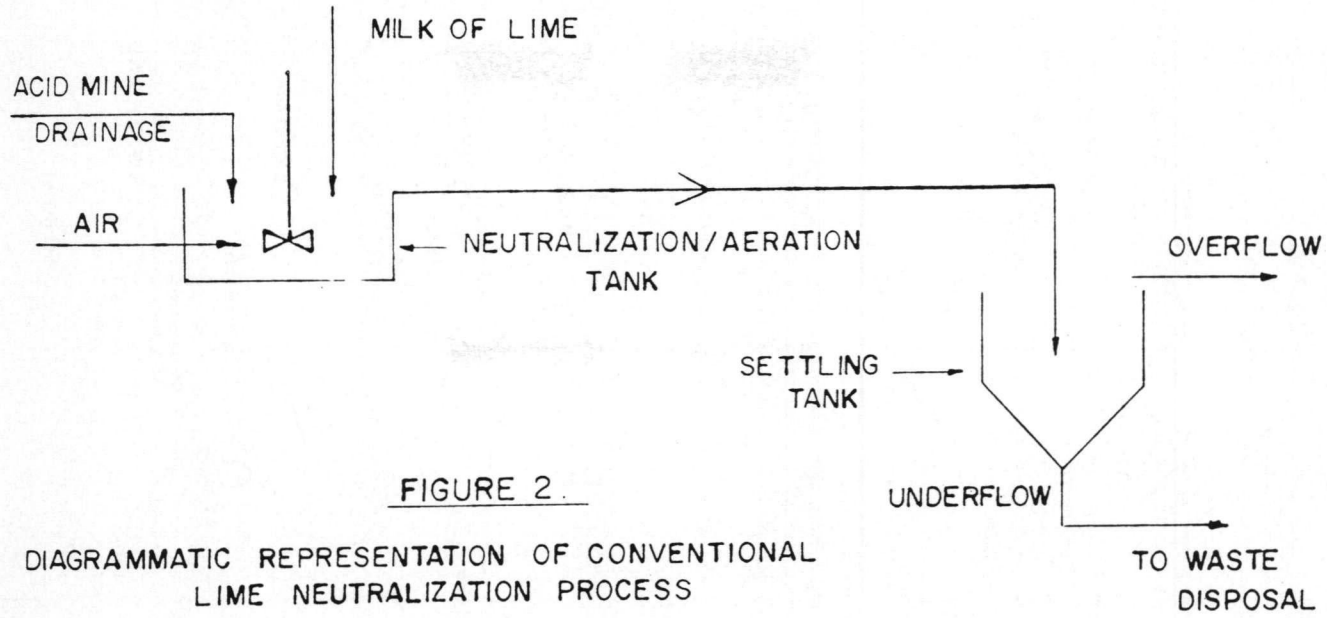


FIGURE 2.

DIAGRAMMATIC REPRESENTATION OF CONVENTIONAL LIME NEUTRALIZATION PROCESS

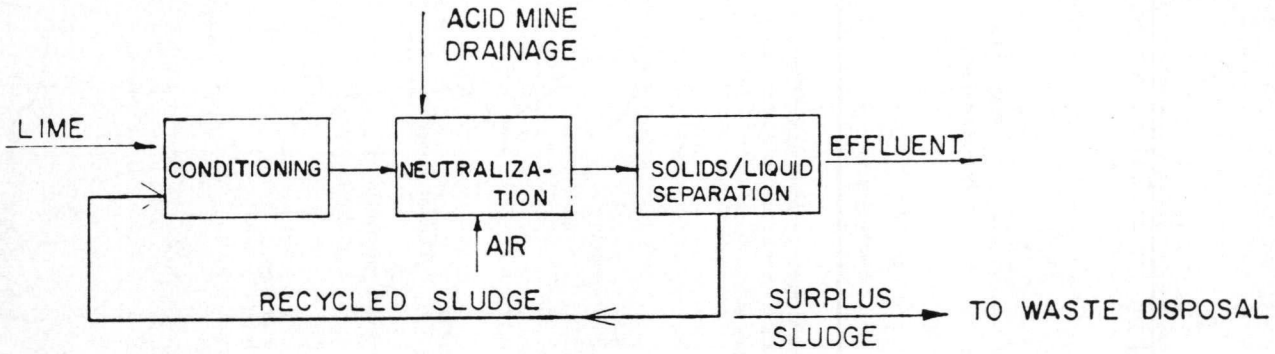


FIGURE 3

FLOW DIAGRAM OF HIGH DENSITY SLUDGE (HDS) PROCESS

Limited at Kromdraai in the Witbank coal mining area and much of the preliminary investigational work was carried out by the Anglo American Research Laboratories. Bosman has reported from time to time on the HDS Process, a recent report of this being that published in "Mine Water Pollution".[21] He has given a comparison of the densities and volumes of sludge obtained by conventional liming and by the HDS Process, as follows (cf. Table IV):

Table IV

Mine water	Conventional Liming		High Density Sludge Process	
	Sludge density g/ℓ	Sludge vol mℓ/ℓ	Sludge density g/ℓ	Sludge vol mℓ/ℓ
1	20	80	210	8
2	10	90	220	4
3	5	500	120	20
4	80	400	390	80
5	10	13	150	1

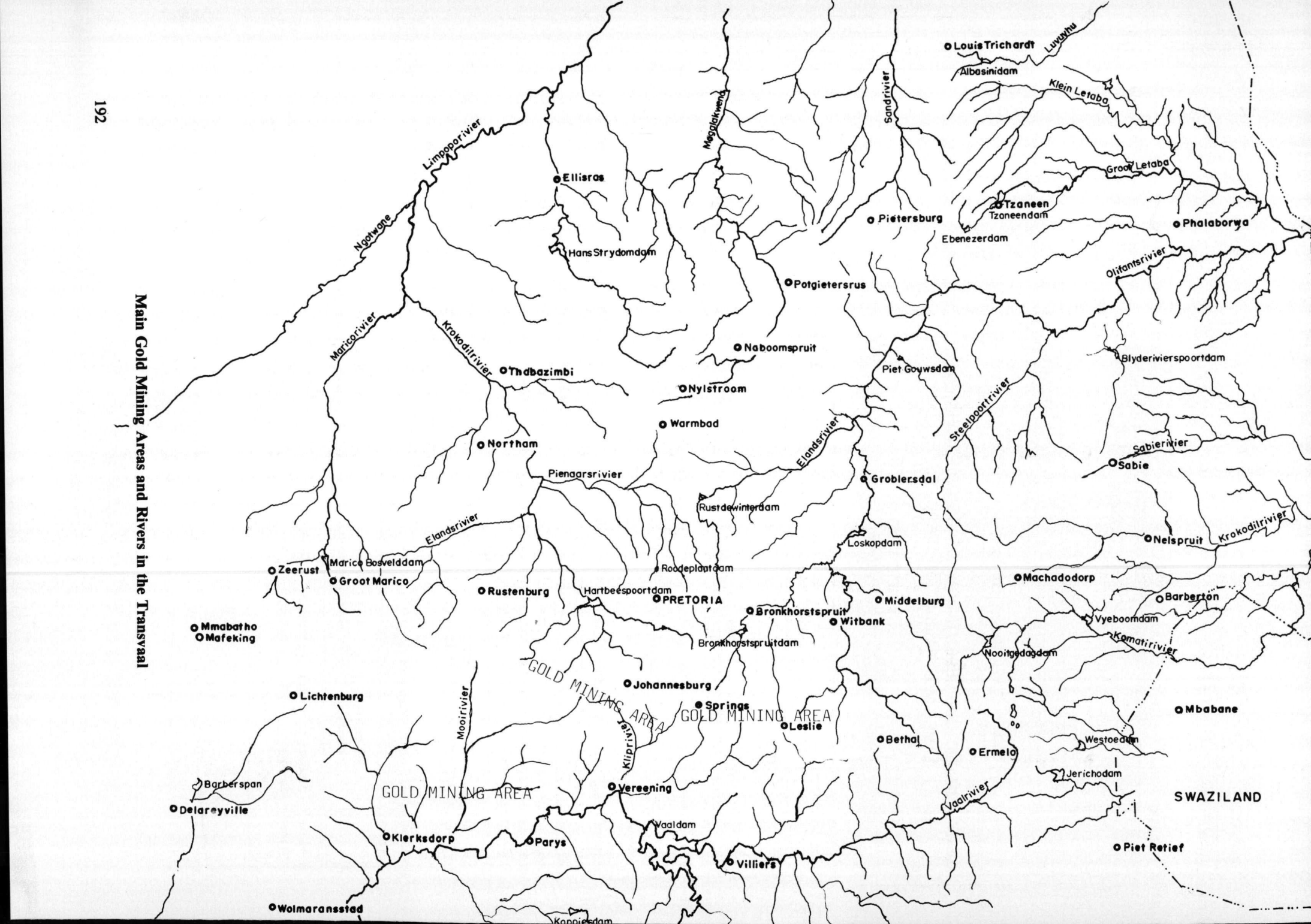
The above results clearly show that the use of the HDS Process results in a denser sludge and the volume of sludge to be dealt with is considerably less in many instances. Also there is a saving in lime usage. However, account has to be taken of the cost of aeration, particularly if aeration is effected by means of electric power-driven aerators.

The fact that the sludge produced is denser and the volume to be disposed of much less than with the conventional process makes disposal a less difficult problem.

Disposal of Slimes and Other Residues from Mining Activities and Metallurgical Processing

The gold-mining industry is unique in relation to manufacturing industries in that to produce a small amount of gold vast quantities of residues have to be disposed of.

Waste-rock Dumps: First of all there is the waste or country rock from mining operations which does not contain gold and has to be suitably disposed of. This is usually dumped near the shaft together with or separate from the sorted rejects from the reduc-



Main Gold Mining Areas and Rivers in the Transvaal

Witwatersrand Gold Mining Area and Rivers of the Southern Transvaal

tion plant. Waste rock may be used up by contractors who operate crushers to produce stone aggregate for building purposes, road construction, rail ballast, filter media for biological filter beds at sewage purification works, etc. The waste rock from underground can also be used for waste-packing underground.

Waste-rock dumps being somewhat free of pyrites should not cause acid pollution. They merely take up space.

Slimes Dams: Originally, insufficient attention was given to the construction and control of slimes dams. The metallurgical staff of mines, naturally, were more concerned with maintaining gold production and mine managers the "daily call". However, after a number of catastrophic collapses of slimes dams, more attention was given to the construction of slimes dams which were unlikely to fail.

However, with the promulgation of the Water Act in 1956 and the promulgation of regulations on 20 February 1976 in terms of sections 26(c) and 26(d) of the Water Act (Act 54 of 1956) "pertaining to measures aimed at the prevention of water pollution resulting from the operation of mines and works", it became necessary for the management of mines to pay particular attention to the satisfactory construction and control of slimes dams.

Legal Constraints

The Chamber of Mines of South Africa has now issued a *"Handbook of Guidelines for Environmental Protection"*. Volume I was issued in 1979 and covers *"The Design, Operation and Closure of Residue Deposits"*.

In dealing with "the legal framework and contraints on mining activities" it is pointed out that "a number of statutes have relevance to the design of residue deposits", viz. –

(1) The Air Pollution Prevention Act.
(2) The Health Act.
(3) The Mines and Works Act.
(4) The Soil Conservation Act.
(5) The Water Act.
(6) The Environmental and Planning Act.

(1) ***Atmospheric Pollution***

Section 28(1) of the Air Pollution Prevention Act provides that any person who, in a dust controlled area –
(b) has at any time or from time to time whether before or after the commencement of this Act deposited, or caused or permitted to be deposited on any land, a quantity of matter which exceeds, or two or more quantities which together exceed twenty thousand cubic metres in volume or such lesser quantity which may be prescribed, and which in the opinion of the Chief Officer causes or is liable to cause a nuisance to persons residing or present in the vicinity of such land, on account of dust originating from such matter becoming dispersed in the atmosphere, shall take the prescribed steps or (where no steps have been prescribed) adopt the best practicable means of preventing such dust from becoming dispersed or causing such nuisance.

(2) ***Health Requirements***

In terms of the Health Act, relating to the pollution of waters, no person shall deposit or allow to be deposited or discharged into a water source any liquid or solid matter which is or may be directly or indirectly infectious or injurious to man or may cause a nuisance.

(3) ***The Mines and Works Act***

This Act empowers the Minister to make regulations for:

(gA) The prevention and combating of pollution of the air, land or sea which arises or possibly arise in the course of operations involved in prospecting or mining for any mineral or after such operations have ceased.
(gB) The making safe of dangerous slimes dams, waste dumps, ash dumps . . ., the imposition of monetary or other obligations in connection with such safe making on persons who are or were responsible for the making of such slimes dams, waste dumps, ash dumps . . ., and the assumption by the State of responsibility or co-responsibility for such safe making in particular cases.
(hA) The conservation of the environment at or near any mine or works including, the restoration of land on which activities in connection with mines or works are performed or have been performed.

Other provisions of the Act include the following:

5.9.1 Water containing poisonous or injurious matter in suspension or solution must be effectively fenced off to prevent inadvertent access thereto, . . .
5.9.2 In no case may water containing any injurious matter in suspension or solution be permitted to escape without having been previously rendered innocuous.

(4) ***Soil Conservation***

The object of the Soil Conservation Act is "to make provision for the combating and prevention of soil erosion and for the conservation, protection and improvement of the soil, the vegetation and the

source and resources of the water supplies of the Republic".

(5) ***Water Pollution Control***

In terms of sections 26(c) and 26(d) of the Water Act 54 of 1956 regulations were published under Government Notice R 287 dated 20 February 1976.

These regulations contain, *inter alia*, the following requirements:

5.1 The manager of a mine or works shall cause a plan to be provided depicting all works constructed for the control of water on the surface of a mine or works or such other works as the Director-General may approve in writing.

7. The manager of a mine or works shall make adequate provision to the satisfaction of the Director-General to prevent as far as is reasonably practicable, runoff from eroding slimes dams and mineral tailings and waste-rock dumps due to rain.

8. The manager of a mine or works shall make adequate provision to ensure that all runoff due to rainfall on a property on which a mine or works is situated, is controlled in such a manner by a system of storm-water drains that it flows clear of slimes dams, mineral tailings and waste-rock dumps and other sources of pollution. Provision shall be made for the maximum precipitation to be expected over a period of 24 h with a frequency of once in one hundred years. A freeboard of at least 0,5 m shall be provided throughout the system above the expected maximum water level. Regional rainfall figures shall be based on information obtainable from the Director-General.

11.1 The manager of a mine or works shall cause all slimes dams and mineral tailings and waste-rock dumps to be so designed and constructed or modified that all rainwater precipitated thereon is retained thereon. Barrier dams and evaporation dams shall be provided where necessary to retain any runoff, including material eroded from slimes dams and dumps. The storage capacities of all dumps and dams shall be sufficient to ensure at least 0,5 m above the expected maximum water level, which shall be based on the average monthly rainfall figures for the catchment area concerned, less the gross mean evaporation in that area, plus the maximum precipitation to be expected over a period of 24 h with a frequency of once in 100 years according to information obtainable from the Director-General.

11.2 Rainwater from tailings dumps and the appurtenant barrier dams and water used in any process at a mine or works shall be recycled wherever possible.

Regional Standards for Industrial Effluents

General Standard: The quality standard for any wastewater or effluent produced by or resulting from the use of water for industrial purposes in all areas of the Republic of South Africa other than in the catchment areas draining into rivers or portions of rivers described in the Special Standard Schedule include the following:

pH Value 5,5 – 9,5.
Chemical Oxygen Demand not exceeding 75 mg/ℓ.
Oxygen Absorbed from acid N/80 $KMnO_4$ in 4 h at 27°C not exceeding 10 mg/ℓ.
Total Dissolved Solids not exceeding 500 mg/ℓ above that of intake water.*
Suspended Solids not exceeding 25 mg/ℓ.
Sodium content not exceeding 90 mg/ℓ.†

Other Constituents: The wastewater or effluent shall comply with the requirements set out in the following table:

Constituents	**Maximum concentration in mg/ℓ**
Residual chlorine (as Cl)	0,1
Free and saline ammonia (as N)	10,0
Arsenic (as As)	0,5
Boron (as B)	1,0
Hexavalant chromium (as Cr)	0,05
Total chromium (as Cr)	0,5
Copper (as Cu)	1,0
Phenolic compounds (as phenol)	0,1
Lead (as Pb)	0,1
Cyanide and related compounds (as CN)	0,5
Sulphides (as S)	1,0
Fluoride (as F)	1,0
Zinc (as Zn)	5,0
Manganese (as Mn)	0,4
Cadmium (as Cd)	0,05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05

(6) ***Planning Act***

Section 2 of the Planning Act is concerned with the establishment of townships which include industrial townships and individual industries.

Section 3 is concerned with the employment of the labour force for a particular industry in an urban or metropolitan area and the decentralization of industries, where appropriate, to an allocated Border Area.

Section 2 requirements do not really affect mines since a mine has to operate where the mineral is

*Conductivity not to increase by more than 75 milli-Siemens per metre (at 25°C) above that of the intake water.
†In terms of amendment R909 of 28 May 1971; (later in R991 of 18 May 1984).

found – in this case gold, and as far as labour is concerned the employment of Black workers from neighbouring territories has long been carried out by the recruitment section of the Chamber of Mines of South Africa.

Slimes Dams: Satisfactory Construction and Operation

The Chamber of Mines Handbook of Guidelines gives numerous drawings for the design of slimes dams illustrating the operation of slimes dams and the requirements and precautions to be taken in connexion with operating dams and those for so-called "retired" slimes dams. (The reader is referred to this publication for further information.)

Figure 4 gives a diagrammatic representation of the water balance for a residue deposit.

Location of Pool of Free Water in a Slimes Dam

The proximity of the pool to the impounding embankments and its level at the embankment are important. Where the pool is situated next to an embankment higher seepage rates are likely to arise: failure by piping through the dam, and reduction in dam stability due to a higher proportion of water in the structure are likely to result.

Therefore, wherever possible the water in a slimes dam should not be allowed to abut directly on embankments and where this is not possible the water level should be kept low.

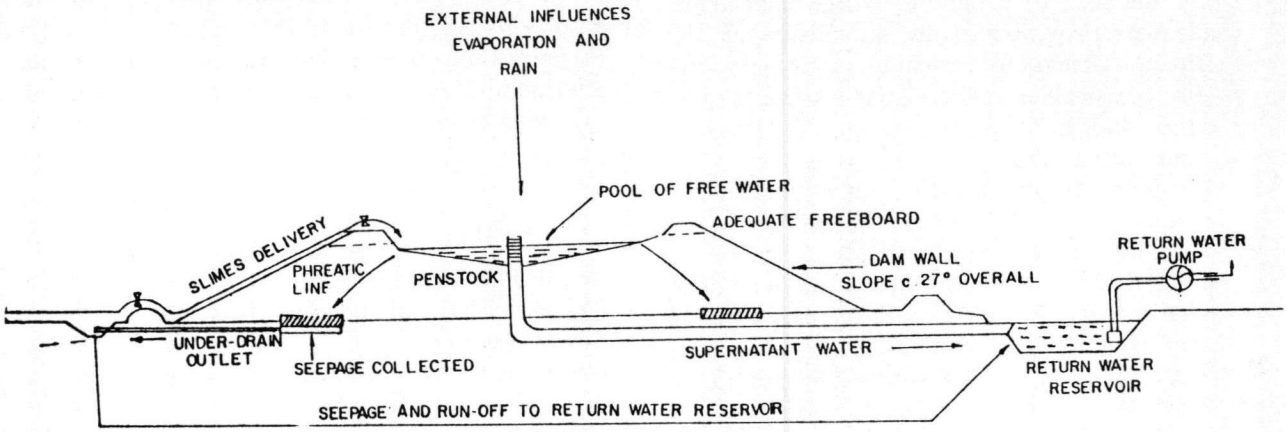


Figure 4
Water Balance for a Slimes Dam: Diagrammatic Representation

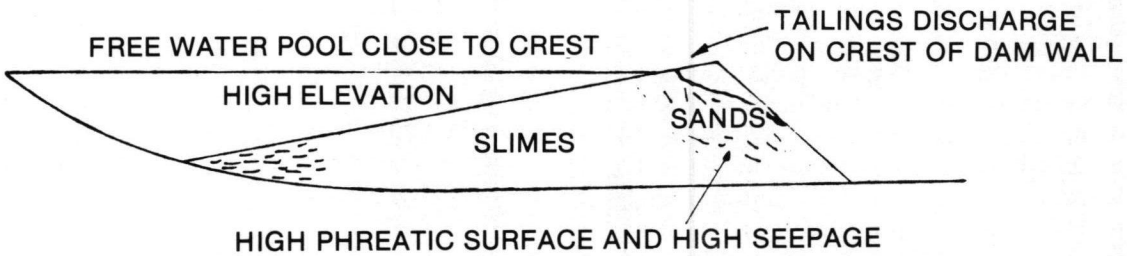


Figure 5

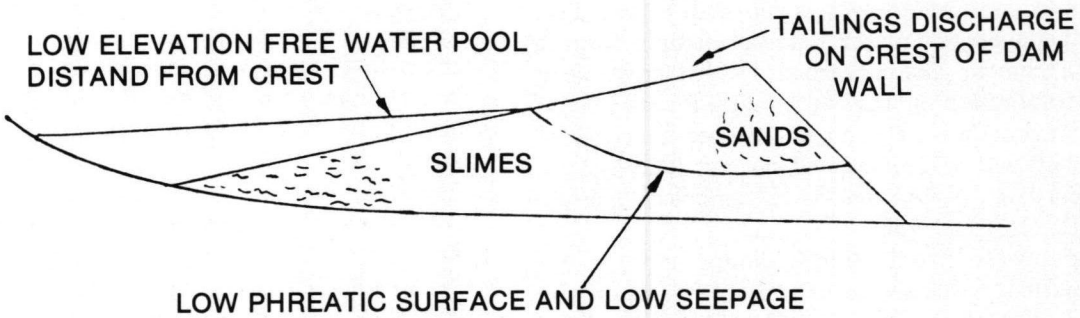


Figure 6

The elevation of the pool in relation to seepage is illustrated in Figures 5 and 6.

When slimes tailings are discharged along the top of a dam wall the coarse particles will settle out nearest to the dam wall and the fines, less permeable "slimes" will settle further away.

At low water levels, the pool will be located some distance from the dam wall and over impervious fine material. Thus, the rate of seepage and the phreatic surface will be low (refer to Figure 6).

Higher elevation of the pool will result in the pool being closer to the top of the dam wall and located over more permeable (coarse) material. This will result in seepage and phreatic surface being higher thereby resulting in dam failure.

Consequently, it would appear from the above *a priori* considerations that to avoid dam failure the pool of free water should be kept as far back as possible from a dam wall.[22]

Other Factors of Importance: Apart from the creation of the pool many other factors requiring attention in the design and successful operation of tailings impoundments include, –

(1) The size and depth of the settling pool. This will be conditioned by the rate of settlement of the particles in suspension and the time necessary to establish chemical equilibrium;
(2) The positions of the inflow points and the penstocks;
(3) Adequate construction of dam walls, satisfactory slope of these, safe free-board allowance and limiting height of walls;
(4) Wind action;
(5) Shortcircuiting;
(6) Seepage;
(7) Drainage facilities.

COAL MINING

The Republic's Coal Measures or Middle Ecca series are part of the Karoo System and are fairly continuous from Central Natal through the Eastern, Central and Northern Transvaal and the Northern Orange Free State. Disconnected fields in the Upper Ecca stage also occur.

However, the coal mined in the North Eastern Cape in 1870 in the Molteno – Indwe district to meet the early needs of the Kimberley diamond mines, lies higher in the succession in the Molteno beds of the Stormberg Series. The coal is of low grade and after having been sporadically worked operations are now dormant. Thus of the four provinces of the Republic, the Cape is lacking in good workable coal deposits, which – of course, has an economic impact on the operation of electric power stations and has led the Electricity Supply Commission (ESCOM) to construct the nuclear power station at Koeberg near Cape Town.

Historical

From a letter of Captain Smith to Sir George Napier K.C.B., Port Natal, August 20, 1842[23] the following has been extracted:

. . . "The more I see of this country, the more convinced I am of it being admirably adapted for the purposes of colonization. Cotton (of which I enclose a single pod as a specimen) grows remarkably well; and Mr Lindley, who comes from the cotton growing country in America, assures me that he makes no doubt it would be a most productive article of commerce. Native labour is not difficult to procure, and this would naturally aid its cultivation. The sugar cane also thrives well; and that coal exists in considerable quantities there is no doubt: its distance, however, inland (about 130 miles) is a drawback; but with the energy, capital and enterprise, this difficulty would vanish. Now might not a company be formed (the road is not bad, and may be greatly improved) to mine for and transport this coal, which is stated to be equal to what they call second-rate coal in England? . . .".

Today Natal's mining activity is centred on coal in the northern area, viz. – Newcastle, Dundee, Vryheid, Utrecht and Paulpietersburg. The coalfields of Natal are South Africa's principal source of anthracite and of coking coal for steel smelting.

Three defined coalfields in Natal are (1) the Klip River Field centred on the town of Dundee; (2) the Vryheid Field to the East of Vryheid and (3) the Utrecht Field between Newcastle, Paulpietersburg and the Transvaal border.

Details of the Northern Natal Coalfield are given in "Coal Survey Memoirs Nos 1 and 2" published by the Fuel Research Institute and the Geological Survey.[24]

Coal was discovered in the Transvaal shortly after the arrival of the Voortrekkers but mining of coal only became a proposition with the development of the Witwatersrand gold mines.

With railway development in the Transvaal and Natal large quantities of coal have been exported.

De Jager[25] has recorded that, "Coal comparable in quality with the best European coals is not present in South Africa, but the greater thickness of the seams and the shallow depth have enabled production at probably the lowest pit-head cost in the world".

Today a considerable amount of coal is exported via the facilities of the Richards Bay Coal Terminal Company Limited at Richards Bay. This company, operating under the aegis of the Transvaal Coal Owners Association, has provision for the export of 20 million tons per annum of coal and operates on a 106 hectare site. Railway truck unloading and ship loading facilities are of modern design and construction and are automated. The terminal has been in operation since 1 April 1976 and handles coal from

suppliers in the Witbank/Ermelo coal triangle.

Coal Petrology

The definition of coal, its formation, properties, rank, etc. have been dealt with under "Coal and Coke" in the section entitled, *"The Iron and Steel Industry: Control of Pollution from Wastewater Arisings"* (cf.).

Colaterally with this, reference may be had to the Presidential Address of Dr G N G Hamilton[26] to section "B" of the South African Association for the Advancement of Science of 1 July 1947 (cf.).

Methods of Coal Mining

Basically there are three methods used in mining for coal, viz. –

(1) Bord-and-pillar* mining;
(2) Longwall mining;
(3) Open-cast or strip mining (also referred to as surface mining).

(1) *Bord-and-Pillar Mining:*

In this method the bords or rooms are separated by pillars of solid coal, so arranged to support the roof of the excavated area. By this method – of necessity – all the coal is not removed from underground as coal remains in the pillars which may be partially removed subsequently. This, of course, results in subsidence of the roof and makes the land above a derelict area and subject to seepage from meteoric precipitation.

(2) *Longwall Mining:*

In this method the coal seam is removed in one operation by means of a long working face (or wall). The operation involves a steady advance in a continuous line which may be of considerable length. The space from which the coal has been removed is either filled with debris or allowed to collapse.

Naturally, to carry out such a method of mining highly mechanized equipment must be used as, for example, the use of coal cutters of advanced design, etc.

(3) *Open-Cast or Strip Mining:*

This method involves removing the over-burden, setting it aside, then extracting the coal and finally replacing the overburden – with the top soil in superimposed position. Thus restoring the land to its natural condition before mining took place.

To carry out this method of mining large earth-moving equipment, coal excavators and other large modern mechanical devices are necessary. The day of "pick and shovel coal mining" has been fast disappearing to be replaced by sophisticated mobile coal cutters, highly mechanized longwall mining equipment and large earth and coal moving mechanical devices, all of which have eventuated with advancing technology since World War II, viz. – bucket wheel excavators, draglines, mobile transfer conveyors, spreaders, mobile crushing units, etc.

Acid Mine Drainage

Attention has been drawn by Kemp[27] to acidic mine drainage from coal mines with special reference to the Natal coalfields while Kempe[28] has pointed out the serious water pollution problem which has arisen in the Witbank area due to the escape of some 800 m^3/day of acid water seeping from five defunct coal mines which cover an area of 37 km^2.

He has also indicated the control measures taken to ameliorate stream pollution from acid mine water in the vicinity of the Burnside Colliery in Northern Natal.

What has been said about acid mine drainage in the section on Gold Mining (vide ante) applies equally well to coal mines.

Kemp[27] states with reference to the Natal coal deposits, –

"Over considerable areas beds of iron ore are in places intercalated with the rocks (shale, sandstone, grits) . . . The coal has a characteristically banded appearance, being made up of thin layers of bright and dull material. Its sulphur content is rather high, often exceeding two per cent, mainly in the form of pyrite and marcasite, but partly in organic combination".

In dealing with the water pollution arising Kemp has paid particular attention to the sulphate content of such water which finally results from the chemical and bacteriological transformation of the iron sulphides.

He considers that in discussing the pollution of streams and rivers by drainage from coal mines, a convenient parameter is the Sulphate Index of the water, viz. –

$$\text{Sulphate Index} = \frac{SO_4 \text{ mg}/\ell \times 100}{SO_4 \text{ (mg}/\ell) + Cl \text{ (mg}/\ell) + CO_2 \text{ (mg}/\ell)}$$

Where the carbonate concentration is taken as the sum of the carbonate and bicarbonate contents and its value is obtained by adding the carbonate and bicarbonate alkalinities, expressed as milligrams $CaCO_3$ and multiplying by 0,60.

The Sulphate Index (SI) can range between zero and 100 and is independent of dilution effects and, in the absence of other sources of pollution can be taken as a measure of the extent to which a stream has been polluted by acid mine drainage. According to Kemp

*Sometimes referred to as "Pillar and Stall".

(unpublished results, 1960) the mean SI for 28 South African rivers was found to be 5,7. The mean for light unpolluted streams of the Klip River Coalfield was 6,4. The individual stream SI ratings were as follows:

	Sulphate Index (SI)
Upper Umzinyatshana	6,4
Upper Tributary A	10,1
Upper Tributary B	5,3
Upper Tributary C	7,7
Upper Sundays	6,3
Dwars	7,4
Upper Inkunzi	5,1
Upper Buffalo (Ingogo)	2,8

However, the results obtained in September 1954 at the sampling points given below, indicated pollution of the Tugela River from mine effluent, viz. –

	Sulphate Index
National Park	0,0
Bergville	0,0
Colenso	0,0
Nkosini	11,5
Tugela Ferry	17,5
Mgobevu	22,5
Below Mgobevu	25,1
Middle Drift	23,1

The Inkunzi and Wasbank Rivers, tributaries of the Sundays River, were found to be highly polluted giving respectively SI 60 and 96,3 and notably the Ebusi, a tributary of the Wasbank, gave a SI of 99,1.

The Department of Water Affairs, in recent years, has devoted significant efforts towards improving conditions in this part of the world.

Kemp considers that pollution from coal mines will not be significant if the Sulphate Index is less than 10.

Role of Micro-organisms in Creating Acid Mine Drainage

The organism *Thiobacillus ferrooxidans* was first isolated by Colmer and Hinkle in 1947.

In coal mining, air and water gain access to the reduced sulphide minerals e.g. pyrite and marcasite which are oxidized to produce sulphuric acid. As the drainage from a mine is diluted either below in the mine or on the surface the pH value rises and "yellow boy" results. This has been referred to in the section on Gold Mining (*vide ante*).

Atkins and Pooley[29] have investigated *"The Effects of Bio-Mechanisms on Acid Mine Drainage in Coal Mining"*.

They have compared the oxidation of pyrite of different size fractions under sterile conditions with similar fractions in the presence of bacteria, viz. –

Per Cent Pyrite Oxidized

Size Fraction	Bacterial Oxidation of Pyrite%	Sterile Control Pyrite Oxidized %
– 53 micron (– 300 mesh)	93,5	25,6
– 1 mm crushed	69	17,6
– 1 mm sieved	85,5	20,7

The above results were obtained with a sample of Amman Rider coal containing 5,6 per cent pyrite. The initial pH value was 2,0, temperature 35°C and pulp density 10 per cent (w/v).

The authors also report on leaching experiments with a variety of substrates which were leached with *T. ferrooxidans* in a five-litre capacity, air-stirred, pachuca to produce cultures for experimental study. The substrates used were Tharsis pyrite, 856 chalcopyrite/pyrite, Tynach sphalerite, ferrous sulphate.

The results obtained indicate that in the case of pyrite the bacterial cells preferentially (to the extent of 87 per cent) associate with the leach residue (solids) rather than with the supernatant solution. However, they state that a limited number of bacterial cells are "free" and able to move around and contaminate mine drainage.

The authors were also able to show that pyrite samples from different geological origins can be leached to completion in the presence of bacteria provided the pH value was maintained within the pH range 2,0 to 1,0. This result, they state, demonstrates that previous speculation on the formation of a protective reaction layer on the surface of the sulphide particles which accounted for their incomplete oxidation, (or the toxicity of metal in solution) is invalid in the case of pyrite.

Control and Treatment of Acid Mine Drainage

Although the use of coal as a fuel was known in Roman Britain, the real inception of its use dates from the thirteenth century. A general predjudice was in evidence against coal as a fuel and coal mining only came about due to the inadequacy of the woods of England to meet the demands made upon them during the sixteenth and seventeenth centuries.[30(a)] These demands on the available timber supplies included household building, domestic fires/hearths, an expanding mercantile marine, industries such as iron, glass, etc.

In fact, the development of coal mining accorded with industrial development.

Mine drainage: A great handicap to the development of the coal mining industry in the seventeenth century was the cost involved in meeting the gravest

handicap of the industry – the drainage of the mines.[30(b)]

A seventeenth century writer[30(c)] (1667) referred to . . . "many brave collieries being worth little or nothing, either by reason there is no shell-stone for a roof to support the ground, or by reason of the great quantities of water which are usually in the caverns of the earth, which are very chargeable in the draining of them, so that many men by such undertakings are often undone"; and while there existed collieries which "do produce in many places great profit to the undertakers" one and all were "subject to the casualties of water and of fire".

It was only when the steam engine came into being through the efforts of inventors such as Thomas Savery (1698) and Thomas Newcomen (1710) that this problem was overcome. In 1711 Newcomen's engine was used for pumping water from mines. Later (1763 to 1781) James Watt improved on the steam engine.

Prior to the advent of the steam engine many collieries in the North of England used chain pumps operated by horse-wheels, tread-wheels or water-wheels.

Today, due to the availability of electric power underground in mines, pumping is no longer a problem but pollution of the water environment arising from the constituents in such mine drainage pumped to the surface is now a recognized problem.

Lovell[31] and Glover[32] have respectively given a review of coal mine drainage and control strategies in the United States and in the United Kingdom.

Identification of the Problem: The impact of coal mining activities on the water environment has to be considered in the light of both operating and abandoned coal mines. In fact, it has been found that prevention or, for that matter, adequate amelioration of the escape of acid mine drainage and the pollution arising from defunct underground coal mines has presented a difficult and challenging problem which, as yet, has not been satisfactorily solved.

In considering acid mine drainage from both active and abandoned mines it is also necessary to deal with the seepage and runoff from the refuse dumps created by such mines in the course of operation – together with any other polluted runoff on the surface.

Open-cast or strip mining which has recently come into being in the Transvaal, affords a means of overcoming, to a considerable extent, the problem of acid mine drainage gaining access to the water environment.

However, underground bord-and-pillar mines, in particular, present problems both during their active lifetime and, worse still, after closure of such mines.

Open-cast or Strip Coal Mining: Until fairly recently coal in South Africa has been extracted by underground mining – large-scale strip mining of coal is a relatively new venture.

The Chamber of Mines of South Africa has issued a *"Handbook of Guidelines for the Rehabilitation of Land Disturbed by Surface Coal Mining in South Africa".*[33]

These guidelines point out that, "Surface mining necessitates alienation and radical disturbance of land".

Further, it is stated that "if proper land rehabilitation follows in the wake of mining, then the alienation of land need be no more than temporary (unlike most other kinds of alienation), reduction in the utility of land need be no more than slight and environmental effects imperceptible. Mining and agriculture are not necessarily mutually exclusive except over a relatively short period of time".

The aim is that the land be restored to a form and productivity consistent with the *status quo* before mining occurred.

Promulgated Acts, Regulations and Notices which have a bearing on surface mining include the following:

- *Mines and Works Act* (Act 27 of 1956). Regulation 537 of 21 March 1980: Amendment of Regulations, Mines and Works Act, 1956.
- *Water Act* (Act 54 of 1956)* Regulation R553 of 5 April 1962.† Regional Standards for Industrial Effluents: Amendment to R553 Regulation 1567 of 1 August 1980. Regulation 3208 of 29 August, 1969: Regional Standards for Industrial Effluents – Methods of Testing. Regulation 287 of 20 February, 1976: Regulations made in terms of sections 26(c) and 26(d) of the Water Act (Act 54 of 1956). Regulation 1029 of 18 June, 1976: Notice in terms of Regulation 19.1 of the Regulations promulgated under Government Notice R287 of 20 February 1976.
- *Atmospheric Pollution Prevention Act* (Act 45 of 1965).
- *Environmental Planning Act* (Act 88 of 1967).
- *Soil Conservation Act* (Act 76 of 1969).
- *Subdivision of Agricultural Land Act* (Act 70 of 1970).
- *Mineral Laws Supplementary Act* (Act 10 of 1975).
- *Physical Planning and Utilization of Resources Amendment Act* (Act 73 of 1975)
- Government Notice R537 of 21 March 1980.

There is no reason why this type of mining should not be satisfactory from a pollution control point of view provided rehabilitation is followed in conformity with the Chamber of Mines Guidelines[33] in which case the water environment is not disturbed and the ecological status of the mined-out area is systematically restored to its former pristine condition.

*Also Water Amendment Act (No. 96 of 1984).
†Superseded by R991 of 18 May 1984.

Active Underground Coal Mines: Strip mining methods can only be applied to coal deposits near the surface. However, for deeper deposits underground (bord-and-pillar and longwall) mining methods are used.

It is these underground coal mining activities which are a threat to the water environment.

It has been indicated earlier in this section that pyrite and other reduced sulphur minerals are present in coal and when moisture and oxygen are present acid mine drainage results.

In an operating mine, movements and dislocations of the coal body arise due to mining activities and this increases the advent of water and air to the sulphur-containing minerals and so exacerbates the problem of acid mine drainage.

This being so, it would seem that every effort should be made to reduce the time of contact of water and air with the ore body and a pragmatic solution of this would be to ensure that water "made" by the mine is pumped, without delay, to the surface to combine with the surface runoff and seepage from waste dumps, etc. The acid mine drainage pumped to the surface can then be treated by the HDS Process with subsequent desalination, if possible, of the HDS effluent where this is necessary. Alternatively, the HDS effluent may be used for certain forms of irrigation where this process is feasible. However, a great deal of investigational work needs to be done in this direction and the desalination of such effluent is still a matter to be resolved economically.

It is well to remember that acid mine water treated by the HDS Process contains calcium and sulphate in undesirable concentrations as well as high total dissolved solids which limits its use as a water resource.

Defunct Underground Coal Mines: The abatement of water pollution from defunct or abandoned underground mines is an on-going process. The Department of Water Affairs has devoted much energy to ameliorating conditions resulting from the escape of acid mine drainage from adits in defunct coal mines in the Witbank area. The technique used is basically one of isolation and evaporation in a dam with controlled discharge to the nearby river. Eventually this water enters the Loskop Dam, thereby increasing the dissolved solids content and sulphate content of this water impoundment.

It is very difficult to seal off a mine to prevent the escape of acid mine drainage and this has been found to be the case in Natal as well as the Transvaal. Theoretically a number of options have been canvassed such as cementing of all likely flow and likely seepage outlets, mine flooding, hydrological isolation of certain areas within the mine, monitoring areas to isolate those of high pyrite content, placing limestone in bulk within the mine before closure, etc. But, in the long-term, effluent exudes from the mine's precincts to the surface water environment. The abandoned mine workings contain unextracted coal: this coal serves as a perennial source for the creation of acid mine drainage since water enters the old workings and air (oxygen) is present, in solution, in this water and, in any case, *Thiobacilli* organisms are also present.

The total extraction of coal before closure of a mine would, of course, be a solution but how this can be achieved it is not easy to foresee.

The nub of the problem, therefore, would seem to be the evolvement of a low-cost desalination process or alternatively the metastasis of HDS Process effluent to render it suitable for irrigation purposes.

Isolating the effluent in evaporation ponds does not really solve the problem in a country like South Africa which is not well endowed with water. Such a procedure merely stores inorganic salt pollution which may be washed away during cloudbursts or floods or just heavy rains. At best, it is a temporary protection of the water environment and this applies also to toe-dams and other evaporation impoundments in the gold mining industry.

Fluoride-containing Mineral Deposits

Handling of Residues and Effluent from Mining and Processing

Mineral Deposits

The two fluorine-containing types of mineral deposits of concern from a water pollution control point of view are fluorspar (also referred to as fluorite and fluor) which is calcium fluoride (CaF_2) and apatite from the Phalaborwa complex.

Fluorspar: Fluorspar occurs as cubic crystals in a large variety of colours from red through to purple on the colour scale. The crystals have a vitreous lustre and fluoresce. The mineral is somewhat brittle with a hardness of 4 on the Moh's scale and a specific gravity of 3 to 3,5.

Fluorspar crystals are not normally contaminated with included impurities but have to be selectively recovered from associated gangue minerals by flotation or gravity concentration methods.

The main uses of fluorspar include the following:

(1) As a flux in the production of steel. "Metallurgical Grade" fluorspar is used for this purpose.
(2) For the production of hydrofluoric acid. "Acid Grade" fluorspar is used for this purpose.
(3) As a flux and opacifier in glassmaking and in enamels for coating metalware.
(4) For the production of fluorine and fluorides.

Fluorspar Deposits in the Republic: Fluorspar is mined mainly in the Transvaal. The longest operating mine is the "Buffalo Fluorspar Mine" situated a short distance North-West of Naboomspruit.

Another (second largest mine), the "Vergenoeg Fluorspar Mine", is situated on the farm Kromdraai and lies some 110 kilometres North-East of Pretoria.

Other mines and deposits include the following: "Zwartkloof Fluorspar Mine", west of Warmbaths; "Rheno Fluorspar Mine" on the Southern Slopes of the Hoekberg. This mine was originally opened up in search of tin. Deposits also occur at Vischgat, South of Naboomspruit and a number in the Rooiberg, Pilanesberg and Marico districts. In Zululand, Natal, fluorspar occurs at Hlabisa. In the North-Western Cape fluorspar occurs in the Gordonia district. Details of fluorspar mineral deposits can be had by reference to the publication of the Geological Survey and the Department of Mines,[34] *"The Mineral Resources of the Republic of South Africa"*.

Fluorine-containing Effluents: As far as fluorine-containing effluent is concerned attention requires to be given to the Rooiberg Minerals Development Company, Limited, which is a large tin producer. McDermott and Oxley-Oxland[35] have stated in regard to the Rooiberg Tin Mines (A, B and C mines), –

"Water is obtained from dams, boreholes and underground workings and, as the supplies are barely adequate during the dry season, maximum possible use is made of re-circulated water . . .".

Kempe,[36] in dealing with fluorspar and tin mines, has recorded that the groundwaters in the Marico district of the Western Transvaal frequently have a fluoride content of up to 4 milligrams F per litre whilst the concentration of recirculated mine process water reaches 100 milligrams F per litre or more. As regards tin mines in the Waterberg area he records that some streams have fluoride levels of between 2 and 3 milligrams per litre F while underground water varies between 4 and 10 milligrams F per litre.

It should be noted that for drinking purposes the F content of drinking water should not exceed 1,0 milligrams F per litre. At this concentration benefit to dental health results in a lower incidence of caries. If the concentration of fluoride in drinking water is less than 0,5 milligrams F per litre the incidence of caries is likely to be high.

Water with values in excess of 2 milligrams F per litre, if imbibed regularly, over a long period of time can lead to dental fluorosis and skeletal impairment.

Apatite: Fluorapatite from Phalaborwa is given the empirical formula $Ca_5(PO_4)_3F$ (ref. 37(a)) though $Ca_{10}X_2(PO_4)_6$ is the general type formula reported, where X is fluorine (F), chlorine (Cl) or hydroxyl (OH). Strontium and manganese may substitute for calcium.

The Phalaborwa deposit is noted for the recovery of copper by the Palabora Mining Company, Limited; and for phosphate (apatite) and magnetite (Fe_3O_4) recovery by the Phosphate Development Corporation, (FOSKOR).

Until the start of operations at Phalaborwa the production of phosphate in South Africa was restricted to sediments and organic deposits in the Western Cape. This material at Saldanha Bay and Langebaan originated from guano, the excrement of birds and bats,[38] which dissolves in water and replaces rock formations – mostly sands to form phosphorite (lime phosphate). Unlike the igneous carbonatite of Phalaborwa these Cape deposits do not contain fluorine and processing thereof is not a fluorine threat to the water environment.

Phalaborwa Igneous Complex: The Phalaborwa Igneous Complex is centred on Loole Kop near the Kruger National Park in the North-Eastern Transvaal.

Loole Kop had been the centre of interest for investigators of various disciplines, not the least, geologists and archaeologists particularly as old workings for copper and possibly for iron ore were in evidence and the remains of primitive smelting furnaces had been found.

Phosphate Concentrates: The most important phosphate-containing ores at Phalaborwa are phoscorite, pyroxenite and carbonatite (apart from magnetite (Fe_3O_4) and copper minerals; vermiculite is recovered from this interesting deposit).

The apatite content and other constituents of the three phosphate-containing minerals are as follows,[37(b)]

Phoscorite* . . . c. 25 per cent apatite (i.e. c. 10 per cent P_2O_5);
c. 35 per cent magnetite;
c. 30 per cent calcium and magnesium carbonate.

Pyroxenite . . . . c. 15 per cent apatite (i.e. c. 6 per cent P_2O_5);
Magnetite is absent;
Most of the pyroxenite (c. 80 per cent) consists of calcium and magnesium silicate as pyroxene with about 2 per cent CO_2.

Carbonatite . . . This is essentially a magnesium-calcium carbonate and magnetic rock together with apatite having 2 to 4 per cent P_2O_5 content.

The processing of the phosphate-containing ore involves crushing, rod-milling and magnetic separation of the magnetite using rotary magnetic separators. The magnetite-free residue is then milled in ball mills and subjected to froth flotation using a fatty acid (e.g. oleic acid) as a collector.

It will be appreciated that with the processing that

*Truswell[39] describes this as an unusual magnetite-olivine-apatite rock known locally as "phoscorite" or "foskorite" which, in turn, he states, encloses a carbonatite core.

takes place fluoride must be present in the process water, in which case care must be exercised in the construction and operation of tailings dams.

Unfortunately, in the Phalaborwa area further processing of the apatite takes place by an industrial chemical company and escape of slimes and seepage from tailings dams has occurred and this has resulted in fish kills and other offending consequences in the Selati and Olifants Rivers.

Apatite from Phalaborwa is used by fertilizer companies at Phalaborwa, Sasolburg, Potchefstroom, Richards Bay, the Western Transvaal, Western Cape and Cape Peninsula.

Fluoride and the Water Environment

Fluorides are absorbed by the animal body but are slowly excreted and can give rise to cumulative poisoning.

Acute poisoning causes vomiting, diarrhoea, convulsions, and a fall of blood pressure. The respiration is first stimulated and then fatally depressed. Calcium salts may be used as antidotes.[40]

Acute poisoning is only likely to occur accidentally as, for instance, the case quoted by Sydney Smith and Fiddes[41] where a worker in a mineral water factory drank etching liquid. He died within an hour. It was found that the mucuous membrane of his pharynx, oesophagus, stomach, duodenum and jejunum was of a grey colour and swollen.

Acute poisonings by silico-fluoride sold as insect powder have occurred.

However, most of the cases of acute poisoning have been by inadvertence. What we are basically concerned with is chronic poisoning caused by a build-up or accumulation of fluorine in the body flesh or skeleton. In this connexion, for fish living in a water (e.g. the sea) with a fluoride content exceeding 6 milligrams F per litre, a build-up of F in the body flesh of such fish can result in the same way as methyl mercury accumulates. Persons then eating the fish regularly will be affected apart from the fact that high concentrations of fluoride can result in death of the fish.

Removal of Fluoride: Bone and other forms of carbonate apatite have been used for removing fluoride from drinking water. This is not surprising when it is realized that the structure of this mineral-type material, resembling as it does, that of apatite will show a tendency for fluorine to settle in the bone structure as happens with certain metal ions.

The above being so, synthetic hydroxy apatites have been prepared for the removal of fluorine from drinking water.

Adler, Klein and Lindsay[42] have prepared synthetic hydroxy apatite $3Ca_3(PO_4)_2.Ca(OH)_2$ in which removal of fluoride is accomplished by anion exchange. The apatite is regenerated with sodium hydroxide and rinsed with an acid to neutralize the excess hydroxide.

The reaction is represented as follows:

$$3Ca_3(PO_4)_2.Ca(OH)_2 + 2F^- \rightleftharpoons 3Ca_3(PO_4)_2.CaF_2 + 2OH^-$$

The authors state that, for regeneration 1 kilogram of exchanger, 3,3 litres of a 1 per cent solution of sodium hydroxide and 1,1 litres of a 0,07 per cent HCl (by weight) solution are required. Fluoride removal is given as 1,8 gram F per kilogram of exchanger. However, losses of exchanger occur due to the use of hydrochloric acid final rinse solution to remove excess sodium hydroxide. Goodwin and Litton[43] later substantially overcame this drawback by using carbon dioxide in place of hydrochloric acid.

With a flowrate of 6,8 litres per minute of water containing 5,2 milligram F per litre the final treated effluent contained an average fluoride concentration of 0,42 milligram F per litre.

In South Africa experiments (results unpublished) have shown that it is possible to reduce the F content of water from 15 milligrams F per litre to only 5 milligrams F per litre by percolating the water through a column of dolomite. This being so, the effluent from this could, it would seem, be further treated using synthetic hydroxy apatite to yield a product containing some 0,42 milligram F per litre.

From experimental studies Elvore[44] concluded that three substances were suitable for removing excess fluoride in drinking water, viz. – tricalcium phosphate, magnesium oxide and magnesium hydroxide.

Recovery of Fluoride in the Phosphate Industry

Fluorine compounds liberated during acidulation of phosphate rock in the manufacture of phosphoric acid and fertilizers are a source of atmospheric pollution and, in turn, of the water environment and every effort must be made by industrialists in the fertilizer industry to suppress fluorine-containing vapours to within very low limits.

During the production of phosphoric acid from fluorapatite ($3Ca_3(PO_4)_2.CaF_2$ also written elsewhere in this text as $Ca_{10}F_2(PO_4)_6$ or $Ca_5(PO_4)_3$ F) using a strong acid the calcium fluoride present in the rock is converted, by reaction with the silica present, into fluosilicic acid according to the following expressions:

$$CaF_2 + 2H \text{ (i.e. } H_2SO_4, HNO_3, H_3PO_4, HCl) \longrightarrow 2HF + Ca \quad (1)$$

$$2HF + SiO_2 \longrightarrow SiF_4 + H_2O \quad (2)$$

$$3SiF_4 + H_2O \longrightarrow 2H_2SiF_4 + SiO_2 \quad (3)$$

The hydrogen fluoride (HF) and silicon tetrafluoride (SiF_4) are evolved partly as vapours and partly form fluosilicic acid (H_2SiF_4) which under heat decomposes again into volatile SiF_4 and HF, leaving the reaction vessel together with the water vapour, viz. –

$$H_2SiF_4 \xrightarrow{Heat} SiF_4 + 2HF$$

In the production of single and triple superphosphate or weak phosphoric acid, SiF_4 is preferentially volatilized and as phosphoric acid is concentrated up to 54 per cent P_2O_5, increasing quantities of HF escape.

A method of recovery of fluoride[45] consists in passing the gases through a series of water sprays located in three separate spray chambers. In the first chamber which is primarily a cooling chamber for the hot exit gases of the furnace the acid water is recycled through the sprays. The second chamber is used to bring the acidic water to a concentration of approximately 5 per cent HF. Acid is withdrawn and fresh water added to the system to maintain the effluent acid at the desired concentration. Scrubbing in the third chamber is supplemented by the addition of finely ground limestone which is blown into the chamber with the entering gases from the exit of the second chamber.

Acid from the spray chambers is collected and processed to produce alkaline fluorides.

Other methods of recovery of fluorides include, –

(1) Absorption in a tower of lump limestone at temperatures above the dewpoint of the stack gas. The reaction product separates from the limestone lumps in the form of fines. Portions of the bed are withdrawn from the tower at intervals, screened to remove the fines and the oversize is replaced in the tower together with fresh limestone as make-up.
(2) Phosphate rock can be defluorinated by heating the feedstock in an atmosphere of steam in a rotary calciner at temperatures of 1 320°C to 1 538°C or by fusion in a vertical furnace. In the absence of silica, hydrofluoric acid is evolved which has to be contained and not allowed to gain access to the air or water environment.

Cryolite

Cryolite, $3NaF.AlF_3$, is used as a flux in the reduction of alumina (Al_2O_3) to the metallic state. Artificial cryolite is made, – (1) by causing aluminium fluoride to react with hydrofluoric acid and a sodium salt; (2) by digesting sodium fluoride and aluminium hydroxide together at c. 175°C; or (3) by reacting ammonium fluoride with alumina in the presence of an aqueous solution of sodium hydroxide or a sodium aluminate solution. Siliceous fluorspar may be used for the preparation of ammonium fluoride.

Production of Aluminium Metal

Apart from the use of natural cryolite or artificial cryolite in the manufacture of aluminium metal, bauxite, which is a mixture of hydrous aluminium oxides, is also used. Bauxite contains 46 to 70 per cent Al_2O_3 depending on its country of origin. The "Standard Requirement" in the United States is 55 to 62 per cent Al_2O_3 with provision for limits on impurities.

The metal is produced by the electrolysis of a molten mixture containing anhydrous alumina dissolved in cryolite to which small amounts of fluorspar and aluminium fluoride have been added.

It will be realized, therefore, that apart from the fertilizer industries using fluorapatite as a feedstock, aluminium metal manufacture as carried out by a large industrial firm at Richards Bay, can give rise to fluoride pollution of the water environment: in this case the sea.

Disposal of Tailings and Effluent

In the hydrometallurgical processing of fluorspar in the Western Transvaal fluorspar mines – working in closed circuit, to prevent the escape of fluoride to the water environment, the concentration of F in processing circuits can exceed 100 milligrams F per litre. Consequently storage or evaporation dams must be well lined and well situated to prevent seepage and overflow.

Slimes dams require to be placed on impervious material which can include fines from the plant (free of fluorite). Such slimes dams must be placed on impervious prepared bottoms (e.g. plastic sheets) away from dolomite and other pervious areas.

In such cases provision requires to be made to collect any seepage by a series of underdrains and cut-off trenches (surrounding dams) connected to evaporation dams.

The same applies to the fertilizer industries using fluorapatite as feedstock. At Richards Bay effluent can, of course, be discharged into the sea via the marine pipeline system of the Mhlatuzi Water Board and subject to certain permit conditions.

At Richards Bay one company uses fluorapatite as feedstock for fertilizer manufacture and another manufactures aluminium metal from imported feedstock. Both discharge effluent into the sea containing fluoride.

Marine Discharge of Fluoride-containing Effluent

Dealing with the biochemistry of the oceans and zoological species in the sea, Armstrong and Miall[46] state, –

"It is recognized that this population is subject to regular cyclic changes. Certain forms appear, reach a maximum of abundance and then decline. These changes have been demonstrated to be accompanied by changes in chemical composition with decrease or increase in the amount of nitrates, phosphates and silicates".

. . . "Diatoms may grow very rapidly, withdraw salts until they are exhausted, accumulate these in their bodies and deposit them in a thick layer on the

bottom. One third of the diatoms are said to die every 24 hours".

These authors go on to state, "Most elements are concentrated more in living matter than they are in the sea" and quote Vernadsky[47] as indicating that "potassium, boron and fluorine are concentrated 10 times . . .".

The concentration of fluorine F in seawater has been given as follows:

(1) Goldschmidt (1933)[48]	1,0 milligram F per litre
(2) Thompson and Taylor (1933)[49]	
	1,4 milligram F per litre
(Average)	1,2 milligram F per litre
(3) Miyake (1939)[49]	1,3 milligram F per litre

If we take the average value of 1,2 milligrams F per litre it would seem possible for fluorine to accumulate in biological life in the sea to a value of 12 milligrams F per litre and, possibly more.

At the outlets of marine discharge pipelines the concentration of F may be considerably greater than 12 milligrams F per litre when reliance is placed on a dilution factor. Fish in an area of high fluoride concentration prior to adequate mixing and dispersion of the effluent (high in F content) with the seawater would suffer acute poisoning. Other biological species would also suffer mortality.

Other Mining Activities

The mining and processing of other minerals mentioned at the commencement of this section on "Mining" do not, at this stage, call for special attention (i.e. other than gold, coal and fluorspar).

It has been mentioned that manganese in solution should not be allowed to reach domestic water supplies (cf.).

On the other hand, sometimes difficulties can occur with tailings dams where settling of particles and the thixotropic nature of the slimes make it impossible to build dam walls of substantial heights. In such cases recourse has had to be had to the construction of a number of smaller dams with low walls to provide for extra settling time and consolidation of the material in each individual slimes dam. This has occurred at a diamond mine at Henneman in the Orange Free State.

In all cases good housekeeping, correct construction and operation of waste dumps, tailings dams and storage or evaporation dams are a *sine qua non* for preventing pollution of the environment.

REFERENCES

1. Kurian, G.T. "The Book of Rankings", Macmillan Reference Books, The Macmillan Press Ltd., 1979.
2. Chamber of Mines of South Africa, 92nd Annual Report, 1981.
3. Van Biljon, W.J. "Our Future in Science and Technology", Presidential Address to the Associated Scientific and Technical Societies of South Africa, Annual Proceedings 1981/82 pp. 17-22.
4. "South African Statistics, 1982", Central Statistical Services, Republic of South Africa, Government Printer, Pretoria.
5. "Mineral Resources of the Republic of South Africa", Geological Survey/Department of Mines, 5th Edition, 1976, p. 1.
6. (a) Letcher, O. "The Gold Mining of Southern Africa", The History, Technology and Statistics of the Gold Industry, published by the author, Johannesburg and Waterlow and Sons, London, 1936 – to commemorate the fiftieth Anniversary of the Proclamation of the Witwatersrand and the Jubilee of Johannesburg.
6. (b) Gray, J. and Gray, E.L. "Payable Gold", An intimate Record of the History of the Discovery of the payable Witwatersrand Goldfield and of Johannesburg in 1886 and 1887, C.N.A. Ltd., 1936.
7. Chilvers, H.A. "Out of the Crucible", Cassell and Company, Ltd., London, Toronto, Melbourne, Sydney, 1929.
8. Struben, C. "Vein of Gold", A A Balkema, Cape Town, 1957 pp. 20-29.
9. Cartwright, A.P. "The Gold Miners", Purnell, Cape Town, 1936.
10. Rosenthal, E. "Gold! Gold! Gold!" The Johannesburg Gold Rush, A.D. Donker (Pty.) Ltd., Hyde Park, Johannesburg 2196, 1 Prince of Wales Passage, 117 Hampstead Road, London N.W.1 3EE 1979, pp. 126-133.
11. (a) King, A. "Gold Metallurgy on the Witwatersrand", Johannesburg, Transvaal Chamber of Mines, 1949.
11. (b) Adamson, R.J. "Gold Metallurgy in South Africa", Johannesburg, Chamber of Mines of South Africa, 1972.
12. Douglas, J.K.E. and Moir, A.T. "A Review of South African Gold Recovery Practice", Trans. Seventh Commonwealth Min. Met. Congress, Johannesburg, 1961, p. 989.
13. (a) Chamber of Mines of South Africa, "Handbook of Guidelines for Environmental Protection" Vol. I, 1979. "The Design, Operation and Closure of Residue Deposits".
13. (b) Blight, C.E. and Cladwell, J.A. "The Abatement of Pollution from Abandoned Gold-residue Dams, *J.S. Afr. Inst. Min. Metall.* 1984, 84(1), pp. 1-9.
13. (c) Cartwright, F.D. "Some Seventy Years in the Shrouding of Mining Residue Deposits for Environmental Protection", I.A.W.P.R. Conf., *Water Science and Technology*, Vol. 15(2), 1983, "Mine Water Pollution", Editor P.E. Odendaal, pp. 85-102.
14. (a) Tyser, J.A. Colloquium on "Pumping, Settling, Treatment and Clarification of Underground Water", The South African Institute of Mining and Metallurgy, Kelvin House, Johannesburg 17 November, 1976.
14. (b) Van Staden, C.M. and Harvey, D. Private Communication entitled "Underground Water Pumped and Treated According to the High Density Sludge (HDS) Process at the South West Vertical Shaft (S.W.V.), East Rand Proprietary Mines, Limited, 11 June 1979.
14. (c) Bosman, D.J. (i) Private Communication entitled "Control of Acid Mine Drainage", Anglo American Research Laboratories, Crown Mines, Johannesburg. (ii) "Lime Treatment of Acid Mine Water and Associated Solids/Liquid Separation", I.A.W.P.R. Conf., *Water Science and Technology*, Vol. 15(2), 1983, "Mine Water Pollution", Editor P.E. Odendaal, pp. 71-84.
15. Reinheimer, G. "Aquatic Microbiology", John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Second Edition, 1980, p. 163.
16. Ellis, D. "Iron Bacteria", Methuen and Co. Ltd., Essex Street, London, W.C., 1919.
17. Brierley, C.L. "Leaching: Use of a High-Temperature Microbe", New Mexico Institute of Mining and Technology, Solution Mining Symposium, 1974, pp. 461-469.
18. Rudd, R.T. "The Impact of Slimes-dam Formation on Water Quality and Pollution", *J.S. Afr. Inst. Min. Metall.* 1973, 74 (5), 184-192.
19. Tyser, J.A. Loc. cit. p. 2.
20. Bosman, D.J. Loc cit. (ii) p. 77.
21. Bosman, D.J. Loc cit. (ii).
22. "Mine and Mill Wastewater Treatment", Economic and Technical Review Report EPS 3-WP-75-5, Water Pollution Control Directorate, Environmental Pollution Service, Canada, December 1975, p. 76.

23. Bird, J. "Annals of Natal, C Struick, Cape Town, 1965. Vol. II, 1495 – 1845", p. 79.
24. "The Northern Natal Coalfield", Memoir 1. The Vryheid – Paulpietersburg Area; Memoir 2. The Utrecht – Newcastle Area; Department of Mines, obtainable from the Government Printer, Pretoria.
25. De Jager, F.S.J. "Mineral Resources of the Republic of South Africa", Geological Survey/Department of Mines, 5th Edition, 1976, p. 289.
26. Hamilton, G.N.G. *S. Afr. J. Sci.*, 1948, 44, 31-43.
27. Kemp, P.H. CSIR Special Report W12, "Acidic Drainage from Coal Mines with Special Reference to the Natal Coal Fields", January 1962, pp. 1-24.
28. Kempe, J.O. "Review of Water Pollution Problems and Control Strategies in the South African Mining Industry", I.A.W.P.R. Conf., *Water Science and Technology*, Vol. 15(2), 1983, "Mine Water Pollution", Editor P E Odendaal, p. 51.
29. Atkins, A.S. and Pooley, F.D. *Internat. J. Mine Water*, 1982, 1, 31-44.
30. Lipson, E. "The Economic History of England", Vol. II, The Age of Mercantilism, Sixth Edition, London, Adam and Charles Black, 1964. (a) p. 112; (b) p. 121; (c) p. 121.
31. Lovell, H.L. "Coal Mine Drainage in the United States – an Overview", I.A.W.P.R. Conf., *Water Science and Technology*, Vol. 15(2), 1983, "Mine Water Pollution", Editor, P E Odendaal pp. 1-25.
32. Glover, H.G. "Mine Water Pollution: An Overview of Problems and Control Strategies in the United Kingdom", I.A.W.P.R. Conf., *Water Science and Technology*, Vol. 15(2), 1983, "Mine Water Pollution", Editor, P.E. Odendaal, pp. 59-70.
33. Chamber of Mines of South Africa, "Handbook of Guidelines for Environmental Pollution", Vol. 3, 1981, "The Rehabilitation of Land Disturbed by Surface Coal Mining in South Africa".
34. Crocker, I.T. and Martini, J.E.J. "Mineral Resources of the Republic of South Africa", Geological Survey/Department of Mines, 5th Edition, 1976, pp. 357-363.
35. McDermott E.K. and Oxley-Oxland, Trans 7th Min. and Metall. Congr. 146, Vol. I, p. 157.
36. Kempe, J.O. Loc. cit., p. 54.
37. Hanekom, H.J., Van H Staden, C.M., Smit, P.J. and Pike, D.R. "The Geology of the Palabora Igneous Complex", Memoir 54, Department of Mines/Geological Survey, 1965 (a) p. 110; (b) p. 105.
38. Mountain, E.D. "Geology of Southern Africa", Books of Africa (Pty) Limited, Cape Town, 1968, p. 215.
39. Truswell, J.F. "An introduction to the Historical Geology of South Africa", Purnell, Cape Town, Johannesburg and London, 1970, p. 68.
40. Gaddum, J.H. "Pharmacology", Oxford University Press, London, New York, Toronto, 3rd Edition, 1958, p. 351.
41. Smith, Sir Sydney and Fiddes, F.S. "Forensic Medicine", London, 9th Ed., J and A Churchill Limited, 1949, p. 440.
42. Adler, H., Klein, G. and Lindsay, F.K. "Removal of Fluorides from Potable Water by Tricalcium Phosphate", Ind. Eng. Chem. 1938, 30, 163.
43. Goodwin, R.C. and Litton, J.B. Ind. Eng. Chem., 1941, 33, 1046.
44. Elvore, E. "Removal of Fluorides from Water", U.S. Pub. Health Rpts., 1937, 52, 1308.
45. Specht, R.C. *J. Water Poll. Control Fed.*, 1960, 32, 1964 – 1974.
46. Armstrong, E.F. and Miall, L.M. "Raw Materials from the Sea", Constructive Publications Limited, Leicester, England, 1946, p. 51.
47. Vernadsky, Rev. Gen. d. Sc., Paris 1924, 35, 5-13.
48. Armstrong, E.F. and Miall, L.M. Ibid p. 19.
49. Harney, H.W. "Recent Advances in the Chemistry and Biology of Sea Water", Cambridge University Press, Cambridge, 1945, p. 31.

15(2) THE CELLULOSE FIBRE INDUSTRY: PROBLEMS AND ACHIEVEMENTS IN THE CONTROL OF POLLUTION FROM WASTEWATERS

This industry may be classified under two main activities, viz. –

I. Pulp and paper manufacture;
II. Fibre-board (or building board) manufacture.

PART I: THE PULP AND PAPER INDUSTRY

Before proceeding with this commentary it is necessary to approach the subject from more fundamental concepts and lead on to present-day technology thereafter.

Cellulose:[1,2,3,4,5] Cellulose may be represented by the empirical formula $(C_6H_{10}O_5)n$. It constitutes the basic substance of the cell walls of plants and forms the framework, or skeleton, of vegetable tissues. It is probably produced from simpler carbohydrates secreted by the protoplasm of the cell. Cellulose in the pure state is best known in the form of cotton wool, linen and pure white (bleached) paper. The differences between cotton, linen and paper are due more to the structure of the fibres than to their chemical composition.

The simple formula above merely suggests a polymeric substance composed of a number (n) of molecules joined together but does not give a picture of the spatial arrangement of these smaller molecules in the overall structure of the large polymeric molecule. The individual smaller molecules of which the larger cellulose molecule is built up are glucose. Glucose is a simple sugar. Cellulose is thus a carbohydrate.

Cellulose comprises at least one-third of all vegetable matter and is the most abundant of naturally occurring organic compounds in the world. The amount of carbon dioxide (CO_2) which is "fixed" in the cellulose of plants is estimated to be about half the weight of carbon dioxide in the atmosphere.

Properties of Cellulose: Cellulose is a white substance, insoluble in most liquids, the best solvent being cuprammonium hydroxide.* Use of this

*Clegg, Tanghe and Brewer[6] state that cellulose is soluble in only a few solvents such as, cuam (cuprammonium hydroxide), cuen (cupriethylenediamine hydroxide, FeTNa (Iron-sodium tartrate; EWNN in German literature) and cadoxen [tris (ethylenediamine) cadmium hydroxide]: Cellulose undergoes slow degradation in these solvents.

solubility property finds application in the artificial silk ("rayon") industry.

When cellulose is boiled in mineral acids it is converted almost entirely to d-glucose.

Analysis of the purest form of cellulose obtained by purification of cotton shows the per cent composition to be,

Carbon	44
Hydrogen	6,2
Oxygen	49,4

These figures correspond to the empirical formula $C_6H_{10}O_5$ i.e. that of a hexose aldehyde identified as anhydroglucose.

Cellulose consists of a long chain of glucose units linked in a single configuration. In natural fibres these long slim molecules are arranged parallel to one another.

Points of Note: An important point concerning cellulose is the fact that it is replenishable and is, generally, easily harvested and transported. Due to its fibrous form it exhibits a high tensile strength. Cellulose has a great affinity for water which is important in paper making. It is resistant to attack by many chemicals.

Cellulose is a fairly inert substance. It is scarcely affected by chlorine or by dilute acids or dilute alkalis. These reagents in solution – the former in the cold and the latter at temperatures above boiling point are consequently employed in separating the fibre from the encrusting non-cellulosic material such as lignin, resin, gum and wax with which it is associated in wood, for instance.

In the manufacture and bleaching of pulp, sodium hydroxide, chlorine, calcium or sodium hypochlorite, chlorine dioxide, peroxide and oxygen may be used to bleach the pulp after its isolation from impurities.

In the case of most fibres it should be noted that a strong solution of caustic alkalis produces a curious thickening and gelatinizing of the walls of the fibre. When applied to cotton fibre and cotton cloth in the textile industry the process is known after the discoverer of this effect, John Mercer, as mercerizing and is used for producing crinkled surfaces on cotton fabrics.

Strong sulphuric acid rapidly attacks and dissolves cellulose as many a chemist has learned to his dismay when spilling concentrated sulphuric acid (H_2SO_4) on his/her clothes while working in a laboratory.

Sources of Cellulose: Cotton and wood, the principal sources of industrial cellulose, contain respectively 90 and 50 per cent cellulose. Flax, hemp, bagasse, cotton, wood and other sources of cellulose contain celluloses of varying molecular weights and fibre structures due to the varying amounts of natural bonding agents such as sap, lignin, resins and mineral matter. Although cellulose may be derived from many vegetable sources, the original costs, difficulties in collection and quality limitations of the eventual purified fibre, etc., have kept wood and cotton linters as the chief industrial source of cellulose.

Manufacture of Cellulose Pulp: South African Pulp and Paper Industries Limited (SAPPI) pioneered the manufacture of cellulose pulp in South Africa when this company commissioned the "Enstra Mill" at Springs in 1939. The feedstock used at this mill, initially, was wheat straw but after the war (World War II) the use of wheat straw was abandoned and timber (wood) was used for pulp manufacture. Subsequently, the previously used "soda" chlorine process was abandoned and the "sulphate" or "kraft" process was installed in its place. (At one stage the company used waste paper as feedstock.)

The original output of the Enstra Mill was only of the order of 30 tons per day!

Today, in South Africa, the main woods used as feedstocks at pulp mills are wattle and pine and certain varieties of eucalyptus.

Wood is not uniform as far as its chemical and physical composition is concerned – there being variations from tree to tree and within a particular tree and, also, with age. Consequently, the strength of the liberated fibres will vary accordingly.

Wood: There are two type-classifications of wood, viz. – "hardwoods" and "softwoods" – the former being exemplified in South Africa by wattle and eucalyptus and the latter by pine. Hardwoods contain large quantities of "extractive matter" including pentosans (polysaccharose gums which, on hydrolysis, yield pentose sugar) while in the latter the amount of resin is high.*

Softwoods include coniferous or needle-leaved trees: non-porous woods, botanically classified as Gymnosperms. The cellular structure is of a lower form of plant life than that of the hardwoods and consists of tracheids, tracheid ray and parenchyma. Some softwoods are harder and heavier than many hardwoods and the softest known woods are hardwoods. Examples of softwoods are cedar, chil, cypress, Douglas fir, numerous species of fir, hemlock, kauri, larch, matai, numerous species of pine, podo, rimu, sequoia, numerous species of spruce, tammarack, totara, yellowwood and yew.

Note: Hardwoods and Softwoods: According to Corkhill,[7] the term hardwood is a description applied to woods from deciduous and evergeeen broad-leaved trees or dicotyledons. The term does not infer hardness in the usual sense, but is a classification. Generally, the timber from broad-leaved trees is harder and heavier than that from needle-leaved trees, but there are many exceptions and the lightest known woods are hardwoods. Hardwoods are more complex in structure than softwoods, and consist of vessels, or pores, fibres and parenchyma. They belong to the botanical group Angiosperms, e.g. ash, beech, birch, elm, chestnut, hornbeam, lime, oak, poplar, sycamore, willow.

The average per cent composition of wood has been reported as follows[8] (Table I):

Table I

Constituents	Hardwood (Broadleaf)	Softwood or Conifers
Cellulose	56	58
Pentosans	18	7
Gums, resins, oils	2	8
Ash	1	1
Lignin	23	26

However, another source[9] quotes the principal constituents of wood as follows (Table II):

Table II

Constituents	Per cent
Cellulose (structural material of cells)	40 – 50
Lignin ("cement" holding cells together)	15 – 35
Hemicellulose (similar in character to cellulose)	20 – 35
Extractives (resins, etc.)	3 – 10

A further source[10] gives the following compositions of hardwood and softwood (Table III):

Table III

Constituents	Hardwood %	Softwood %
Cellulose	40 – 50	40 – 45
Lignin	20 – 25	25 – 35
Pectin	1 – 2	1 – 2
Starch	Trace	Trace
Hemicellulose	25 – 35	25 – 30
a. Glucuronoxylan	Very large	Small
b. Glucuroncarbinoxylan	Trace	Small-medium
c. Glucomannan	Small	Large
d. Galactiglucomannan	Very small	Small-medium
e. Arabinogalactan	Small	Very small[b]
f. Other galactans	Trace-small	Trace-small

Table IV gives results for the ultimate analysis of wood from a number of tree types.

Chemical Composition of Wood: Wood has been aptly described as "an interpenetrating system of high polymers". It represents a complex, irregular, intermingling of chemical components. The separation and isolation of the components without significantly altering their physical and chemical nature is an undertaking of no mean order.

Table IV
Ultimate Analysis of Wood[11]

Name	Carbon	Hydrogen	Oxygen	Nitrogen	Ash
Ash	49,18	6,27	43,91	0,07	0,57
Beech	49,06	6,11	44,17	0,07	0,57
Birch	48,88	6,06	44,67	0,10	0,29
Elm	48,89	6,20	44,25	0,06	0,50
Fir	50,36	5,92	43,39	0,05	0,28
Oak	50,16	6,02	43,36	0,09	0,37
Pine	50,31	6,20	43,08	0,04	0,37

Browning[12] states that among the components present in wood we have carbohydrates – mainly polysaccharides – which account for about 75 per cent of the wood substance. They include cellulose, hemicellulose, starch, pectic substances and water-soluble polysaccharides such as arabinogalactans. Cellulose is the major wood component and is present to the extent of 50 per cent of the wood weight. Sugars occur in the sap and developing tissues but do not feature in mature woody tissues.

Phenolic substances are present in wood and the greater part of these, some 20 to 30 per cent of the woody tissue comprise the so-called lignin. A further fraction containing terpenes and related compounds and resin acids are present to the extent of about 5 per cent in softwoods but are practically absent in hardwoods.

Other constituents present in wood include the esters of aliphatic acids together with a portion of the polysaccharides which are present to the extent of 1 to 5 per cent. Aliphatic alcohols and sterols also occur.

Whilst proteins are notably present in developing wood the low content of nitrogen in mature wood indicates a protein content of only about 1 per cent. Inorganic constituents as indicated by the ash content are low but may vary from 1 to 5 per cent depending on the climate of origin of the trees. Many other organic compounds may be present in minor amounts e.g. polyhydric alcohols, aldehydes, hydrocarbons, alkaloids and dibasic acids.

Principle Involved in Producing Pulp: The principle involved in pure cellulose manufacture is to treat the timber used in such a way that the binding or associated encrusting substances such as lignin, resins, oils, gums, etc., are removed in such a way that as little as possible of the cellulose is lost or degraded in the process.

Varieties of Wood Pulp: There are five (5) varieties of wood pulp produced in the Republic, viz. –

(1) Mechanical pulp;
(2) "Sulphate" or "kraft" pulp;
(3) "Sulphite" or dissolving pulp;
(4) "Soda" pulp and
(5) "N.S.S.C." pulp (Neutral sulphite semi-chemical pulp).

(1) ***Mechanical Pulp***

This is prepared purely by mechanical means. Two methods are used, viz. –

(i) The groundwood process in which the logs of wood are ground by being forced against a rotating synthetic stone;
(ii) Wood chips are disintegrated mechanically in refiners. The refiner consists of two discs upon which patterns are cut and one or both plates revolve while the material is pulverized and comminuted by forcible grinding between the plates.

During mechanical preparation [(i) and (ii) above] of the pulp, the pulp suspension temperatures reach 70°C to 80°C due to frictional energy release and water sprays have to be used to control the temperature rise and also to continuously remove the pulp.

Mechanical pulp is usually prepared from debarked softwood. In this process approximately 95 per cent of the timber is converted into pulp. However, the paper prepared from mechanical pulp lacks strength and is used mainly in the newspaper and magazine industries where strength and appearance are not important as its use is somewhat ephemeral. It also has the tendency to discolour with age and exposure due to the impurities present.

The yield, of course, is high (95 per cent) and the cost of production is lower than chemical pulps, it being, in fact, the cheapest pulp.

2, 3, 4, 5 Chemical Pulps: Mechanical pulp contains all the wood except the bark and that lost during storage, transportation and grinding. Chemical pulps, however, result from attempts to produce pure cellulose pulps, the unwanted and unstable lignin and other non-cellulosic components of the wood having been eliminated by the treatment processes (to a lesser or greater extent). Chemical pulps are much superior to mechanical pulp for the manufacture of fine paper and are more expensive and priced "out of range" for newsprint users.

The manufacture of chemical pulp, of course, gives rise to serious pollution problems.

(2) ***"Sulphate" or "Kraft" Pulp***

The most generally used process for producing pulp today is the sulphate or kraft process ("kraft" is German for "strength". It has the same connotation in Swedish). Its greater use is governed by the fact that it is rapid, reasonably simple and insensitive to wood variations. In fact, any type of wood can respond to the process and the quality of the final product (with the exception of dissolving pulp) exceeds that of other methods extant at present.

An advantage of the process is the fact that spent chemicals may be recovered efficiently. The chemicals used are hydroxide and sodium sulphate.

In the process, debarked logs are mechanically reduced to chips in special rotary knife chippers. The chips are then passed to digesters which are large pressure vessels. Sodium hydroxide and sodium sulphide in a fixed ratio and requisite concentration are then added to the digesters and the temperature of the contents is raised by direct or indirect steaming. After a time the contents of the digesters are "blown" into a receiving vessel. In the digestion process lignins, resins and non-cellulose constituents go into solution. The "blow tank" now contains unbleached pulp and organic and inorganic substances in solution. To this dark-coloured solution is given the name "Black Liquor" – the black liquor is highly polluting! However, this is separated from the pulp by rotary vacuum filtration. The black liquor is then passed to multiple effect evaporators to raise the concentration to 60 per cent after which it is fed into waste heat boilers or special furnaces where the organic constituents are burned off and the inorganic chemicals, now in the form of sodium carbonate and sodium sulphide, pass out of the bottom of the furnace as smelt. The smelt is then dissolved ("green liquor") and re-causticised ("white liquor") and recycled to the digesters for reuse.

Initially mills used a batch system of digestion. Today the tendency is to install continuous digesters.

The unbleached pulp recovered by vacuum filtration is screened, filtered, pressed and dried where necessary.

Where bleached pulp is to be manufactured the screened unbleached pulp is bleached in a multistage process. Firstly, it is reacted with chlorine and subsequently subjected to filtration and washing. The second stage of the bleaching process involves reacting the chlorinated pulp with sodium hydroxide solution followed again by filtration and washing. Subsequently, the pulp is whitened further by using either one stage of hypochlorite bleach followed by chlorine dioxide treatment or, alternatively, by using two successive chlorine dioxide treatment stages. The first two stages of chlorine and sodium hydroxide treatment can be replaced by a special oxygen bleaching process.

From this brief description it will be realized that apart from spillages and adventitious discharges and accidents the combined effluent from a kraft mill will contain a variety of pollutants including the black liquor, so assiduously washed out from the pulp, as well as chemicals used in bleaching the pulp and also substances arising from the bleaching processes used.

Sources of Odour in the Kraft ("Sulphate") Process: The main compounds responsible for the unpleasant odour emanating from a kraft mill are methyl mercaptan,* di-methyl sulphide and hydrogen sulphide. The first two compounds are produced significantly in the digester and are released when the pressure is released and the pulp discharged. Methyl mercaptan (CH_3SH) is formed by the reaction between hydrosulphide or sulphide ions in the cooking liquor and methoxyl groups present in the lignin of the wood. Only a small amount of the methoxyl groups are attacked, hence, after the lignin has been dissolved the reaction can continue in the black liquor if reaction conditions are favourable. Methyl mercaptan is weakly acidic and reacts with hydroxyl ions in the alkaline cooking liquor to form methyl mercaptide ions. This is an equilibrium reaction and consequently at high temperatures when steam is being evolved rapidly (e.g. in the blowing of a digester or during evaporation) the equilibrium will be reversed as methyl mercaptan is carried away in a stripping action. Dimethylsulphide is formed in a secondary reaction between methyl mercaptide ions and the methoxyl groups of lignin. The formation of dimethyl sulphide will also occur when there is a build-up of mercaptan ions. In short cooling periods, far more methyl mercaptan is formed than dimethyl sulphide. In longer cooling periods, the amount of methyl mercaptan present tends to reach a steady state since it is consumed in forming dimethyl sulphide as rapidly as it is formed – and may exceed the amount of mercaptan present. On the other hand, if a reaction proceeds for a short time only, the amount of dimethyl sulphide formed may be negligible.

It is not surprising, therefore, that the odour from a kraft mill may be smelt, on occasions, some considerable distance away!

(3) *"Sulphite" Process Pulp (Dissolving Pulp)*

Serendipity: While in Paris in 1857 Benjamin C Tilghman, an American, investigated the action of sulphurous acid on fats. The sulphurous acid which he used was kept in barrels provided with softwood conical plugs as bungs in the bung-holes drilled in the side of the wooden barrels. He observed that, after some time, the softwood bungs had become soft and fibrous due to exposure to the sulphurous acid solution.

Thereafter, he experimented with wood and sulphurous acid at high temperatures and under pressure and was able to isolate the fibres. To prevent consequent damage to the fibres by the resulting sulphuric acid formed he added lime to the cooking liquor, and pulp suitable for the manufacture of paper was obtained.

He patented the process in 1866 but the process did not prove a financial success due to difficulties encountered with the cooking equipment. However, in 1872 Carl D Ekman, a Swedish chemist, developed a sulphite process based on magnesium bisulphite solution. This new process was brought into commercial use by Charles Weelwright in 1882.

Variations of the process based on calcium, magnesium, sodium or ammonium bisulphite solutions containing an excess of sulphurous acids are used. Wood chips are treated in such bisulphite solutions, under pressure, and at elevated temperatures.

The calcium base method has been largely displaced by magnesium, sodium and ammonium base processes.

Gordon[13] states that for many decades following 1890 the sulphite process was the most important wood pulping process throughout the world because it yielded the brightest unbleached chemical pulp and could be easily bleached to high brightness. Today (1970), he further stated "the sulphite and kraft processes were the main methods for producing chemical pulp although the 'sulphite' had lost much ground to 'kraft'."

In South Africa the major pollution problem of the sulphite pulping industry arises from the use of calcium base sulphite cooking liquor. The waste arising contains the residues cooked from wood by a solution of calcium bisulphite and contains, in addition to the spent chemicals, between 40 and 55 per cent of the total wood substance. The purpose of the process is to produce very pure short-fibre cellulose for export – for use by the artificial silk (Rayon) industry overseas.

The major constituents of sulphite waste liquor are sugars (pentoses and hexoses), calcium lignosulphonate, sulphur dioxide, cellulose residues, etc. The effluent has a low pH value (acidic).

In the Republic today (1983) we have only one such plant – South African Industrial Cellulose Corporation's ("SAICCOR's") Plant at Umkomaas in Natal. The effluent from this plant is pumped out to sea in deep water by marine pipelines on the seabed.

(4) *Soda Pulp*

In producing pulp by the soda process the sole chemical used is sodium hydroxide (in solution). Considerable amounts of wood pulp were previously made by this process which involved cooking the wood chips at 150°C to 165°C. However, with the introduction of the "kraft" ("sulphate") process it is now only used in South Africa for materials such as

*Note: Mercaptans belong to the class of organic compounds known as thioalcohols (RSH). The word developed from the fact that a mercaptan forms a characteristic crystalline compound with mercuric oxide or an alcoholic solution or mercuric chloride ("corrosive sublimate").

The word mercaptan is said to originate from "mercurium" (mercury); "captans" (seizing) OR the phrase "corpus mercurio aptum".

Mercaptans are volatile substances and are extremely foul smelling. They are also found in sour petroleum and can be present in septic sewage.

bagasse. However, it has been re-introduced to allay odour complaints due to the kraft process.

The soda process is particularly suited to the production of pulp from bagasse since pulping takes place rapidly due to the high reactivity of the lignin in the bagasse as well as the open structure of the bagasse (after de-pithing). About 10 min at 130°C is sufficient to produce a pulp yield of approximately 70 per cent.

(5) *N.S.S.C. Pulp*

The Neutral Sulphite Semi-chemical Process (N.S.S.C.) is used in two mills in South Africa. The term "neutral" is derived from the fact that the pH value of the reaction mixture during pulping is kept close to neutrality (pH 7,0) by buffering with sodium carbonate and bicarbonate.

This process is applicable to hardwood and the pulp yield is of the order of 70 per cent compared with about 50 per cent for kraft pulp.

Hardwood logs are chipped and processed in a continuous digester using a neutral solution of sodium carbonate and sodium sulphite. The pulping solution is made on the site by passing sulphur dioxide (gas), made by burning sulphur, through a sodium carbonate solution.

The softened chips are mechanically disintegrated to pulp, washed in a continuous washer, and passed to pulp presses and stored for later use in paper making, etc.

By-products from Alkaline Pulping

Sanyer and Chidester,[14] have drawn attention to the compounds produced during alkaline digestion of wood.

Methanol only is formed in the soda process whereas in the kraft process, in addition to methanol, methyl mercaptan, dimethyl disulphide are formed giving rise to the characteristic unpleasant kraft mill odour (*vide ante*). These are discharged to atmosphere particularly during blowing of a digester. However, some remain in the black liquor and collect in the condensate from the evaporators, and, if burned or suitably oxidized, amelioration of odour pollution in the vicinity of the kraft mill may be effected.

Dimethyl Sulphoxide: This can be produced by heating black liquor with additional sulphur at elevated temperatures. Dimethyl sulphoxide, an oil, is used as a solvent for certain purposes.

Turpentine: Resinous wood produces turpentine which is recovered by condensation of the relief gases emitted during digestion. The turpentine captured is purified by fractional distillation and washing with sulphuric acid.

Tall Oil: During alkaline pulping of resinous wood, the resin acids and fatty acids are removed by the cooking liquor and their sodium salts with some unsaponifiable material rises to the surface of the partly evaporated black liquor as so-called "sulphate soap" which is skimmed off, treated with sulphuric acid, washed with warm water, and then de-watered. The crude tall oil produced is a dark oily liquid containing 8 to 10 per cent unsaponifiables, 30 to 50 per cent resin acids and 40 to 60 per cent fatty acids.

The crude tall oil is then refined by vacuum distillation to improve the colour and remove objectionable odour. The two major fractions, viz. – resin acids and fatty acids are then separated by fractional distillation before or after total esterification.

The fatty acid fraction of tall oil is made up of oleic, linoleic, linolenic, palmitic, ricinoleic acids in decreasing order of importance.

The principal constituent of the resin acid fraction is abietic acid. Resin acids are used in sizing paper.

Tall oil is a useful agent in the flotation of certain minerals, e.g. apatite, $Ca_5(F, Cl)(PO_4)_3$ – the main source of phosphate.

Turpentine and tall oil are recovered at the Mandini Pulp and Paper Mill of SAPPI Limited.

Progress in the Hierarchical Use of Water in the Industry

It will be realized from the foregoing that a company seeking to establish a pulp mill or integrated pulp and paper mill will require a large amount of water, both for its initial requirements and contemplated expansion which is inevitable. Such a company will not only have to realize its considerable water requirements but also the difficult effluent disposal problems associated with the manufacture of pulp and paper. The company also has to concern itself with the best positioning of the mill in relation to the supplies of raw materials and also its markets.

In the Republic today (1983) there are 8 large mills producing pulp for various end uses. Three major controlling houses have an interest in the industry, viz. – General Mining Union Corporation Limited (GENCOR), Barlow Rand Limited and Anglo American Corporation of South Africa Limited.

Constructive attempts have been made at two large paper mills – one in the Transvaal and the other in Natal – to use purified sewage effluent in place of pure wholesome water purchased from local authorities.

Transvaal Mill (Springs): In the case of the Transvaal mill the management was faced with a water problem. However, by arrangement with two gold mines in the vicinity and, subsequently, the neighbouring local authority (Springs) which supplied them with all the town's purified sewage effluent from two sewage purification works, plus the exercise of extensive internal re-cycling at the mill, it has

been possible to obviate the use of mine water and there has been sufficient water available to meet the company's process requirements of water at this mill.

In order to ensure that the process water used in the mill was of such a quality as not to adversely affect the degree of brightness and the quality of the bleached paper the following had to be considered as being of vital importance:

- Low suspended solids content;
- Low organic matter content;
- Low hardness;
- Low dissolved inorganic matter content;
- Suitable pH value.

Freedom from heavy metals such as iron and manganese was also considered important.

More particularly, the following were the standards required for process water:

Constituent/parameter	**mg/ℓ (Range)**
Total hardness (as $CaCO_3$)	Less than 200 – 300
Iron (as Fe)	Less than 0,05
Manganese (as Mn)	Trace to 0,02
Organic matter (volatile solids at 550°C)	50 to 100

After much experimentation using purified sewage effluent after sand filtration, the following process (similar to that of Stander and van Vuuren), at that time developed by the National Institute for Water Research of the CSIR, was found to be satisfactory. The basic treatment steps were as follows:

(1) Addition of slaked lime to give a pH value above 10,5 i.e. in the range of 10,8 to 11,0 followed by settlement or flotation to remove flocculated material.
(2) Addition of carbon dioxide and settling to produce a pH value of 9,5 in the effluent at this stage.
(3) Re-carbonation of this effluent to the desired end pH value required.
(4) Final sand filtration of the effluent.

It was not considered necessary for pulp and paper making to also include ammonia stripping, foam fractionation, chlorination or activated carbon treatment as is done when producing drinking water from purified sewage effluent.

After successful pilot runs the company successfully adapted the treatment processes to meet their requirements and is using purified sewage effluent as a process water supply for the pulp and paper manufacturing processes at the mill.

Natal Mill (Merebank, Durban): The Natal mill is a groundwood pulp mill but also uses purchased bleached pulp from outside sources. It is an integrated mill producing high quality paper and newsprint. Originally 3 and now (1983) 5 paper machines are used to produce newsprint and fine paper grades.

A condition of the sale of the land to the company by the local authority was that the entire process water requirements of the mill would have to be derived from secondary sewage effluent supplied by the local authority.

The company proceeded to install a series of process units to produce a water of sufficient quality to meet the strict demands for the production of fine paper.

The process units included the following:

(1) Activated sludge aeration tank (6 h retention) provided with a surface aerator, settlement tank and sludge return system.
(2) A gas chlorinator.
(3) Chlorine contact tank (10 min contact).
(4) Three chemical mixing tanks with stirrers (1 min retention in each case).
(5) Chemical dosing equipment.
(6) A combined flocculator and upward-flow clarifier with slurry re-circulation system (1,5 h retention).
(7) Rapid gravity sand filter.
(8) Foam fractionator.
(9) Two activated carbon columns.

These two cases indicate quite clearly that sewage effluent (after further treatment) can be satisfactorily used in pulp and paper mills and thus represent progress in the hierarchical use of water by the industry.

Disposal of Effluent

I. ***Disposal by Marine Pipeline:*** Three mills in Natal discharge their final effluents to sea, viz. –

(1) A mill at Umkomaas which manufactures dissolving pulp (for export) from *Eucalyptus saligna* wood using the calcium base sulphite process (q.v.). The calcium base sulphite waste liquor is disposed of far out to sea in deep water by marine pipeline.
(2) A pulp and paper mill at Felixton manufacturers pulp and paper from bagasse by the soda process and disposes of the final effluent to sea near Port Durnford by pipeline in the surf zone. A dissolved air flotation ("DAF") plant is being used to recover fibre in the effluent prior to discharge from the mill.
(3) A pulp and paper mill at Merebank, Durban, just referred to, discharges its effluent from groundwood pulp manufacture into the City of Durban's Southern Marine pipeline which receives other industrial effluents and sewage for deep sea disposal.

Efforts by the Companies to Improve Conditions

(1) At Umkomaas difficulties have arisen from

foaming in the sea from time to time. This is overcome by spraying anti-foaming agents at selected points by the surveillance team employed by the company. However, accidents have taken place due to electric power failures at the pump station pumping effluent out to sea. These failures have resulted in effluent overflowing on to the beach at Umkomaas. This state of affairs has been rectified by providing two independent electric power supplies to the pump station near the beach – one supplied by the Electricity Supply Commission (ESCOM) and the other from the mill's own power supply generated by the mill power station.

Unless the mill alters its method of manufacture – which may not suit overseas purchasers of the pulp and the company can face up to the considerable capital outlay in changing their plant and processes it is unlikely that the quality of the effluent will improve.

(2) At Felixton the company has employed consultants and this has resulted in a number of internal plant re-arrangements. Further, a dissolved air flotation unit has been commissioned to recover as much fibre as possible from the effluent which was previously finding its way into the sea towards Richards Bay.

(3) At Merebank, Durban, the company concerned has been assisted by the National Institute for Water Research and maintains a careful water balance and control of the amount of settleable solids in the effluents and maintains a close liaison with the local authority's senior technical officials.

II. *Disposal on Land*

Three mills in the Transvaal have disposed of mill effluent by irrigation.

(1) At Ngodwana in the Eastern Transvaal, a mill has maintained a satisfactory irrigation system by careful attention to the concentration of sodium in the effluent by rigorous internal control of spillages and by control of application rates and the Sodium Adsorption Ratio (SAR) of the effluent by the judicious addition of gypsum and dolomitic lime to ensure that the SAR value does not exceed 9.

The Sodium Adsorption Ratio is given by the expression –

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

where Na, Ca and Mg are in milliequivalents per litre.

Due to good farm management of Kikuyu grass pasturage the company has been able to graze a large number of beef cattle. There have been no complaints of mismanagement of the overhead irrigation operations.

(2) At the Piet Retief Mill a similar method of disposal to that used at Ngodwana is employed. In order to obtain a suitably large pasturage area for disposal of the effluent a plantation of wattle trees had to be cut down and the stumps killed off by a purpose-made flaying machine.

In addition to the irrigation scheme the company uses a large number of evaporation ponds.

The irrigation dam is large and a tail or catchment dam is provided at the lower end of the irrigation area. This collects any seepage and runoff and water which collects in the dam from time to time is pumped back to the large irrigation dam.

Since the commissioning of the irrigation scheme and also the construction of an emergency reservoir at the mill to collect runoff, spillages, adventitious discharges, during both dry and wet weather, there have been no complaints of pollution of the Blesbokspruit and the Assegai Rivers.

Gypsum is added to the effluent at the irrigation dam before jet spraying onto the pasturage area and the SAR values 8 to 9 are adhered to.

(3) At Springs a large volume of highly mineralized effluent arising from bleaching is disposed of by spray-irrigation over an area of approximately 140 ha. Here, too, gypsum requirements were taken care of.

III. *Disposal by Aerated Lagoons*

One mill in the Stanger (Natal) area manufactures pulp from bagasse from a nearby sugar mill. A soda digestion process is used on the de-pithed bagasse and chlorine bleaching is practised.

The effluent discharges into a series of lagoons, forming part of a river, and the water mixture in the lagoon is aerated by a number of anchored (floating) surface aerators.

Difficulties have been encountered due to clogging of the lagoon aerators by fibre. However, these problems have been circumvented and, also further aerators have been installed. There had been complaints from farmers along the Umvoti River during a drought period and the mill management staff had to prevent a "shut-down" by abstracting further water by a well-point system in the bed of the river.

The company evaporates the mill's black liquor for final incineration in a "Copeland" plant. Systems of bund walls have been placed around pump clusters and other points where gland leakages, floor spillages and adventitious discharges might arise to prevent undesirable effluent gaining access to the river. Further, the stacking slab for bagasse storage has also been taken care of to prevent seepage and runoff therefrom. Progress is being made at the mill but further improvements in the operation of the aerated lagoons are desirable.

IV. *Discharge into a River Estuary after Primary Treatment*

The largest presently operated pulp and paper mill is located at Mandini (Natal) near the estuary of the Tugela River.

The effluent from this mill discharges into the Mandini River just before its confluence with the Tugela River.

In the past the company had relied on the fact that the Tugela River was a major one and considerably diluted the mill's effluent during normal flow and, furthermore, when in flood, became a mighty torrent and washed considerable mud and debris out to sea.

The company has improved conditions in many directions, viz. –

A second large rectangular clarifier has been commissioned and this together with the original circular clarifier have increased the recovery of fibre from the effluent – such recovered fibre can be returned to process and so increases the mill's pulp yield. So far recoveries have not been all that good and the company is experimenting with a dissolved air flotation test unit.

In juxtaposition to the new clarifier and, structurally, joined to it a large emergency reservoir has been constructed. This collects runoff, from the mill area, adventitious discharges, spillages, etc. of undersirable content which are prevented from entering a watercourse and are dealt with later by judicious addition to the normal clarified effluent. This prevents large slugs of highly polluting effluent discharging into the Mandini and Tugela Rivers.

To ensure that the effluent when mixed with the river water is not inimical to fish life the company called in the service of the NIWR and installed a very sensitive fish monitoring station at the new clarifier emergency reservoir complex. The equipment electronically records the heart beats of small fish ("Guppies").

In practice a number of small "perspex" tanks are used, each with one fish. The room housing the tanks and equipment is kept locked to prevent entry by uninformed persons and disturbance of the fish. Conditions are controlled under the supervision of the company's Effluent Control Officer.

The tanks are filled with mixtures of effluent and river water (on a continuous basis) by a system of apportioning pumps to ensure the correct proportions to match the river flow in relation to effluent flow at any time. The normal Tugela River water is used as the baseline: the Mandini River upstream is also minotored.

The heart beats of the fish subjected to the different water and effluent/water mixtures are continuously recorded electronically. By this means it is possible to ensure that the effluent from the mill will not affect fish life in the Tugela River since discharge of effluent can be stopped and (use is made of the emergency reservoir) when fish-reaction in the monitoring station is severe – indicating an unsatisfactory effluent.

It has been found, in practice, that on a number of occasions the fish have adversely reacted to water from the Mandini River: this was probably due to discharges of effluent from factories in Isetebe industrial township in KwaZulu.

If this method of controlling pollution by the aid of an emergency reservoir to prevent runoff, spillages, adventitious and accidental discharges from gaining access to either of the two rivers and also controlling the effluent discharge into the Mandini River by means of the fish monitoring set-up is inadequate, then the company will be faced with the necessity to spend a further large capital sum on the construction of an activated sludge plant which has already been canvassed as well; or, alternatively, the construction of an aerated lagoon by effecting a diversion of the Mandini River.

Other Lesser Sources of Pollution

The mill management has successfully contained pollution from the mill's main waste/rubbish dump. The seepage from this is collected in a small dam and pumped to the mill for incineration in the "Copeland" plant together with the mill's black liquor. Only effluent, surplus to the normal seepage flow (during rainstorms) is allowed to discharge into the watercourse.

It is also likely that with the extra clarification and further re-use of recovered fibre the sludge dams will disappear thus eliminating another pollution hazard. So far this has not happened and the company has concerned itself – as stated previously, with the use of dissolved air flotation (on an experimental basis) for the more effective removal of suspended fibre in the effluent.

Recycling of Waste Paper

A number of the mills use wastepaper, cardboard, etc., which is received in compacted bales. This is repulped and bleached (where necessary) and added in certain proportions to the normal pulp of the mill. This is akin to re-cycling which takes place in the textile industry where old wool (for instance) is taken from bundles of used woollen garments, bleached and a portion of the new wool added. The mixture is then spun into yarn and duly woven into woollen materials such as rugs, blankets, etc.

Many paper companies do not produce their own pulp but merely purchase pulp (bleached or unbleached) from one of the operating mills – or alternatively import pulp to meet their requirements. This pulp is used to make a variety of paper, cardboard and industrial board material e.g. tissues, toilet rolls, paper towels, table napkins (serviettes), packaging containers, etc.

These companies usually have premises in the in-

dustrial areas of local authorities and discharge their effluents into the local sewerage system. In some cases, due to lack of supervision and concern, these companies have caused sewer blockages and given rise to trouble at the respective sewage purification works mainly from excessive suspended solids and slug discharges of pulp.

It has been stated earlier that wood is replenishable. But, of course, it is important that fresh plantings of trees should more than make up for those used up. The pulp and paper industries today have their own forest companies which operate separately from the mills. Further, the Government has been responsible for afforesting large tracts of mountain and other areas. A great deal of timber is used in the mining industry (which also has its own forests) for "props" and "mat packs" underground. Wood is also used in the building industry and for furniture making etc. Unfortunately, from time to time some forests are destroyed by fire. For these reasons it would seem desirable to re-cycle as much cellulose-containing material as possible.

Toxicity of Pulp Mill Effluents

Chlorinated Compounds: Most of the chlorinated compounds discharged from bleaching processes are *non-toxic*. However, a small amount of chlorinated phenolic compounds is produced. Bleaching of hardwood (e.g. wattle and eucalyptus pulp) gives rise to less chlorinated compounds than is the case with softwood (e.g. pine) pulps.

The use of chlorine dioxide (ClO_2) instead of chlorine reduces the content of chlorinated organic compounds in the effluent.

From tests carried out overseas it has been found that with ordinary bleaching there is a tendency for such effluents to give rise to the following adverse circumstances:

(1) Toxicity to fish;
(2) Impairment to fish reproducibility;
(3) Biological accumulation of chlorinated compounds in fish;
(4) Reduction of primary production of phytoplancton;
(5) Mutagenic effects.

It is considered that with chlorine dioxide bleaching these effects do not occur. (*Note:* Care has to be exercised in the generation and use of chlorine dioxide both in the laboratory and on the large scale, as in bleaching in a pulp mill – explosions have been known to occur.)

Certain investigations in Canada have indicated, however, that for dilutions of twenty times and over, ecological effects are highly improbable beyond the threshold concentration of acute toxicity [LC 50 (96 h)] – value.

Toxicity of Bleach Plant Effluents[15]

The toxicity of bleach plant effluents has been studied extensively by Canadian investigators – toxicity to fish being their main interest.

It has been found that combined effluents were less toxic than individual bleaching process streams, the most toxic stream being considered as that from the first alkaline extraction. Next in order of toxicity were unbleached whitewater and effluent from the first chlorination stage.

Rainbow trout were killed when the free chlorine in an effluent was present to the extent of 0,5 mg/ℓ. Hypochlorite, chlorine dioxide and chlorate are all toxic but at the concentrations normally occurring in effluents are low. The most toxic compounds contained in the alkaline extract of kraft pulp were found to be 3, 4, 5 – trichloroguaiacol; 3, 4, 5, 6 – tetrachloroguaiacol; monochlorodehydroabietic acid and dichlorodehydroabietic acid, and 9, 10 – epoxistearic acid.

The toxicity of an effluent is related to the concentration of chlorinated phenolic compounds in the effluent. This being so, the toxicity of an effluent will depend on the lignin content of the pulp and the kappa number.

Resin acids are toxic compounds that are present in kraft pulping liquor from softwood. Consequently, the amount of these acids reporting in an effluent will depend on the type of softwood used and the degree of washing of the unbleached pulp.

Amelioration of Toxic Qualities of Effluent: One method of improving the toxic nature of an effluent is to change the method of bleaching, and, in this regard, switching to oxygen bleaching should be considered.

Lignin Compounds: In the mill pulping and bleaching processes it is found that considerably less lignin waste is produced from hardwoods (e.g. wattle and eucalyptus) than from softwood (e.g. pine).

Chlorinated lignins can exercise a major toxic effect on fish through lignin degradation products.

Lignins, it should be mentioned, are essentially branched chain polymers. They are different in structure from the polysaccharides such as cellulose.

In the (sulphate)/"kraft" process lignin is dissolved completely to thiolignin.

Part of the methoxy groups (CH_3O) in the lignin molecule are ruptured forming malodorous compounds e.g. CH_3SH and $(CH_3)_2S_2$ and CH_3OH (cf. previously).

Proposals have been made to reduce odours at mills using the kraft process by introducing anthraquinone at convenient stages.

Organic Substances in Black Liquor: The following is a typical representation of the organic solids content of black liquor:

Organic Constituents	kg/BD ton pulp
Thiolignin	350 – 500
Polysaccharides	10 – 20
Monosaccharides	1 – 2
Carboxylic and hydroxy acids	120 – 200
Sugar acids and lactones	200 – 300
Methanol	5 – 15
Ethanol and acetone	1 – 2
Extractives (resin and fatty acids, fats, pectins, etc.)	30 – 80

Leakages of black liquor into the effluent through poor control, accidents, etc., add, naturally, a proportion of the above constituents to the final effluent discharged from a mill.

Research and Development[16(a)]

The Sapoxal Oxygen Bleaching Process[16(b)]

In conventional bleaching it has been stated in connexion with the kraft process (cf.) that the pulp is first reacted with chlorine and subsequently filtered and washed. The second stage of the bleaching process involves reacting the chlorinated pulp with sodium hydroxide solution – again followed by filtration and washing. Subsequently the pulp is treated with sodium hypochlorite followed by chlorine dioxide treatment or two stages of chlorine dioxide treatment in place of hypochlorite followed by chlorine dioxide. In some bleaching sequences hydrogen peroxide treatment is incorporated.

The following symbols are given to the process stages:

Chlorine C; Sodium hydroxide E; Chlorine dioxide D; Calcium or Sodium hypochlorite H: and Hydrogen peroxide P.

Typical sequences of these bleaching procedures are as follows: CEDED; CEHDED; CEDPD and, sometimes CEHD; CEHH may be used.

In all cases, the bleaching sequences start with CE i.e. chlorine followed by sodium hydroxide in which the major portion of the residual lignin is solubilized.

Through laboratory research followed by pilot plant investigations South African Pulp and Paper Industries (SAPPI) Limited have developed an oxygen bleach stage which replaces the C, E stages of bleaching.

The SAPPI oxygen bleach method was developed in association with L'Air Liquide, the well-known French firm, and development of the full-scale plant and equipment was carried out in collaboration with Kamyr AB, the Swedish machinery and plant manufacturers. This has been called the "SAPOXAL" bleaching process.

Oxygen bleaching by the Sapoxal process has obvious advantages as far as the effluent discharged from a mill is concerned since due to the elimination of chlorine, chlorinated compounds which may be toxic are not present. However, the plant requires careful supervision and fail-safe devices to prevent fires or explosions due to the poor control of pulp consistency (which should be less than 30 per cent W/V) and also correct fluffing of the pulp as well as avoidance of the ingress of combustible matter, e.g. grease or oil must be carefully watched.

The development and use of the Sapoxal bleaching process was a notable chemical and chemical engineering achievement by SAPPI which has been suitably recognized by the chemical fraternity and profession.

Multistage Bleaching of Chemical Pulp[17]

Bleaching of pulp can be carried out in any of eight (8) stages. This being so, it being impractical and time-consuming to characterize each step in writing, it has become common practice to use a single (capital) letter for a particular stage, viz. –

C = Chlorination.
E = Alkaline extraction.
H = Hypochlorite bleaching.
D = Chlorine dioxide bleaching.
P = Peroxide bleaching.
O = Oxygen bleaching.
C_D = Chlorine, with addition of a small amount of chlorine dioxide.
D/C = Sequential bleaching, with chlorine dioxide and subsequent chlorination without washing between the addition of chemicals.
C+D = Chlorination, with a mixture of chlorine and chlorine dioxide, with chlorine as the larger part.
A = Acid treatment.

Washing between the stages is indicated by a hyphen. No washing between application of two chemicals is indicated by an inclined line as shown by the sequential treatment with chlorine dioxide followed by chlorine.

Final Comment

The achievement of SAPPI Limited clearly indicates the benefit of a research and development department. It is hoped that the efforts of this and other companies' research teams will not only be turned towards better production methods but also towards satisfactory solutions of the effluent problems of certain mills where they occur.

At many mills the improvements in the control of pollution have eventuated from the positive drive and thinking of the officers of the Pollution Control Division of the Department of Water Affairs and in certain cases, the National Institute for Water Research (NIWR) of the CSIR who, happily, have succeeded in gaining the co-operation of the respective managements.

One fact, however, is clear and that is that every mill should appoint a technically trained scientist (chemist) or engineer as "Pollution Control Officer" and such appointed person should be directly responsible to the Managing Director or General Manager of the company or mill.

Such officer should be "*au fait*" with the plant and all the processes involved and have a knowledge and understanding of wastewater treatment with respect to the mill and sewage purification as well. He should confer with the Managing Director/ General Manager about pollution matters and submit monthly reports to him for onward transmission to the Director-General, Department of Water Affairs.

PART II: FIBREBOARD AND FIBRE BUILDING BOARD, ETC.

In Part I, the Pulp and Paper Industry was discussed and also the effluent problems arising therefrom.

However, there are many other uses to which wood can be put – some creating effluent problems of a major nature and others rather minor ones.

In Part II reference, *inter alia*, will be made to the following wood products:

- Hardboard;
- Fibreboard and fibre building board;
- Chipboard;
- Laminates (plywood).

In South Africa today we have a number of companies making products incorporating wood pulp, cellulose fibre, paper, laminates, etc.

The effluent problems that these give rise to are inconsiderable with the exception of hardboard in comparison with the manufacture of pulp and paper dealt with in Part I.

(1) *Masonite (Africa) Limited:* At Estcourt, in Natal, Masonite (Africa) Limited make pulp in their mill from hardwood. From the pulp manufactured, fibre building board, hardboard ("Masonite") are made. Mineral wool and mineral fibre ceiling panels are also fabricated. Use is made of waste slag material from the Newcastle works of ISCOR.

The effluent from the mill is filtered, clarified and pumped to two irrigation farms, viz. Wilgenspruit (area 364 ha) and Broomcliffe (area 300 ha). The total daily volume of effluent is of the order of 3 500 m^3. Bleaching is not practised but resins, gums, etc., are present in the effluent which contains waste fibre. Domestic sewage is discharged into the sewerage system of the Estcourt municipal sewage purification works. Kikuyu grass is irrigated with the factory effluent on both farms and efforts are made to prevent runoff into Bushman's River.

(2) *South African Board Mills, Limited:* This company has established factories at Springs, Durban and Belville.

At *Springs* waste pulp is slushed in water, cleaned and refined. The clean fibrous suspension, to which substances such as clay, resin size, dyes, etc., may be added is formed into a continuous sheet, which is pressed, dried, surface treated and sold in reels or sheets. Boards are processed into containers or cartons used for a wide variety of products, including foodstuffs.

The following is a list of the products manufactured:

(a) All types of folding boxboards;
(b) Rigid boxboard;
(c) Gypsum ceiling boards;
(d) Grey felts for use as roofing felts and floor coverings;
(e) Sugar containers.

The plant's water consumption is about $97{,}8 \times 10^6$ gallons ($4{,}45 \times 10^5$ m^3) per annum.

The effluent is discharged into the Springs sewerage system.

(3) *Kimberly-Clark of South Africa (Proprietary) Limited:* Kimberly-Clark has a factory at Germiston, Transvaal, which produces paper, cellulose wadding and paper specialities, e.g. facial tissues, household towels, toilet tissues, etc. The factory is at Roodekop to the south of Germiston: the water supply is obtained from a borehole.

Fibre in suspension is refined and passed on to a paper machine. Glue, resin, soap and detergents are used in the processing.

On the paper machine, a web of fibres is formed on a conventional Fourdrinier machine and finally wound up in rolls. A subsequent re-reeling and slitting process produces rolls of the desired width and diameter. Water extracted is re-cycled.

The raw material used is purchased dry pulp.

(4) *Transvaalse Suiker Korporasie Beperk:* A company working in juxta-position with the Transvaalse Suiker Korporasie Bpk. and in concert with it uses the wet bagasse from the sugar mill to produce fibre-board. No effluent problem has been created at Malelane.

(5) Likewise another company, *Bisonbord Limited*, uses bagasse and bonding resins to produce their type of building board. Pollution has taken place to a limited extent.

(6) *Carlton Paper Mill (Proprietary) Limited*, Enstra Mill, Springs, processes pulp into tissues, towels, etc. From time to time trouble has been encountered due to sewer blockages.

(7) *Bruply Saw Mills, Stellenbosch, Cape* have not given cause for serious complaint. Their products include doors, plywood, boards, veneers, timber, block and mosaic, lockwood, "Presto", logs, slabs. Various glues and adhesives are used.

Miscellaneous Timber Products

Diamont[18] deals with a number of products made from wood and used as building materials. These include the following:

Plywood: Two basic grades are made, viz. –

(1) *Exterior grade* plywood which employs a hot pressed phenolic resin glue as binder which is virtually insoluble on exposure and when in contact with hot water;

(2) *Interior grade*, which accounts for about two thirds of plywood produced. In its manufacture protein glues having a soya bean – blood base are used. This type of plywood does not stand up to continuing damp conditions.

Insulation Board: This is a fibre board and is made from wood pulp to which bagasse, re-pulped waste paper, etc., have been added. The mixture is heated for one minute with steam at a pressure of 10 bar (gauge) which softens the lignin and is then subjected to attrition in a suitable attrition mill and then refined, sizing in the form of phenol-formaldehyde resins, etc., added; after which the pulp is caused to flow on to a closely-woven gauze which is allowed to drain and then the mat formed is passed through rollers and dried in a hot air tunnel. The end product is a rigid fibre board with an open structure and low density, which is used for insulation purposes.

Hardboard: The production of a fibrous pulp is somewhat similar to that used for the manufacture of insulation board. Pulp made from wattle or *Eucalyptus saligna* may be used. A small quantity of wax emulsion is added to the pulp as a water proofing agent followed by 2 to 3 per cent phenol formaldehyde resin. The fibrous slurry is then passed on to a gauze belt and dewatered. The semi-wet sheets are then pressed at a temperature of 180°C to 210°C and a pressure of about 48 bar. Lastly the board is removed from the supporting wire gauze and heated for several hours at 160°C.

Water resistant hardboard is made by impregnating the board with linseed oil or tung oil. The hardboard after removal from the oil bath is subjected to a temperature of 160°C for 10 h. This causes the drying oil to polymerize within the fibres of the hardboard.

Hardboard is today being embossed for special decorative uses in the furnishing of offices and entrace halls of factories.

Particle Board: Particle board or chipboard is made, as its name implies, from wood particles or chips which are held together by means of a synthetic resin binder. The dried chips are mixed with either urea-formaldehyde or phenol-formaldehyde resin – the former resin being preferred for chipboard for indoor use and the latter for more durable use. The resin is applied by spraying into a sealed drum (kept in agitation) thereby ensuring complete coverage of the chips by the resins, the mixture is then extruded under pressure and at a temperature of 100°C to 140°C to give a single layer or three-layer board.

REFERENCES

1. Karrer, P. *"Organic Chemistry"*, Second English Edition, Elsevier, Pub. Co. Inc., New York, 1946, pp. 308-354.
2. Browning, B.L. (Editor) *"The Chemistry of Wood"*, Interscience Publishers, 1963, pp. 58-63.
3. Geissman, T.A. *"Principles of Organic Chemistry"*, N H Furman and Co., San Francisco and London, 1963, p. 460 et seq.
4. Lewis, W.R., Squires, L. and Broughton, G. *"Industrial Chemistry of Colloidal and Amorphous Materials"*, The Macmillan Co., New York, 1943, p. 149 et seq.
5. Bikales, N.M. and Segal, L. (Editors) *"Cellulose and Cellulose Derivatives"*, Part IV, Wiley – Interscience Publishers, New York, London, Sydney, Toronto, 1971.
6. Clegg, R.E., Tanghe, L.J. and Brewer, P.J. *"Cellulose and Cellulose Derivatives"* Part IV, Wiley – Interscience Publishers, New York, London, Sydney, Toronto, 1971, p. 492.
7. Corkhill, T. *"A Glossary of Wood"*, Stobart and Son Ltd., London, 1961.
8. Shreve, R.N. *"The Chemical Process Industries"*, McGraw Hill Book Co. Inc., New York, London, 1945, p. 678.
9. Nunn, J.R. *"The Chemistry of Pulping"*, Paper presented at Symposium of S. Afr. Inst. Chem. Engnrs, 11 March, 1975.
10. Timell, T.E., Glaudemans, C.P.J. and Gilham, J.K. *"Pulp and Paper Mag. Canada"*, 1958, 59, 242.
11. Olsen, J.C. (Editor), *"Van Nostrand's Chemical Annual"*, Chapman and Hall Ltd, London, 1935, p. 857.
12. Browning, B.L. Ibid p. 58.
13. Gordon, L.J. *"Handbook of Pulp and Paper Technology"*, Edited by Britt, K W, Van Nostrand Reinhold Company, New York, Cincinnati, Toronto, Melbourne, 1970, p. 159.
14. Sanyer, N. and Chidester, G.M. *"The Chemistry of Wood"*, B.L. Browning (Editor), Interscience Publishers, 1963, p. 490 et seq.
15. Casey, J.P. (Editor) *"Pulp and Paper – Chemistry and Chemical Technology"*, Third Ed. Vol. I, John Wiley and Sons, New York, Chichester, Brisbane, Toronto, 1980, p. 726 et seq.
16. (a) Job, L.A. *"Chlorine in the Cellulose Pulping Industry"*, - *J. S. Afr. Chem. Inst.* 1942, XXV(2), pp. 42-48.
    (b) Myburg, C.J. *"The Sapoxal Oxygen – Bleach Process from Laboratory to Commercial Installation"*, Paper presented at Symposium of the S. Afr. Inst. Chem. Engnrs., 11 March 1975.
17. Casey, J.R. (Editor) Ibid, p. 669.
18. Diamont, R.M.E. *"The Chemistry of Building Materials"*, (Gen. Editor, Ramage, G.R.), Business Books Limited, London, 1970, pp. 88-90.

15(3) THE IRON AND STEEL INDUSTRY: CONTROL OF POLLUTION FROM WASTEWATER ARISINGS

I. HISTORICAL EVOLUTION OF THE INDUSTRY

Abundance of Iron: The approximate percentages of the more abundant elements in the earth's 10-mile (c.16 km) crust including the air and the ocean are as follows:[1(a)]

Element	Per cent	Element	Per cent
Oxygen	50,0	Fluorine	0,10
Silicon	26,0	Barium	0,08
Aluminium	7,3	Manganese	0,08
Iron	4,18	Nitrogen	0,03
Calcium	3,22	Copper	0,02
Sodium	2,36	Strontium	0,02
Potassium	2,28	Nickel	0,016
Magnesium	2,08	Cerium	0,009
Hydrogen	0,37	Tin	0,008
Titanium	0,37	Lead	0,003
Chlorine	0,20	Silver	2×10^{-5}
Carbon	0,18	Gold	$1{,}4\times10^{-7}$
Sulphur	0,11	Radium	$1{,}4\times10^{-12}$
Phosphorus	0,11	All other elements	0,874

From the above it will be seen that iron is the second most abundant of the metals and fourth in abundance among all the elements.

Iron Age: Historians have been wont to deal with the cultural evolution of *Homo sapiens* according to the material used by him for implements and for instruments of war during certain time-spans. Hence we have the "Stone Age" (or age of neolithic man) followed by the so-called "Bronze Age" and then the "Iron Age". However, these categories are somewhat ill-defined and vary measurably from country to country. The Iron Age still persists though it might be considered by some that the Age of plastics is now extant.

Iron as the free metal is not commonly found. Most native iron is of meteoric origin. Numerous meteorites have been found throughout the world. The largest known meteorite according to Newton Friend[1(b)] is the Hoba West* meteorite at Grootfontein, South West Africa. Its approximate weight is 60 tons.

Notwithstanding, iron has been found in the coal measures of Missouri, USA, at depths of the order of 9 m. Analyses of samples have shown nickel to be absent indicating that the iron is not of meteoric origin.

In assessing the antiquity of iron objects e.g. "beads" found in ancient Egyptian graves, now completely oxidized to rust, the assumption has to be made that the original artefacts were made of iron. Based on such reasoning and other historical and archaeological associations it has been concluded that iron was known in Egypt some 4 000 years BC. However, iron did not come into general use in Egypt before 1350 BC.[1(c)]

The use of steel in China has been traced back to 2550 BC.[2]

Iron in Europe: The Greeks and the Cretans[1(d)] appear to have been the first European peoples to use iron; the Grecian Iron Age began about 1400 BC, whilst for most of the Celtic and Teutonic peoples it did not commence until some 900 years later.

Iron in Britain: Iron was known in Britain well before the arrival of Julius Caesar in 55 BC.

According to Richmond[3] "The iron mines of Britain were numerous and hardly less productive than the lead mines" . . . "The principal deposits exploited by Rome lay in the Weald and the Forest of Dean . . ."

Arthur Raistrick[4(a)] states that Clure[5] has indicated that, "A recent study of Roman ironworks suggests that Britain might have been a major producer of iron for Gaul, Germany and Spain".

Raistrick further states,[4(b)] "The smelting and use of iron was introduced to this country (Britain) about 650 BC and an industry was well developed by the time of the Roman occupation. The ores occur in three main groups. Carbonates occur as nodules in the coal measures of all the coalfields and among the wealden series of the south-east. Haematites occur in Furness, West Cumberland and parts of South Wales. Limonite is the principal ore of the Forest of Dean, and iron also occurs as the 'bog-ore' of northern moors".

Iron in the United States: Most of the iron ore smelted in the United States comes from the Lake Superior Area. Scott[6] states that "This iron ore area is chiefly in Minnesota but extends also into Wisconsin, Michigan and Canada and supplies 80 – 90 per cent of American output and more than one-third of the world's production".

Scott further states, "The ores from this highly productive region are mainly haematites concentrated by the action of surface waters from iron-bearing sedimentary rocks of pre-cambrian age". "In their original form", he contends, "the iron compounds were carbonates and silicates, chemically

*Details of the Hoba West meteorite are given in Geological Survey Bulletin 57 compiled by Frick, C and Hammerbeck, E C I, 1973, Government Printer, Pretoria. – *"Catalogue of South African and South West African Meteorites"*.

deposited and inter-stratified with slate quartzites. Percolating waters of meteoric origin containing carbon dioxide in solution have decomposed the iron compounds, producing the ferrugionous cherts and jasper of the region. Later, descending waters leached much of the silica, leaving high grade, usually porous masses of haematite".

Hard haematite has been mined in the Gogebic, Marquette and Menominee ranges in northern Michigan since 1953. Near Birmingham, Alabama, there is a mountain of iron ore containing limestone. A not inconsiderable amount of US iron ore is smelted at Birmingham.

Iron in South Africa: Du Toit,[7] in his book *"The Geology of South Africa"* states, "South Africa is wonderfully well supplied with iron ores, though geographical and other considerations have long delayed their exploitation". He gives information in regard to the various deposits which are available and can be exploited.

Mountain[8] likewise in his book, *"Geology of Southern Africa"* paints a similar picture of the wide spread of iron ore deposits in South Africa and contiguous countries.

The same theme is echoed by Hamilton and Cooke[9] who state, "Deposits of iron ore are of great variety and types, both with regard to the mode of origin and mineral composition. They are also exceedingly widespread . . .".

The first comprehensive report on the country's iron ore was written by Dr Percy Wagner and was published by the *"Geological Survey"*.

The following are the main iron-containing minerals of economic importance:*

Mineral	Chemical Formula	Per cent Fe
Haematite	Fe_2O_3	70
Magnetite	$FeO.Fe_2O_3$	72
Siderite	$FeO.CO_2$	48
Limonite	$Fe_2O_3 3H_2O$	59 – 63
Goethite	FeO.OH	61
Lepidocrocite	FeO.OH	61
Chamosite	$3FeO.Al_2O_3.2SiO_2.6H_2O$	c.35

Early Iron Age Settlements in South Africa: Mason[10] has described an Early Iron Age settlement, some 25 ha in extent, at Broederstroom, in the Brits district, near Pretoria. The accumulation of site debris he considers took place over a period of 250 years of intermittent settlement by Early Iron Age people. From radiocarbon dating he has concluded that the site was occupied between c.350 and 600 AD. He states that the occupants were Negroid pastoralists who apparently, at times, shared the site with Late Stone Age people.

Heaps of iron ore were discovered with scattered amounts of iron and slag spread over an area of 150 m^2. Six furnace areas were observed but no complete furnace was discovered – only the tuyères with what appeared to be an associated thick bowl-like structure in the north-east corner of the site. He considers that these remains of a furnace indicate a similarity with the furnace discovered at Melville Koppies, Johannesburg.

He notes that no fewer than six types of iron ore were found on the site but, in the main, there were two predominant types, viz. – a "limonitic göthitic ore" and an "ochrous limonite". A number of rusted iron fragments including iron beads were found.

Friede and Steel[11] state that the production of iron from ore involved a simple reduction process whereby the iron oxide (e.g. Fe_2O_3) is reduced to the metal by the agency of carbon monoxide (CO) produced by the burning of charcoal. Apparently the Bavendas were not as selective as other tribes being content to fell trees which were of no use otherwise, whereas wood used by other tribes included the "water berry", the "Cape beech", the "wild seringa", "mopane", "protea", "camel thorn" (mokala), "knob thorn" (mokhalo), "kaffir-thorn", "red bush willow" and "leadwood".

Air Supply: The early black smelters of South Africa used hand-made bellows to provide the air supply to the burning charcoal. These were of the skin (bag) type and were usually made of goat skin though, in some instances, antelope skins (particularly the skin of the sable antelope) were used.

The goats were skinned alive, the skin bag being obtained by starting the cutting at the hindquarters and pulling the skin over the neck of the animal. The skins were softened by scraping, pushing and stretching, but were occasionally rubbed with tree bark or cattle manure. The bag was then sewn together using sinew thread and "stitches" individually fastened to give a neat and strong seam. A wooden hand-valve, consisting of two slats or sticks was then fastened with leather thongs to the hindquarter incision of the skin bag, and a nozzle – usually an antelope horn (from waterbuck, sable antelope, eland or gemsbok) or an oxhorn was tightly bound to the neck end.

The art of producing the metal consisted in the art and endurance of the operator to work the bellows correctly.

The tuyères and the body of the furnace were made of clay.

The same authors describe furnaces which they constructed and operated at the University of the Witwatersrand to simulate conditions that were likely to occur with the early Black smelters' furnaces and after experimentation concluded, *inter alia*, "It appears from the results of analyses, tests and experiments that, in the African Iron Age, the smelting and forging of iron were complex processes, and it is

*"Mineral Resources of the Republic of South Africa", Fifth Edition, Handbook 7, Department of Mines, Geological Survey.

much to the credit of the smelters of that time that they could turn out, with the simple means available to them, relatively uniform, high-grade products in quantities sufficient for their needs".

In a subsequent publication by Friede[12] entitled, *"Iron-smelting Furnaces and Metallurgical Traditions of the South African Iron Age"*, he refers to the Early Iron Age as lasting from the 4th century AD to the 11th century AD and mentions that apart from the Broederstroom archaeological site, only a few Early Iron Age smelting sites have been discovered but state that by the 11th century AD iron production appears to have spread over wide areas of South Africa and many fairly well-preserved furnaces of this period have been found.

In collaboration with Professor C E Mavrocordates the results of metallographic investigations of Iron Age artefacts are given. Mavrocordates reported, amongst other considerations that "All the specimens consisted of pearlite structures. These varied from very large grains of coarse pearlite to fine pearlite, to small grains of fine pearlite".

He concluded that the blacksmiths produced implements by consolidating small "nuggets" of iron reduced from ore. The consolidated nuggets were then reheated and hot-worked to produce the final article.

During this reheating process, any excess carbon was oxidized, leaving lamellae with various amounts of carbon which was not uniformly distributed within the specimens examined.

No attempt at "quenching for hardening" was detected.

Alberts and Ortlepp[13] contend that iron ore was mined in Southern Africa by the Blacks for many centuries. They state that evidence of these mining activities has been found in places scattered throughout the Northern Transvaal, North West Cape, Zululand and Natal.

Apparently, these workings for iron ore were mainly for the following purposes:

(i) Obtaining ochre and specularite for making a paint which was used on the body and a powder for dressing the hair;

(ii) Mining ore, which was used specifically for smelting. Until recently the art of smelting was carried out by the Bavendas in the Northern Transvaal. The smelting operation was a mystic ritual and only the initiated were allowed to be present at a smelting operation.

Fairly extensive iron ore workings by Blacks have taken place at Thabazimbi where remnants of the stone and clay furnaces, slag and utensils were observed.

Krüger, Klein and Warden[14] have echoed the views of Alberts and Ortlepp and further, state that "The processes used by early Native smelters were those of primitive iron makers throughout the world".

First Conventional Blast-furnace in South Africa: Iron ore from Natal was used in the first small conventional blast-furnace built at Sweetwaters near Pietermaritzburg by S L Green. He smelted about two tons of pig iron according to Alberts and Ortlepp.[13]

In 1913 the first steel, melted from accumulated railway scrap was poured from a 10 ton open-hearth furnace of the newly founded Union Steel Corporation at Vereeniging.

Later in 1918 experimental blast-furnaces erected in Pretoria and Vereeniging successfully treated iron ore.

C F Delfos, after producing good foundry iron in his blast-furnace from Pretoria ores – was convinced that a large integrated steel works should be started. His strenuous efforts and representations eventually culminated in the formation of the South African Iron and Steel Industrial Corporation (ISCOR) by Act of Parliament in 1928.

Today the iron and steel industry includes the following producers:

(1) South African Iron and Steel Industrial Corporation (ISCOR), the largest producer, with plants at (i) Pretoria (the original); (ii) Vanderbijlpark (the second venture); (iii) Newcastle (South and North Works);
(2) Highveld Steel and Vanadium Corporation at Witbank;
(3) "Southern Cross Steel" of Middelburg Steel and Alloys, (the sole producer of stainless steel) at Middelburg, Transvaal;
(4) Dunswart Iron and Steel Works, Limited, at Dunswart, Transvaal;
(5) Scaw Metals Limited at Union Junction near Germiston, Transvaal;
(6) Union Steel Corporation, Vereeniging.

II. THE PRODUCTION OF IRON AND STEEL

(1) Production of Iron

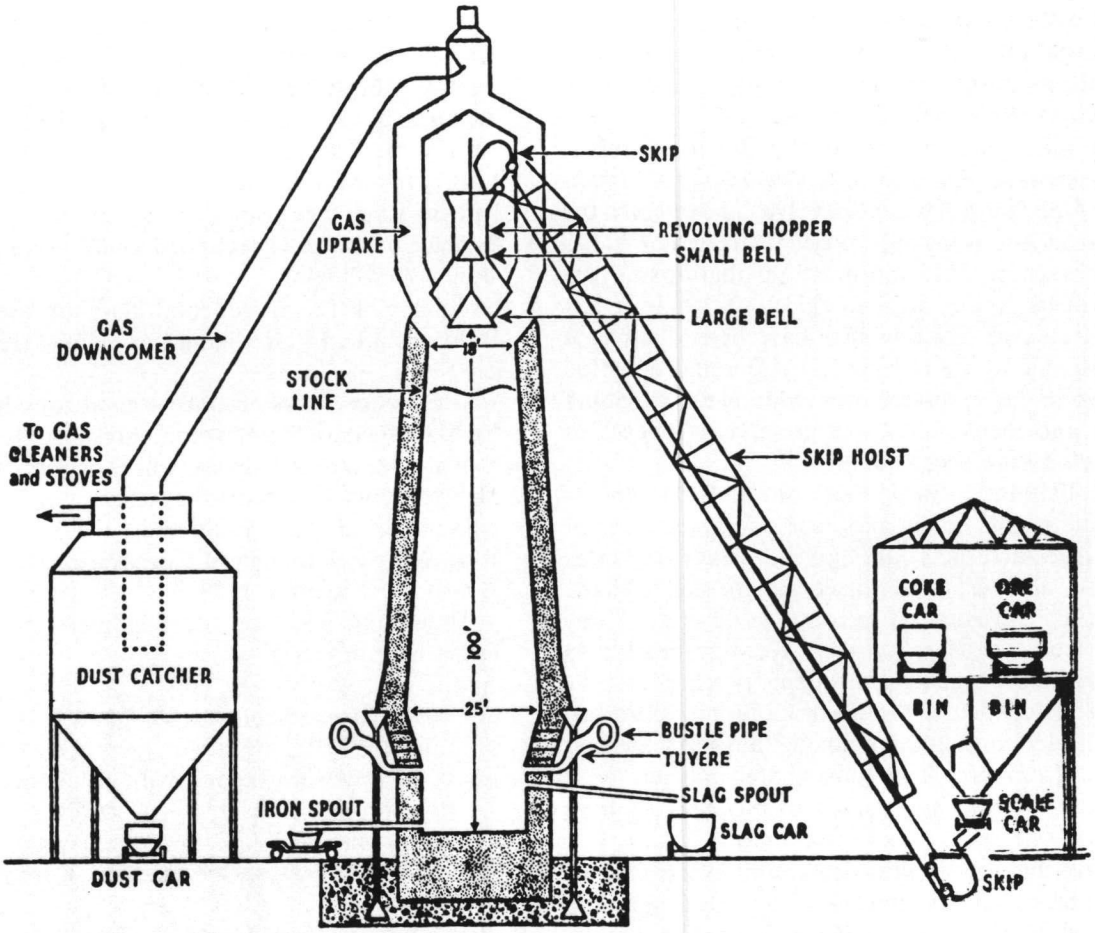
The first stage in the commonly adopted method of steel making is the reduction of iron ore to pig iron.

This is done by means of a blast-furnace which is a very efficient process unit for producing pig iron on a continuous basis.

The main economic iron-containing minerals have been indicated previously (q.v.) and include oxides and carbonates of iron.

Iron ore, limestone and coke are fed to the top of the furnace structure. Hot air is blown through the tuyères near the bottom. The high temperature needed for reduction of the ore to the metal is achieved by the reaction of the coke with the oxygen in the hot air blown into the furnace via the tuyères.

Reduction of the iron ore in the feedstock starts at a temperature of c. 400 to 450°C increasing as the charge descends. The limestone decomposes at 800°C



Sectional view of blast-furnace

into lime (CaO) and CO_2 combining with the silica and alumina impurities in the ore to form slag.

By the time the roasting mass has descended to the tuyères zone the decomposition is complete.

It should be noted that as the operation of the blast-furnace is continuous the molten iron which collects on the hearth of the furnace is tapped off and transferred to the steel furnaces or cast into sand or chill moulds to form "pigs".* The slag which is lighter than the molten metal floats as a layer on the top of the heated mass and, likewise, is tapped off when necessary.

Formerly, molten iron from the blast-furnace was run out of the furnace along channels to moulds made in the sands, known as "pig beds" from the notion that the sand beds resembled a sow suckling her young. In the chilling type of casting operation the molten metal is run into a pig casting machine. This consists of a series of moulds carried on an endless chain track. As the moulds fill and move along slowly they are sprayed with water to ensure that when they arrive at the discharge point the metal has solidified and the pigs are cool enough for discharge.

Constituents of Pig Iron: In the blast-furnace the iron absorbs carbon, silicon, manganese, sulphur, nitrogen plus all the phosphorus in the charge. Pigs are graded accordingly.

The gas emerging from the top of the blast-furnace during the operation is caused to flow into a gas cleaning plant.

Reactions in the Blast-Furnace: Bailey[15] states, that "Coke is the usual fuel and reducing agent in the blast-furnace, being first used in the early part of the eighteenth century, although charcoal is still used in a few cases. The amount of coke required depends on the ore and is somewhat under a ton per ton of pig iron produced".

A variety of reactions take place in the blast-furnace depending on the temperature and the feed-stock. The carbon monoxide produced by interaction of the coke with the oxygen in the air blown through the tuyères acts as a reducing agent but the coke, *per se*, also causes reduction of the iron oxides. Carbon is present in the blast-furnace iron as Fe_3C.

The porosities of the ores and also that of the coke are important in speeding-up the reaction rate. The porous iron ores are more rapidly reduced than hard

*Pigs are formed when iron is required in the solid form for further processing into different forms of iron or is to be used elsewhere for further processing into steel or alloys.

ones (cf. porous and hard haematites).

When the mixture of the ore, coke and limestone is fed in at the top of the blast-furnace the adsorbed and contained water of the feedstock are driven off by the hot gases rising through the stock column after which a number of reactions take place, viz. –

Reactions with CO (carbon monoxide):

(1) $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$
(2) $Fe_3O_4 + CO = 3FeO + CO_2$
(3) $FeO + CO = Fe + CO_2$
(4) $Fe_3O_4 + 4CO = 3Fe + 4CO_2$

Reactions with C (carbon):

(5) $3Fe_2O_3 + C = 2Fe_3O_4 + CO$
(6) $Fe_3O_4 + C = 3FeO + CO$
(7) $FeO + C = Fe + CO$
(8) $Fe_3O_4 + 4C = 3Fe + 4CO$

Different Types of Iron: Pig iron, cast iron, wrought iron and purer forms of iron such as ingot iron and electrolytic iron are produced.

Blast-furnace Slag: Blast-furnace slags consist essentially of calcium and aluminium silicates, a typical composition according to Dennis[16] being: 35 per cent SiO_2; 40 per cent CaO; 15 per cent Al_2O_3 and 5 per cent MgO. He states that the amount of iron lost in the slag does not, in general, exceed 0,5 per cent and is mainly present as oxide.

(2) Production of Steel

Steel is produced by a number of methods including the Bessemer, Open-Hearth, Electric Arc, Electric High Frequency (Induction), Crucible and Basic Oxygen Processes.

The Bessemer Process: In 1856 the Bessemer Converter, conceived by Sir Henry Bessemer came into being. This method of steel production is simple and was popular until about 1900.

The Acid Bessemer Process: In the Acid Bessemer Process as originally developed by Bessemer, the lining of the converter was composed of silicious material which rendered it unsuitable for pig iron conversion to steel when phosphorus was present in the pig iron.

In the process molten pig iron is refined by blowing air through an egg-shaped vessel known as a converter containing molten pig iron fed in from a ladle when set in a horizontal position. An air blast is then applied and the converter vessel turned to a vertical position. Oxidation of the impurities is rapid and the reaction self-sustaining, the heat evolved during the reaction being derived mainly from silicon. Thus the iron in the converter should have enough silicon – about one per cent for this purpose.

Oxidation reactions involved for the removal of manganese, for example, are as follows:

$2Fe + O_2 = 2FeO$
$2FeO + Si = 2Fe + SiO_2$
$FeO + Mn = Fe + MnO$
$SiO_2 + MnO + FeO = MnO.FeO.SiO_2$

For the elimination of carbon we have the following oxidation: $FeO + C = Fe + CO$.

The end of the reaction is signalled by the dropping of the flame which was initiated at the start of the blow.

The oxidation takes about 25 min.

The Acid Bessemer Process is still used for chrome steel, manganese steel, rails, grinding rods and balls.

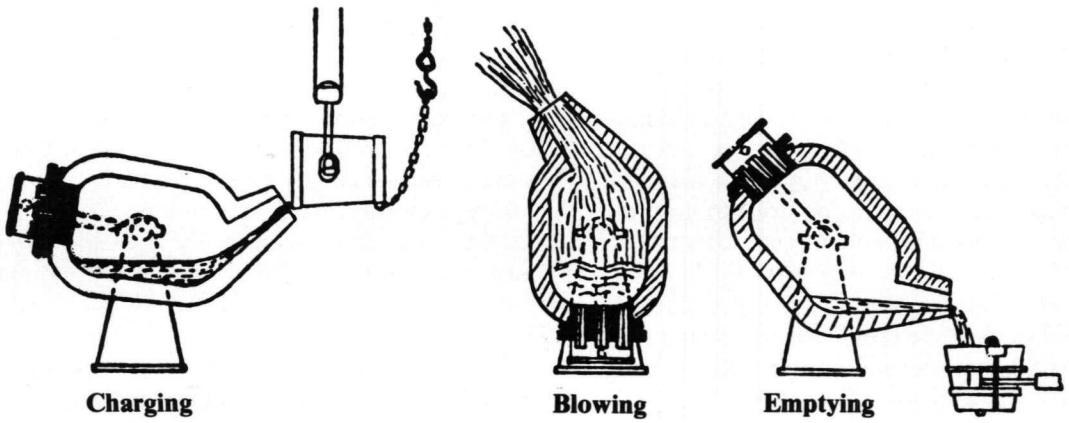
Only manganese and carbon are removed by this process.

The Basic Bessemer (or Thomas) Process: This process is favoured in Europe for making from suitable grades of pig iron, a cheap class of steel e.g. strip plates, structural units, etc. It is also used for the production of low carbon welded tubes.

In the Basic Process silicon, manganese, carbon, phosphorus and sulphur can be removed from the iron charge.

This process was invented by Thomas and

BESSEMER PROCESS



Charging **Blowing** **Emptying**

Gilchrest some 20 years after the advent of the Bessemer Acid Process. In this process, which removed phosphorus, the basic lining is made up of dolomite worked with tar to a thickness of some 30 to 50 cm (12 to 20 in.) to form the lining of the converter. Lime is added to form a slag with phosphorus.

Unlike the Acid Bessemer Process the end of the reaction is not signalled by the flame dropping but the blow continues in the form of an afterblow which lasts for about five (5) minutes. During this period dense brown fumes indicate the removal of phosphorus. In order to maintain an afterblow it is necessary to ensure a content of phosphorus of 1,5 per cent or more.

From the above it will be realized that for both Bessemer Processes (Acid and Basic) there is a restriction on the type of ore used for making the pig iron fed to the converter.

Unfortunately, steel produced by the Bessemer Process contains dissolved nitrogen to a greater degree than that produced by the Open-Hearth Process. However, the Oxygen Steam Process developed in 1950 overcomes this disability.

Open-Hearth Processes: According to information published by the American Institute of Mining and Metallurgical Engineers[17] ninety per cent of the steel produced in the United States in 1944 was the product of the basic Open-Hearth Furnace – the then most widely used metallurgical process in the United States.

However, since 1955 there has been a world-wide swing away from Open-Hearth Processes towards the Basic Oxygen Process.

In the Open-Hearth Process, both Acid and Basic, the heat necessary for melting and working the charge is supplied from a gaseous source, e.g. producer gas or a mixture of plant furnace and coke oven gas.

The Open-Hearth Steel Furnace is flexible as far as its capability to cope with varying quantities of steel scrap and pig iron are concerned, irrespective of the phosphorus and sulphur content of the charge.

However, the rate of production is slow but can be speeded-up by the use of oxygen. Nevertheless, the amount of fuel consumed is high.

The raw materials used are pig iron and scrap steel together with lime in the case of the Basic Process.

The Acid Open-Hearth Process is used for the production of higher grade carbon steels which are used for such purposes as axles, gun forgings, springs, mining drills, wire rope and when alloyed with nickel, chromium and tungsten for steels to meet the requirements of the automobile and aircraft industries.

The Basic Open-Hearth Furnace produces cheaper grades of steel to meet the requirements of mild steel users, free cutting steels, ingot iron and rimming steel.

The Electric Arc Process: Steel scrap is heated by means of an arc struck between carbon electrodes via the charge in a tilting-type electric furnace. Usually, steel scrap is melted under an oxidizing basic slag which is built up during melting thereby removing phosphorus and carbon. Removal of this slag and addition of a reducing slag containing lime, fluorspar, silica, carbon and/or ferrosilicon, effects removal of sulphur. Better control of the composition and temperature of the metal can be exercised than is the case with the Open-Hearth Furnace.

Crucible and High Frequency Methods: In these methods blister or cement steel, ferro alloys and scrap are melted in a crucible. In the Crucible Process, the crucible is heated by means of a coke fire or with producer gas.

The Electric High Frequency (coreless induction) Furnace consists of an acid or basic-type refractory crucible surrounded by a water-cooled unit of flattened copper tubing which acts as the primary for the high-frequency current. The frequencies may range from 500 to 60 000 cycles per second if necessary but the most common is 1 000 cycles per second.

When a high-frequency primary current is applied a heavy secondary current is induced in the charge in the crucible since the eddy currents increase according to the square of the frequency.

Since 1929 the use of induction furnaces for the production of special steels and non-ferrous alloys has expanded considerably. (In the mining industry induction furnaces are used for making diamond drill crowns.)

Basic Oxygen Process: In this process a basic-lined converter similar to that used in the Bessemer Process is used. But, in this method the melt is reacted with pure oxygen at very high velocities by the agency of a water-cooled lance which burns off the impurities in 20 to 25 min.

The popularity of this process in the United States away from previous addiction to the Basic Open-Hearth Method of steelmaking reached a stage in 1973 where Basic Oxygen Furnaces produced some 55 per cent of the total raw steel production. This is in contrast to 90 per cent for Basic Open-Hearth Furnaces in 1944 (*vide ante*).

Direct Processes for Steel Making: If a method can be devised whereby the iron ore is reduced in a solid state to iron then the use of the blast-furnace is no longer necessary.

Much thought has been given to this possibility and as far back as 1877 Siemens carried out investigations to evolve such a direct conversion technique. Since then many techniques have been developed of which only about five or so are in current commercial use.

Most of the direct methods make use of the fact that many of the reactions which take place in the blast-furnace occur in the upper (cooler) part of the furnace where the temperature does not exceed 800°C (*vide ante*).

At 800°C (red heat) the reaction $Fe_2O_3 + 3CO = 2Fe + 3CO_2$ for example, is substantially complete whereas decomposition of other minerals present does not take place.

Thus "sponge iron" can be produced by allowing hot iron ore to pass through a revolving kiln where a reducing gas e.g. producer gas is present. By this method the resulting sponge iron is free of nitrogen and other undesirable ingredients encountered in the blast-furnace production of pig iron.

Sponge iron, by itself, or in admixture with scrap iron can be melted in an electric furnace to produce "pigs".

Pitt[18] has described a number of direct reduction processes, including the following, – Hyl; Midrex; SL/RN and Lurgi; Krupp sponge iron. Pitt also describes, at the time of publication of his paper, processes still in the pilot plant stage of development, viz. – Armco; Purofer; Novalfer; Fior.

In the Krupp Sponge-iron Process lump iron ore or pelletized fines are fed to a rotary kiln by means of a heated travelling grate. At the same time coal, anthracite or coke breeze plus limestone or dolomite are also fed to the kiln. The kiln discharge is then cooled, screened through a 5-mm screen and the sponge iron removed by magnetic separation. The lime-coke-ash mixture is subjected to further screening and magnetic and gravity separation; the final tailings are disposed of.

Recoveries of 95 per cent Fe (metal) from haematite and 67,5 per cent (metal) from magnetite have been reported. The sponge iron recovered is then fed into an electric arc furnace.

Dealing with the future prospects of the Direct Reduction Method, Pitt[19] points out that one of the ways by which the steel industry can offset the shortfall of high quality scrap as the steel production escalates is to increase the usage of directly produced material.

Willars and Madden[20] have described the experiences of The Georgetown Steel Corporation, South California, USA in the use of a plant based on the Midrex Process.

They state that fluctuations in the cost and quality of scrap strongly supports the economics of using direct-reduced sponge iron.

A spinoff from the use of the Direct Process is the successful production of artificial rutile in a plant used by "Western Titanium" in Australia where fine-grained material is treated without any agglomeration being necessary.

In South Africa also, use has been made of such a method by "Richards Bay Minerals". The feedstock used is that recovered by Tisand (Proprietary) Limited, a company which dredges beach sands and dunes. A mixture of the economic minerals, viz. – zircon, ilmenite and rutile are recovered by gravity concentration using a Reichert Cone associated with the dredge.

Richards Bay Minerals comprise Tisand (Proprietary) Limited and Richards Bay Iron and Titanium (Proprietary) Limited.

The mining area at Richards Bay consists of a coastal strip some 2 km wide by 17 km in length. The annual saleable production, in metric tons, is of the order of the following: rutile, 56 000; zircon, 115 000; titania slag, 399 000; low manganese iron, 217 000; titaniferous magnetite, 130 000; non-pigment grade ilmenite, 280 000.

The mining operation which is carried out by Tisand (Proprietary) Limited is similar to that used in Australia. At the start a pond is excavated in the sand and filled with water. Floating dredges remove sand on one side of the pond and feed the sand to the floating concentrator (Reichert Cone) which then feeds the stacker boom which, in turn, deposits the tailings on the opposite side of the pond. The process is continuous resulting in the pond moving by about 1 to 3 m/day.

The mixed concentrate (some 2 000 t/h) is transported about nine kilometres by haulage trucks to the concentrator where this mixed concentrate is subjected to gravity concentration (cone and spiral techniques, wet and dry magnetic and electrostatic separation methods) to obtain concentrates of the heavy minerals present.

At this minerals separation plant ilmenite, rutile and zircon are recovered. The rutile and zircon are sold and the ilmenite fraction stock-piled for pyrometallurgical treatment.

Zircon is used, *inter alia*, in the steel industry as a mould lining in steel casting, for refractory bricks, for lining the side walls of steel ladles; it is also used as a refractory in glass and ceramics manufacture.

The titania slag known as "R.B. slag" produced pyrometallurgically has a TiO_2 content of the order of 85 per cent. Rutile, the purest titanium-containing mineral has a TiO_2 content of 95 per cent. Both these products are used by pigment manufacturers who produce pure TiO_2 of different particle sizes (grades) by either the sulphuric acid or chlorine routes. The TiO_2 powder produced which is white in "colour" is used in paints; incorporated in plastics and paper of quality grades. Its importance lies in the fact that it gives a very large surface coverage per unit weight of TiO_2.

The process of direct reduction, in general, is accomplished by way of a reducing furnace which may be a retort, fluidized bed, rotary kiln or crucible, and the reducing agent can be in the form of a solid, liquid or gaseous fuel.

There is no fusion of the iron in the reducing furnace as with a blast-furnace. After cooling, the iron can be recovered from the ash, etc. by magnetic separation.

III. WASTEWATER ARISINGS AND THEIR CONTROL

In Section II a brief survey of the iron and steel industry is given. From this it is necessary to set out the nature and extent of the effluents encountered and to indicate what techniques may be practised to prevent pollution of the water environment by such effluent arisings.

Water Requirements: In dealing with *"Pollution Control in the Steel Industry"*, Kemmer[21] states that in producing a finished ton of iron by means of a blast-furnace about 3,5 tons of air must be supplied to the blast-furnace and this amount of air produces about 5 tons of blast-furnace gas. On this basis the amount of air and gas exceeds the solid charge to the furnace and the products tapped from the furnace.

He states, further, "In order to produce 1 ton of finished iron in the normal iron-producing facility, the blast-furnace requires 150 tons of water. A troublesome by-product is the 0,2 ton of dust that contributes to air pollution".

Centi[22] in *"A Survey of Wastewater Treatment Techniques for Steel Mill Effluents"* states, "The water use is possibly the highest of any manufacturing industry and averages 3 000 – 40 000 gallons* per ton of finished steel".

Harrison[23] in dealing with *"Iron and Steel Works, Pollution Control: Water and Effluents"* refers to the statement by Darnell[24] that 200 tons of water are required per ton of steel in an integrated steelworks.

He gives figures for water consumption at the Appleby – Frodingham Works in the UK as follows:

	Steel Output 10^8 Ingot Tonnes	(Fresh Water & Plant Drainage) Total Water Consumption $m^3 \times 10^8$
1962	1,24	7,58
1972	1,44	7,11
1976	4,60 (estimated)	12,58 (estimated)

Martin,[25] in a discussion of papers on wastewater management presented at a conference on engineering aspects of pollution control, stated "That a water supply to steel produced ratio of 150:1 on a weight basis was needed. Approximately two per cent of the water is actually lost from the system".

On this basis the actual consumption would be of the order of 3 tonnes water: 1 tonne steel produced.

The processes involved in iron and steel making require large amounts of water for cooling purposes but the amounts consumed are, say, only two per cent of the total amount of water in the system.

Hence, the large amount of water in the system which should be cooled, treated, re-circulated – not used on a once-through basis, requires adequate treatment to ensure its satisfactory re-use. In quoting figures for water requirements per ton of iron or steel produced it is necessary to indicate what the amount of water quoted really connotes.

Heynike and Von Reiche, in a paper delivered at a conference of the Institute of Water Pollution Control (Southern African Branch) on 16th May 1968, cited the Kaiser Steel Company operating at Fontana near Los Angeles, USA and the Dunkirk Steel Works on the north-east seaboard of France both of which operate on limited supplies of water (In a separate publication Heynike quotes 1 400 US gallons per ton of steel for the Fontana Works).

For the Iscor Works at Pretoria Heynike and Von Reiche have quoted a figure of 1 100 gallons (5 m^3) per ton (2 000 lb or 909 kg) of steel produced and for Iscor's Vanderbijlpark Works they state that this Works was drawing 7 million gallons (31 822 m^3) of water per day and in 1968 they had reduced to 6,6 million gallons per day (30 004 m^3/day) which they state is equivalent to 1 250 gallons per short ton of steel. However, when making allowance for the water used by Black employees housed next to the works a figure of some 600 – 700 gallons per short ton (2 000 lb) of steel is obtained.

In dealing with the water requirements of the Vanderbijlpark Works Heynike[26] states that 30,2 per cent of the water is lost by evaporation, 58,7 per cent returned to the Vaal River as effluent and 11,1 per cent is polluted beyond permissible limits and is discharged into evaporation dams.

It seems clear that the amount of water used will depend on a number of factors, viz. –

(1) The extent of operations in processing the steel;
(2) The amount of water used for purposes other than steelmaking;
(3) The degree of salinity allowed in the final effluent discharge to meet Government effluent quality requirements;
(4) The nature of the receiving water for the effluent, e.g. river or sea.

Naturally, if a steelworks is allowed to discharge its final effluent into the sea and re-circulation of effluents within the works is practised to a considerable degree the daily demand of water can be substantially reduced.

At an integrated steelworks the principal sources of polluted water arisings are as follows:

Production Unit	Water Use	Nature of Effluent and adverse Constituents
(1) Coke ovens and by-products	Cooling for heat exchangers, gas cooling and washing	Heat, ammonia, phenol, cyanide, tar and tar oils

*This would seem to imply the total water in the system and not the water consumed.

(2) Blast-furnace	Cooling, gas washing, blowing	Heat, flue dust and sludge from gas washing
(3) Steel furnaces	Cooling and waste gas cleaning	Heat. High solids content
(4) Hot rolling and forging	Cooling, scale removal	Heat, oil, scale
(5) Cold rolling mills	Cooling	Oil emulsions and sludge
(6) Finishing processes, viz. –		
(i) Pickling and galvanizing	Pickling and rinse waters	(i) Spent pickle liquor, acid and alkali rinses
(ii) Electrolytic tinning	Pickling and rinse waters	(ii) Stannic, chromic, fluoride and cyanide wastes

From the above it will be seen that the principal wastes of the steel industry may be broadly categorized as suspended solids, oils, acids, metal salts and coke plant chemicals. Of these the coke plant effluents represent the greatest threat to the water environment since they include phenol, cyanides and ammonia.

Coke Oven Wastes: The production of metallurgical coke from coal can be carried out by two methods, viz. –

(1) The beehive coke process;
(2) The by-products process.

In the beehive process the admission of air to the coking chamber is regulated to enable burning of the volatile products distilled from the coal in the chamber and to generate heat to maintain the distillation while in the by-products method air is excluded from the coking chamber, the heat for distillation being supplied from the external combustion of fuel gases.

At present, practically all the metallurgical coke used in the industry is produced by the by-product process.

The Beehive Process: In this process, so called, a non-recovery oven was used. This has an arched roof resembling a beehive. Though popular at the beginning of this century beehive plants have fallen out of use principally due to the air pollution problems resulting and water regulating difficulties for optimum operation.

By-products Process: In the by-products process coal is converted to coke by heating the coal in the absence of air to a temperature at which the volatile matter is driven off and certain chemicals are recovered from the evolved vapour.

Silica brick ovens are used and heat is supplied by burning gas in conveniently placed flues.

A coking cycle lasts about 16 to 24 h and the residual coke at a temperature of about 900 to 1 100°C is ejected for quenching with water.

The volatiles are cooled using water spraying.

The principal liquid wastes discharged from a coke oven plant are ammonia still waste, coke quenching effluent, indirect cooling water, light oil recovery wastes, and final cooler overflow water.

The volume of still wastes is of the order of 50 ℓ/t of dry coal treated.

The final gas cooler (waste) water contains cyanide and thiocyanate compounds.

Effluent from the light oil recovery plant contains, *inter alia*, phenol, cyanide, ammonia and oil.

Heynicke[27] gives a typical average analysis of effluent from coke ovens, as follows:

pH Value	8,7
Chemical oxygen demand (C.O.D.)	1 800
Permanganate Value (PV)	1 040
Total ammonia as N	262
Total phenol as C_6H_5OH	500
Monohydric phenol C_6H_5OH	280
Thiocyanate as CNS	130
Total Dissolved Solids 180°C	500
5 Day B.O.D.	1 400

(All results expressed in mg/ℓ except pH value)

Harrison[23] gives the following results of analysis of effluents found on coking plants (due to Pearce and Punt[28]):

Constituent mg/ℓ	Decantation tank	Final cooler condensate	Benzole separator water	Oil generation plant separator water	Spent limed liquor
Free ammonia	1 070	308	994	85	840
Fixed ammonia	3 425	84	210	12	139
Monohydric phenols	1 750	2 750	159	137	1 260
Total phenols	1 774	—	—	—	—

Constituent mg/ℓ	Decantation tank	Final cooler condensate	Benzole separator water	Oil generation plant separator water	Spent limed liquor
Thiocyanate	464	93	161	99	315
Thiosulphate	400	69	736	Nil	384
Cyanide	8	196	2 736	104	4
Sulphide	56	46	472	100	42
Chloride	9 060	—	71	71	10 700
Permanganate Value (PV 4h)	3 920	5 600	730	730	3 410

Coal and Coke

Coal

Definition: Coal may be defined as a compact stratified mass of mummified plants of terrestrial origin which has been altered chemically over a diuturnity and is interspersed with certain amounts of inorganic material.

The initial transformation is to peat. This is then further transformed according to a time sequence as follows:

(1) Peat;
(2) Lignite (brown coal);
(3) Sub-bituminous;
(4) Bituminous;
(5) Sub-anthracite;
(6) Anthracite.

The above products in the process of coalification are collectively referred to as humic coals.

Two other types of coal are (1) cannel coal and (2) boghead coal. Cannel coal contains as main constituents, finely divided vegetable matters, spores, algae and fungal material, and sometimes, resin globules are present. Boghead coal consists of algal material, together with some fungal matter. Torbonite, the oil shale, is a typical boghead coal.

Coal is present in seams separated by rock bands of varying thickness. However, coal is not a pure substance of constant composition and mineral-like quality but an organic rock the composition of which changes as coalification advances.

In 1919 Marie C Stopes[29] proposed the following nomenclature for coal:

Vitrain: "A coherent and uniform whole, brilliant, glossy, indeed vitreous in texture."

Clarain: "Has a definite and smooth surface when broken at right angles to the bedding plane and these faces have a pronounced gloss or shine: the surface lustre is seen to be inherently banded."

Durain: "Hard, with a close, firm texture, which appears rather granulated to the naked eye; a broken face is never truly smooth but always has a fine lumpy or mat surface."

Fusain: "Occurs chiefly as patches or wedges; it consists of powdery, readily detachable, somewhat fibrous strands."

The above nomenclature has been fairly generally adopted for humic coals.

However, in the study of coal as a rock various constituents called macerals have been distinguished microscopically. (The macerals bear relation to coal (rock) that minerals in an ore bear to the ore-body.)

Van Krevelen and Schuyer[30] distinguish macerals as follows:

(a) Macerals whose origin is definitely due to wood and cortical tissue. This group includes, –
- Vitrinite: The principal coal maceral and primary constituent of bright coal. If a polished sample reveals a picture of woody tissue it is called telinite and when structureless it is called collinite.
- Fusinite: This is found in fossil charcoal and is cellular in structure. Physical appearance, dull black, hard but friable.
- Semi-fusinite: This is the transition stage from fusinite to vitrinite.

(b) Macerals whose origin is difinitely due to plant material other than wood tissue. This group comprises, –
- Exinite: The fossil remains of spores and cuticles. Exinite is a major ingredient of dull coal.
- Resinite: The fossil remains of plant resins and waxes. Found mainly in bright coal.
- Sclerotinite: The fossil remains of fungal sclerotia.

Francis[31] states that his experience of the use of methods of rational analysis has shown "that the usual range of chemical components in various rock types found in humic coals is as follows":

Usual Range of Chemical Components in Rock Types

Chemical Component (Maceral)	Rock Type			
	Vitrain %	Clarain %	Durain %	Fusain %
Ulmins (vitrinite, anthraxolyn)	90 – 97	70 – 95	20 – 80	33 – 66
Opaque matter (micrinite, opaque attritus)	Nil	0 – 5	5 – 50	Nil
Spores exines and cuticles (exinite, translucent attritus)	Nil	2 – 25	5 – 35	Nil
Waxes, resins and hydrocarbons (resinite)	3 – 9	3 – 10	3 – 15	0 – 2
Carbonized fibres (fusinite, micrinite)	Nil	0 – 2	0 – 10	66 – 33

Coking Coals

Only coals which have the power of caking and forming a residue of sufficient coherence are suitable for the production of coke.

Elsden and Griffiths[32] state "there is no simple relation between coking power and chemical composition, but it may be said that coals which are either very rich or very poor in hydrogen and oxygen do not melt or cake.

The coking property is probably determined by the presence in greater or less amount of certain compounds of carbon, hydrogen and oxygen, which at high temperatures are decomposed into volatile substances and carbon, the latter serving as a cement to bind the particles of the residue together".

Another view (due to Donath) ascribes the variation in behaviour as due to differences in the structure of the carbon substance and the arrangement of the carbon atoms within the molecule.

Elsden and Griffiths state that washed coking coal should not contain more than 6 per cent ash and 7 per cent water and point out that it is sometimes profitable to use a mixture of coals for the production of coke.

Metallurgical Coke: Gas coke is a by-product in the production of coal gas and so the main attention is in the direction of producing the right type of gas. However, in the production of metallurgical coke the emphasis is on the quality of the coke product. Metallurgical coke should be free of impurities such as sulphur and phosphorus to prevent these constituents from reporting in the pig iron produced in a blast-furnace.

Rank of Coal: The following table has been quoted by Plumstead:[33]

Coalification Process – Enacted by Time, Pressure and Heat

	Per cent			
	C	H	O	N
Wood	50	6	43	—
Peat	58,88	5,06	33,1	2,58
Lignite	70,97	4,35	23,1	1,16
Bituminous	81,37	5,37	10,1	1,91
Anthracite	92,91	3,09	2,41	0,91

Plumstead states that "The period between the initial burial of the peat bog under sediment and the ultimate mining of the coal is known as the "Dynamo-chemical stage". During this time a progressive metamorphism occurs involving both chemical and physical changes. The term 'Rank' as applied to coal is the degree of metamorphism attained during this stage. The chemical changes which accompany increasing rank are well known and may be summarized as a steady decrease of volatile matter and increase of fixed carbon. This is illustrated by the above table – which also indicates the progressive reduction of oxygen content".

Tests on Coal: Standardized methods have been devised (e.g. British Standard B.S. 1016 and A.S.T.M. Standards for coal and coke) for testing coal. Some of these are accurate methods such as the calorific value determination and others such as the determination of carbon, hydrogen, nitrogen and sulphur. On the other hand the "swelling index" is empirical in nature.

Normally, in coal analysis the following methods of analysis and testing are carried out, viz. –

(1) *Proximate analysis*, which involves the determination of moisture; volatile matter (carried out at 925°C) and fixed carbon.
(2) *Ultimate analysis*, which involves the determination of carbon, hydrogen, nitrogen and sulphur content.

Other determinations of importance are the calorific value (accurate) and swelling index (empirical).

Carbonization of Coal

The nature of the products resulting from the carbonization of coal depends on a number of factors, viz. – The type of coal and the type of coke oven or retort used; the temperature of carbonization; the rate of heating and the length of time of application of heat at a particular temperature.

If the temperature is kept low, with slow heating and rapid removal of volatiles the tendency will be for aliphatic hydrocarbons to be formed. Whereas, if high temperatures, rapid heating and long exposure of the volatiles to such high temperatures (above 700°C) take place the tendency will be for aromatic hydrocarbons and hydrogen to be formed.

Thus it is usual to refer to "low temperature carbonization" and "high temperature carbonization". In the former case a greater quantity of liquid products are produced and a smaller quantity of gaseous products. Whilst for high temperature carbonization little tar is produced and the amount of gaseous products is greater.

In addition to coke, the by-products recovered from carbonization of coal include ammonium salts, naphthalene, anthracene, cyanogen compounds, hydrogen sulphide, ammonia and nitrogen.

Low Temperature Carbonization: This term is given to processes in which coal is heated in such a way that the temperature of the partially-formed coke does not exceed 600°C. The resulting coke is used as a fuel for domestic and industrial purposes.

High Temperature Carbonization: Metallurgical coke is produced by heating (or "coking") certain types of bituminous coals at a high temperature out of contact with air in a coke oven at a temperature of 900°C and over (cf.). The solid residue is mainly carbon with minor amounts of hydrogen, nitrogen, sulphur and oxygen plus altered mineral matter originally present in the coal feedstock.

High temperature coke is used for metallurgical purposes e.g. in blast-furnaces and foundry cupolas.

Heynike[26] has drawn attention to the installation by Iscor of a dephenolating plant at its Newcastle Works. This, he states, was built and supplied by the Lurgi Company of Germany. This is a solvent extraction plant employing either butyl acetate or isopropyl ether.

The phenolic liquors are first filtered through gravel filters to remove oil and tar and then passed into a multi-stage extractor in counter current to the solvent. The solvent is recovered from the extracted phenol as well as from the dephenolized liquors. The phenol and solvent are separated by distillation whilst the separation of the solvent from the dephenolized liquor is achieved by gas stripping. The suppliers claimed an efficiency of up to 99 per cent.

Quality Limits for Water Use: Harrison[23] gives the following tolerable limits of quality for water used for various purposes, viz. –

	Boiler feed	Cooling			Processing	
		(a)	(b)	(c)	(a)	(b)
pH Value	10,8 – 11,0	8,0	7,5 – 8,0	8,0	8,0	8,0
Total dissolved solids	450	1 000	650	1 000	650	1 000
Suspended solids	3	5	10	20	5	20
B.O.D.	trace	5	5	5	5	5
C.O.D.	trace	5	5	5	5	5
Ammonia (NH_3)	0,5	1	1	2	1	2
Chloride (Cl)	40	200	200	250	200	250
Sulphate (SO_4)	250	400	200	400	200	400
Phosphate (PO_4)	0,5	1	1	2	1	2
Detergents						
(a) Anionic (as Manoxal OT)	Nil	0,3	0,3	1,0	0,3	1,0
(b) Non-ionic	Nil	0,3	0,3	1,0	0,3	1,0
Total hardness as Ca CO_3	5	600	300	650	400	650
Any other constituent (e.g. Fe, Mn)	trace	2	2	5	2	5

All the results (except pH value) expressed as mg/litre.

Cooling (a) Once-through systems (no direct contact with product);
(b) Re-circulating systems;
(c) Direct contact (e.g. quenching).

Processing (a) Sulphate of ammonia production;
(b) Moistening of sinter mix.

Note: Harrison states that the levels given in the foregoing table do not represent ideal water quality, but rather the quality of water which can be effectively used. A water which is free from scale-forming, corrosive, and foaming tendencies or which can be made to comply fairly readily with these criteria is the requirement of the iron and steel industry.

From the foregoing it will be realized that there is a limit to the amount of re-cycling of effluents that can be practised at an iron and steel works.

Use of Purified Sewage Effluent: On the other hand, Wolman[34] described his experience with The Bethlehem Steel Company of Sparrows Point, Md. USA, a subsidiary of the Bethlehem Steel Company which operates plants in several localities on the United States Atlantic Seaboard.

The Sparrows Point facility's water supplies, derived from underground sources, were attenuating considerably and the company negotiated with the city of Baltimore to use purified sewage effluent from the city's Back River Sewage Treatment Works at its steel works.

Wolman states that field observation throughout the US indicated that the following characteristics determine a desirable quality of water for steel manufacture, viz. –

(1) Temperature preferably below 75°F.
(2) Chlorides preferably below 175 mg/ℓ.
(3) pH Value between 6,8 and 7,0.
(4) Hardness below 50 mg/ℓ.
(5) Suspended matter below 25 mg/ℓ.
(6) Organic content as low as possible.
(7) Corrosion potential at the lowest possible limit.

Two sewage treatment plants constitute the Back River Sewage Treatment Works, one using biological filtration and the other activated sludge treatment.

The Bethlehem Steel Company uses the activated sludge plant effluent without additional treatment save for continuous chlorination at a dosage of 5 mg Cl/ℓ. The effluent from the biofilter plant, however, is further processed by chemical precipitation with alum.

In order to reduce and control the chloride concentration a survey of the industries in Baltimore was carried out to eliminate intermittent or slug discharges of effluents containing high concentrations of chloride e.g. from meat pickling and packing, salting of hides, salt water discharges from zeolite water softening plants and salt water from harbour infiltration at breaks in low-lying sewers.

By eliminating some of these sources, peak concentrations in excess of 175 mg Cl/ℓ were eliminated.

At the end of 1947, 65 million gallons per day of effluent were made available – made up of 50 million gallons per day of chemically processed biofilter effluent and 15 million gallons per day of activated sludge plant effluent.

From the above experience at Sparrows Point, Maryland it would seem possible, in certain situations, to use purified sewage effluent as process water at iron and steel plants. At least this possibility in South Africa needs pursuing further. It is practised, to a minor extent by the Highveld Steel and Vanadium Corporation at Witbank.

Disposal of Effluents

Wastewater from Coke Ovens: The volatiles produced in the coking of coal, as has been stated earlier on, include ammonia, benzene, xylene, toluene, naphthalene and phenol, some of which may be recovered to advantage.

In the recovery process, the coke oven gas is washed with water thereby producing a weak ammonia liquor which after treatment with sulphuric or hydrochloric acid will contain, correspondingly, ammonium sulphate or ammonium chloride. Apart from this the wastewater will be highly coloured and will also contain phenol, cyanide and thiocyanate.

Even after vapour re-circulation or solvent extraction methods have been used it will be found that up to 25 per cent of the phenol and up to 10 per cent of the ammonia and cyanides will still be retained in the wastewater.

Most of the water used in coke production is for cooling purposes. However, the wastewaters from process operations are strongly contaminated and difficult to handle and this situation can be aggravated from time to time when leaks in the pipe circulating system occur due to faulty plumbing, corrosion of pipework or failure of the plant fabric due to inappropriate steel having been used in the construction thereof.

Strong concomitant pollution resulting from the processing include spent acid from washing the light oil, spent sodium hydroxide from the neutralization procedure and spent absorber solution (e.g. sodium carbonate) used for removal of sulphur when such is necessary.

The quality of this wastewater may be improved by treatment in either an activated sludge plant or a biofiltration plant. Alternatively, where extensive suitable land is available the effluent, after settlement in a series of large ponds can be spray-irrigated on grassland which requires to be treated with gypsum on a regular basis. Provision requires to be made also to prevent pollution of any nearby watercourses due to surface runoff particularly during rainstorms and from seepage. Careful monitoring of the land surrounding the irrigated area requires to be carried out on a systematic basis.

Wastewater from Blast-Furnaces: The wastewater from the operation of a blast-furnace is derived mainly from the use of water employed for washing the exit gases which contain suspended matter.

Thus this wastewater will contain suspended solids (up to 3 000 mg/ℓ), phenol, cyanide and ammonia and the concentration of the last three constituents will depend on whether the coke used in the blast-furnace has adsorbed constituents and "carry-over" of still waste in the water used for quenching of the coke.

The suspended solids in the wastewater from a blast-furnace may be considerably reduced by sedimentation (down to 100 mg/ℓ) and with the prior addition of flocculants the suspended solids may be reduced to c. 25 mg/ℓ after settlement.

Wastewater from Acid Pickling: Removal of undesirable surface oxides from steel is carried out by treatment with acid (sulphuric or hydrochloric). The treatment of steel in an acid bath is called "pickling". In the pickling process the iron oxide coating on the metal is dissolved yielding ferrous sulphate or ferrous chloride (depending on the acid used) and the bare surface of the metal is exposed thereby making the steel, so treated, suitable for finishing operations such as plating, galvanizing, electrolytic tinning, etc.

Pickle liquors present a serious problem only secondary to coke oven and blast-furnace wastewaters. Pickling may be done either batchwise or as a continuous process. Usually the acid used has a strength of 5 to 15 per cent. As pickling proceeds there is a build-up of iron compounds in the bath and the strength of the acid is reduced. When the acid becomes somewhat spent the contents are either dumped or re-processed to recover iron and ferrous sulphate. In some cases this is done on a continuous basis.

The metal on removal from the pickling bath will have some of the liquor associated with it which will report in the effluent after rinsing and neutralization. The loss of acid by such "drag-out" can be as high as 20 per cent of the acid used.

Heynike[26] states that, "Of the several acid recovery systems marketed, the most efficient one appears to be the vacuum cooling/crystallization process which produces uniform cooling to temperatures down to zero. This process ensures consistently high ferrous sulphate heptahydrate formation – low solubilities being obtained at low temperatures . . .".

Heynike[26] states, further, that at a Lurgi Acid Recovery Plant which was used successfully at the Vanderbijlpark Works from 1966 to 1969, up to 40 t/d of the heptahydrate were produced, but there was little demand, at the time, for this product.*

This sulphuric acid pickling plant and associated recovery plant was shut down and was replaced by a HCl pickling unit.

Wastewater from Hot Forming: In the methods used whereby an ingot is transformed through all the hot forming, reducing, shaping, rolling, etc. stages to produce the final product considerable volumes of wastewater are produced.

High-pressure water is used to remove scale and for flushing flumes, etc.

The wastewater resulting from this intense application of water contains suspended solids and emulsified oil. This wastewater may be treated by settling which results in some of the oil adhering to the scale particles settling with the scale. Further unadhered oil may be removed by the aid of suitable skimmers.

This combined treatment results normally, in an effluent containing 100 mg/ℓ suspended solids and with effluent settlement this can be reduced to 40 mg/ℓ and an oil content of about 15 mg/ℓ.

Wastewater from Cold Finishing: Cold finishing operations include pickling, cold rolling, tin plating, galvanizing, in fact coatings of all types. Cold shaping includes cold drawing of wire rods and other shapes, nuts, bolts (screw and nail making), etc.

Pickling wastes have already been dealt with (q.v.). The remainder of the finishing operations give rise to wastewater resulting from the use of water for cooling hot metal arising from heat due to friction (e.g. drawing of wire) and in the case of cold rolling and reducing operations friction takes place between the strip and the rolls. This heat load is controlled by a system of "flood lubrication" in which oil or oil/water emulsions are jetted against the roll and the steel surface or alternatively high pressure water may be directed on the rolls and oil on the steel being processed.

In some cases, a once-through system is used and in others the wastewater is re-circulated – which, of course, has to be replenished when the circulating load of solids and oil becomes too great, in which event, the spent mixture must be suitably disposed of.

Plating and coating operations can give rise to wastewaters containing, *inter alia*, tin, chromium, cadmium, zinc, nickel metals as well as cyanides, acids and alkalies. However, these wastewaters are mainly rinse waters but a check needs to be kept on the concentration of these heavy metals to ensure that the final combined effluent from the iron and steel works, the amounts present in the effluent, do not exceed the limiting values set by Government legislation.

Fluoride: A disturbing feature in the production of steel these days is the use of fluoride (e.g. fluorspar). Fluoride is added to slag in the electric arc furnace

*There is now a possible outlet for these salts for addition to sewage effluents, in "sensitive areas" to remove phosphate in order to prevent eutrophication of water impoundments and rivers.

and also to moulds for the molten metal in casting. This has often reported in the effluents in concentrations well above the statutory limit of 1 mg F/ℓ which is the drinking water limit. Every effort should be made to prevent the escape of fluoride to the water environment or better still, the use of an alternative chemical(s) in substitution for fluoride should be investigated to remove this threat to the water environment.

REFERENCES

1. Newton Friend, J. *"Man and the Chemical Elements"* (From the Stone-age Hearth to the Cyclotron), Charles Griffin and Company Limited, London, 1951, (a) p. 7; (b) p. 253; (c) p. 260; (d) p. 267.
2. Mellor, J.W. *"Modern Inorganic Chemistry"*, Longmans Green and Co., London, 1925, p. 586.
3. Richmond, I.A. *"Roman Britain"*, Penguin Books, Ltd., Harmondsworth, Middlesex, England, 1964, p. 159.
4. Raistrick, A. *"Industrial Archaeology"*, Granada Publishing, London, 1979, (a) p. 9; (b) p. 29.
5. Clure, H.F. *"Roman Ironworks in Britain"*, British Steel, 1969, March, pp. 6 – 9.
6. Scott, W.D. *"An Introduction to Geology"*, 3rd Edition, Vol. I, The Macmillan Company, New York, 1932, pp. 531-532.
7. Du Toit, A.L. *"The Geology of South Africa"*, Oliver and Boyd, Edinburgh, 1939, p. 471.
8. Mountain, E.D. *"Geology of South Africa"*, Books of Africa, Cape Town, 1968, p. 214.
9. Hamilton, G.N.G. and Cooke, H.B.S. *"Geology for South African Students"*, Central News Agency Ltd., South Africa, 4th Edition, 1960, p. 360.
10. Mason, R.J. *"Early Iron Age Settlement at Broederstroom 24/73 Transvaal, South Africa"*, *S. Afr. J. Sci.* 1981, 77(9) pp. 401-414.
11. Friede, H.M. and Steel, R.H. *"J.S. Afr. Inst. Min. Metall."*, June, 1977, pp. 233-241.
12. Friede, H.M. *"J.S. Afr. Inst. Min. Metall."*, August, 1979, pp. 372-381.
13. Alberts, B.C. and Ortlepp, J.A.L. *"Trans. Seventh Commonwealth Mining Metall. Congress"* Vol. II, S. Afr. Inst. Min. Metall, 1961, p. 855.
14. Krüger, C.M., Klein, E. and Warden, C.P. *"Trans. Seventh Commonwealth Mining Metall. Congress"* Vol. III, S. Afr. Inst. Min. Metall., 1961, p. 1057.
15. Bailey, A.R. *"A Textbook of Metallurgy"*, Macmillan and Co., Ltd., London and New York, 1960, p. 327.
16. Dennis, W.H. *"Extractive Metallurgy"*, Sir Isaac Pitman and Sons, Ltd., London, 1965, p. 202.
17. Seeley W. Mudd Series, *"Basic Open-Hearth Steelmaking"*, Physical Chemistry of Steelmaking Committee, Amer. Inst. Min. Metall. Engnrs., 1944.
18. Pitt, R.S. *"Direct Reduction of Iron Ore"*, Part I, Iron and Steel International, June 1973, pp. 242-251.
19. Pitt, R.S. *"Direct Reduction of Iron Ore"*, Part II, Ibid, August, 1973, pp. 347-353.
20. Willars, H.M. and Madden, R.C. *"The Development of a New Steelmaking Process Utilizing Highly Metallized Sponge Iron"*, Iron and Steel International, August 1975, pp. 313-321.
21. Kemmer, Frank N. *"Industrial Pollution Control Handbook"*, Editor-m-Chief, Herbert F Lund, McGraw Hill Book Company, 1971, Chapter 10.
22. Centi, Thomas J. *"The Steel Industry and the Environment"*, Edited by Julian Szekely, New York, Marcel Dekker, Inc., 1973, pp. 169-170.
23. Harrison, J.L. *"Steel Times"*, September 1975, pp. 313-321.
24. Darnell, H. *"The Iron and Steel Industry and the Environment"*, Metals and Materials, January, 1974.
25. Martin, J.R. *"Future Trends in Water Treatment in the Steel Industry"*, *Steel Times*, 1975, 203(8), 678.
26. Heynike, J.J.C. *"Some Aspects of Water and Effluent Management in the Iron and Steel Industry"*, Paper presented to 1976 Conference of Inst. W.P.C. (Southern African Branch), Durban, 1976.
27. Heynike, J.J.C. *"Water and Effluent in the Iron and Steel Industry"*, Paper presented to Conference of CSIR, Pretoria, 21 – 25 October, 1963.
28. Pearce, A.S. and Punt, S.E. *"The Biological Treatment for Removal of Toxic and Noxious Substances in Aqueous Effluents"*, Symposium on Water Pollution – Its Control in the Iron and Steel Industry, North Lindsey Technical College, Scunthorpe, October, 1973.
29. Stopes, M.C. Proc. Roy. Soc. (London), B1919, **90**, 470.
30. Van Krevelen, D.W. and Schuyer, J. *"Coal Science"*, Elsevier Pub. Co. Amsterdam, London, New York, Princeton, 1957, p. 53.
31. Francis, W.F. *"Coal, its Formation and Composition"*, Edward Arnold (Publishers) Ltd., 1954, p. 286.
32. Elsden, J.V. and Griffiths, J. *"Analyses of British Coals and Coke"*, The Colliery Guardian Company Ltd., London 1924, p. 3.
33. Plumstead, Edna P. *"Coal in Southern Africa"*, Witwatersrand University Press, 1957, partially reprinted from *"Coal, Gold and Base Minerals"*, Oct., Nov., Dec. 1956 and Jan. 1957.
34. Wolman, A. *J. Water Poll. Control Fed.*, 1948, XX(1), pp. 15-21.

15(4) TANNING AND THE TREATMENT AND DISPOSAL OF TANNERY EFFLUENTS

TANNING

Definitions: *Tanning* may be defined as "processing whereby putrescible raw hides and skins are converted into leather".[1]

"Leather" is defined as hide or skin which still retains its original fibre structure more or less intact, and which has been treated so as to be imputrescible even after exposure to water. The hair or wool may or may not have been removed. Certain skins, similarly treated or dressed, and without fur removed are termed "fur".[2]

The epithelial covering of cattle is referred to as hide and that of sheep, lambs, goats and pigs as skin.

Fellmongering is primarily concerned with the removal of wool from sheep skins for use in the textile industry. Fellmongered sheep skins are subsequently used for leather manufacture.

Apart from the mechanical operations and manipulations necessary, the tanning process as such is basically chemical and to understand the process and the nature of the resulting wastewater arising from the operation of a tannery it is necessary to have a clear understanding of hide and skin structure and the chemical transformation of the derma or corium layer into leather. A colloid-chemical theory of tanning was set out by Procter[3(a)] in the *"First*

Report on Colloid Chemistry and its General and Industrial Applications" (British Association for the Advancement of Science) and Procter and Wilson[3(b)] reported on *"Collagen and Gelatin"* in the Fifth Report.

However, due to subsequent knowledge gained in the field of chemical bonding, tanning has been explained in relation to its effect on the collagen fibrils, as follows:

(1) Vegetable tanning – by hydrogen bonding;
(2) *Chrome and alum tanning – by olation (i.e. bridging by OH groups);
(3) Tanning with syntans (e.g. of the naphthalene sulphonic acid type) – electrovalent bonding.

Shuttleworth[4(a), 4(b), 4(c), 4(d)] has given extensive reviews of the theories of chrome tanning and vegetable tannage as well as the *modus operandi* of syntans.

Structure of Animal Hide and Skin

The outer covering of the animal body consists essentially of two main layers, the surface epithelium or epidermis and the subjacent dense connective tissue layer – the skin proper or the corium or derma.

Although the skin structure varies greatly with species and the locations on an individual hide or skin certain broad generalizations are possible.

The *epidermis* usually forms about one per cent of the total thickness of the two layers, viz. – epidermis and derma or corium. In hides and skins received in practice by the tanner a third layer may be present, the fascia or fleshy material which properly belongs to the body of the animal.

The epidermis[5] is a stratified squamous epithelium, the external surface of which hornifies and forms a resistant surface. It is not easily moistened and prevents the underlying tissues from drying and so serves as a protective layer on the animal body. It is a thin layer of bloodless cells which receives nourishment from the blood vessels of the derma. As the cells reproduce, the older ones are pushed outwards, gradually die and become dry and scaly, easily rubbing off. At the bottoms of pockets or follicles the hairs grow through this layer. The "sebaceous" or oil glands, and the "sodoriferous" or sweat glands drain through the tubes which also penetrate the epidermis.

The *derma*[5&6] consists of a reticulated fabric of closely interwoven, and to some extent intergrown, fibres and the protein collagen. Blood vessels, nerves and fat cells are situated throughout the fibre network while the binding protein, elastin, is also present in the upper and lower layers of the derma. The upper layer of the derma is dense and chemically resistant, forming the "grain surface of leather".

Burton and Reed,[7] in a review of the interfibrillary material in hides and skins, have stated that certain investigators regarded the cementing substance to be mucoid in character whilst others considered that the bulk of interfibrillary material consisted of globular proteins. They further stated that Day[8] had concluded that hyaluronic acid of the interfibre fluid coats the collagan fibrils and renders them water repellent but Meyer,[9] researching in the medical field, had shown that chondroitin sulphate is more firmly bound to the skin. There is a considerable amount present at the junction of the epidermis and the corium or derma and in parts of the skin which are rich in elastic tissues. It has been shown that mucolyte enzymes are much more efficient in removing the cementing material than solutions containing lime and sulphide and they leave the fibre structures in a well-opened-up condition ready for tanning without the usual subsequent treatment with tryptic enzymes.

Loeb[10] called attention to the fact that pepsin digestion occurs in nature in an acid medium. The reason for this connection of an acid reaction with pepsin digestion was cleared up by Northrup,[11] who found that the hydrogen ion concentration at which pepsin commences to act as a protein always occurs on the acid side of the iso-electric point of the protein.

On the other hand, trypsin digestion occurs generally in an alkaline medium. Northrup has shown that the hydrogen ion concentration at which trypsin commences to act as a protein varies also with the iso-electric point of the protein, and that the digestive action of trypsin occurs on the alkaline side of the iso-electric point. If this mucoid material is not completely removed before tanning it remains in the leather and interferes with the dyeing, particularly where uniformity of colour of the leather in pale shades is necessary.

Enzymes (such as pepsin and trypsin referred to above), may be defined as definite material catalyzers of organic nature with the specific powers of reaction, formed by living cells, but independent of the presence of the latter in their operation (i.e. they may be regarded as organic catalysts).

Hydrogen-ion Dependence: The enzyme pepsin is mainly found in the mucous membrane of the stomach and is secreted together with the stomach juice. Its action is pH dependent (cf.) and operates best in the digestion of protein such as egg albumin at a pH value of c. 1,5. Trypsin is the principal proteolytic enzyme of the pancreas from which it is excreted from this organ with the pancreatic juice in the intestine. This pancreatic secretion is slightly alkaline. With peptone as substrate this tryptic enzyme operates at an optimum pH value of 8,0.

*By coordination bonding of the carboxyl side chains of the collagen molecule by chromium or aluminium complex ions linked by olation (i.e. bridging of OH groups).

Gelatin, Glue and Leather

Gelatin, glue and leather form the major commercial products derived from animal hides and skins (and in the cases of gelatin and glue – from ossein, the protein of bone also). The behaviour of the different layers of the hide or skin towards chemical reagents is important since in leather, gelatin and glue manufacture the epidermis and fascia layers must be removed and only the derma used.

Gelatin and glue differ essentially in the quality of the raw material used and the attention and care given in the preparation. Edible gelatin may be prepared from a number of selected clean collagen and ossein-containing materials including calves heads, bone, tanyard cuttings, etc. In producing photographic gelatin care must be taken to avoid contamination with metals.

The Tanning Process

The objectives of tanning are to render hides and skins resistant to decomposition or bacterial decay, particularly when wet; to achieve specified physical properties in the tanned hides and skins such as tensile strength, flexibility, resilience, abrasion resistance; and to render leather insoluble in water at relatively high temperatures. Untanned hide or skin material becomes soluble at 60°C, whilst many types of leather remain stable at the boiling point of water (100°C).

Vegetable and Mineral Tanning

The oldest method of tanning was carried out using extracts of vegetable material containing tannin or tannic acid but in recent times vegetable tanning has been superseded to a significant extent by mineral tanning – mainly chrome tanning, although for certain types of leather vegetable tanning is used, e.g. in the production of sole leather and belting.

Tannin-bearing Materials

Tannin (or tannic acid) is present in many forms of plant life. Originally, tanners used oak bark for tanning.

The tannins occur in the bark of certain trees, nut galls and the roots and leaves of certain plants.

Aqueous extracts which can be used are derived from the following:

Oak bark;
Myrobalan (dried fruit of *Terminalia chebula*, India);
Valonia (acorn cup of *Quercus aegelops*, Asia Minor);
Sumach (leaf of *Rhus coriaria*, Sicily);
Cutch (extract of wood of *Acacia catechu*, India and Burma);
Divi-divi (pod of *Caesalpinea coriaria*, S. America);
Hemlock bark (*Abies canadensis*, N. America);
*Wattle bark (mimosa) (*Acacia pycnantha*, S. Africa, India);
*Quebracho bark (Quebracho, Colorado);
Hamameli tannin (from the bark of *Hamamelis virginica*);
Oak (*Quercus*) galls;
*Chestnut bark; Mangrove bark.

Tannins

The tannins are complex compounds of high molecular weight and, in general, may be regarded as condensation products of aromatic phenolic acids particularly gallic and protocatechuic acids which can be obtained from them by hydrolysis.

Perkin, on the one hand, considered there are three groups of tannins, viz. –

(1) Gallotannins (also used in the manufacture of inks – together with iron salts);
(2) Ellagitannins; and
(3) Phlobatannins or catechol tannins.

Freudenberg on the other hand, divided tannins into two groups, viz. –

(1) Those which are esters in character and are broken down by hydrolysis (In most cases such tannins are derived from gallic acid e.g. Chinese and Turkish tannins as well as Hamameli tannin);
(2) Condensed tannins which are not esters. (e.g. wattle and quebracho).

Gallic acid according to Karrer[12] is one of the most widely encountered plant acids. Gall nuts, blue galls, divi-divi, sumach, tea leaves, oak bark, pomegranate etc., he states, always contain some free gallic acid. He further states that it occurs in particularly large amounts as esters or glucosides in the substance known as tannin.

The conversion of skin (or hide) into leather is an art dating back a considerable number of centuries of time. Whilst the durability of wet raw hide can be measured in days or weeks, Roman footware has been dug up which is hardly of worse condition than the modern worn-out discarded varieties of modern times encountered on the roadsides from time to time. The art of leather manufacture was practised by the American Red Indians who tanned the buffalo skins by rubbing the brain of the animal onto the dried skin.

The substance commonly known as tannic acid or gallotannin is a colourless non-crystalline solid of high molecular weight. On hydrolysis it yields gallic

*However, the main vegetable tanning materials of present-day commerce are wattle, quebracho and chestnut.

acid and glucose in the proportions of 10 molecules to 1 respectively.

Desha[13(a)] considers it is a glucoside in which each of the five hydroxyl groups of glucose is esterified by 1 molecule of digallic acid.

Roux and Evelyn[13(b)] state that tannins comprise 61 to 62 per cent of mimosa (wattle) extract. They consider them to be a complex mixture of flavanoid polymers based mainly on the flavan structure with molecular weight within the range 550 – 3 250.

More recently Roux[13(c)] has concluded that the polymeric mimosa extract molecules are composed exclusively of flavan-3-ol units. Further, he has extracted and characterized the biflavanoids and triflavanoids from mimosa bark.

According to Riegel[14] tanning materials may vary in tannin content from 3 per cent in chestnut wood to 30 per cent in the dried myrobalan fruit.

Commercially used extracts, however, may have a tannin content as high as 68 per cent.

The catechol-type tannins, on heating give rise to the parent substance catechol 1,2-dihydroxy benzene and this together with iron salts give a greenish-black coloration.

The pyrogallol-type tannins give rise to pyrogallol on heating and with iron salts give a blue-black colour. The hydrolysable tannins are associated with sugars which on fermentation give rise to organic acids whilst the catechol tannins require the addition of acids in tanning.

Syntans

Synthetic tanning materials "syntans" have been applied successfully. These include cresols, naphthalene and higher hydrocarbons (e.g. the Neradols (D and ND) can be respectively produced by the condensation of cresol and naphthalene sulphonic acids with formaldehyde).

The polyphenolic syntans were intended as a replacement for the natural vegetable tannins. However, they cannot compete, on price, with the natural variety and so the tendency is to use syntans in combination tannages, e.g. following chrome tannage. They are used to control leather fullness, area yield, colour and electrical charge of the leather prior to dyeing and fat-liquoring which operations are affected by the charge.

Plumping agents

Water-soluble melamine-formaldehyde and other resins are used prior to the finishing process to render the leather more receptive to the finishing agents and result in a firmer and fuller finished leather.

Properties of Leather

Apart from the properties indicated previously, leather possesses a common physical property namely water vapour permeability which is attributable to the internal action of the fibres in the leather and to surface evaporation. The principal hides or skins used in the manufacture of leather are cattle hides, calf skins, goat and kid skins, sheep and lamb skins. These categories represent over 90 per cent of the world's production of leather. Other hides and skins processed commercially include horse, pig, kangaroo, deer, alligator, lizard, snake, seal and walrus. In the Republic of South Africa many types of game skins are tanned e.g. crocodile, ostrich, elephant and antelope of various types (e.g. kudu, impala, etc.).

Hides and skins arriving at a tannery may have been cured by baking in the sun, salting or conserved with short-term biocides. The curing processes involved are practised to eliminate the danger of decay by removing the natural moisture of the hide or skin by creating a medium in which the bacteria cannot live.

However, salted hides are no longer in favour in South Africa in inland regions since the salt (NaCl) remains in the wastewater discharged from a tannery and if discharged into the sewerage system of a local authority, the salt will eventually reach a river and may make such river water unfit for irrigation of certain crops (notably tobacco and citrus) as well as altering the tilth and permeability of the soil by increasing the Sodium Adsorption Ratio (SAR). The SAR is represented mathematically as follows:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where the concentrations of the ions Na^{+}, Ca^{++} and Mg^{++} are expressed in milliequivalents. The SAR values of irrigation waters should not exceed 8 to 10.

Tanneries may deal with green hides, i.e. hides substantially as removed from the animal, or cured hides (e.g. salted, biocide treated). Initially, at the tannery it is necessary that the hides are thoroughly hydrated. This is achieved by soaking in water and adhering blood and dirt are removed by washing. Green hides do not require long soaking in contrast with dry hides which take a longer time to hydrate.

The initial soakage of hides may be done in concrete pits and final washing by tumbling in large rotating drums. Small amounts of soluble proteins are extracted from the hides in the washing process.

Crops Sensitive to Chloride and Sodium in Irrigation Water

Richards[15] has edited a handbook for the US Department of Agriculture which draws attention to the low tolerance for salt of the following crop plants, viz. – Pear, apple, almond, apricot, peach, avocado, radish, cellery, green beans and clover.

Apart from chloride (Cl) in the salt (NaCl) used in the common curing process we have to contend with sodium (Na).

According to Hirsh[16] "Sodium is unique among the cations in its effect on the soil. Sodium from the irrigation water is adsorbed or fixed, in an exchangeable form, on the surface of the clay particles. After continued use of irrigation water and the exchangeable sodium of the soil come to a mass-action type of 'steady state' relationship. Very adverse physical conditions develop in most soils if the exchangeable sodium exceeds 10 to 15 per cent of the total exchangeable cations of the soil. Such soils, when wet, are plastic and sticky and only slowly permeated by air or water. They shrink and crack, when dry, and form hard clods that are difficult to work into a seedbed".

Rehydration and Swelling[17]

Water alone will soften hides causing the hides to swell but the reaction is more rapid in a dilute acid or alkali solution.

For the production of soft thin leather the hides are soaked in dilute alkali solution. The action of acids (e.g. sulphuric acid) "pickling" is more intense and is applied for the production of heavy sole leather or belting.

The swelling has been explained as being analogous to that of gelatin[18] (a protein) as follows: The cell substance, possessing both free amino and carboxyl groups, is an amphoteric substance (ampholyte) and so can function as an acid or a base. Although the basic property is somewhat stronger the dissociation is very small and the osmotic pressure correspondingly low. When the hide comes in contact with the solution of acid or alkali a highly dissociated salt is formed with the amphoteric contents of the cell. The osmotic pressure is greatly increased as a consequence and water entering the cell will cause distention or swelling. The swelling process must not be continued too long otherwise the cell walls begin to disintegrate into a more soluble and mechanically weaker material. The disintegration is considerably assisted by the presence of certain ferments and especially by the hydrogen ion. Thus pickling is fraught with a certain amount of danger.

According to Ernst von Meyer[19] tanning processes were empirical up to 1860 but were later scientifically investigated by a number of scientists such as Knapp, Eitter and Bottinger. According to Knapp tanning constituted a special case of dyeing which had earlier been investigated chemically by Macquer in 1795.

As practised today the chief processes employed at a tannery are:

(1) soaking;
(2) liming and removal of hair;
(3) de-liming;
(4) tanning;
(5) finishing.

According to Southgate[20] in Great Britain the processes used in the same section of the leather industry usually differ considerably in detail from one works to another, and there are corresponding differences in the volume and character of the waste liquors from the different works. These differences, he states, "are due partly to the fact that there is a considerable range of variation in the quality and the character of the skins as they reach the tanner, coming as they do from countries of widely different climate and culture".

For the American scene this has been succinctly put in the publication *"The Marvels of Modern Industry"* in the section edited by W N Mitchell, associate professor, University of Chicago (published, Chicago 1940, at p. 214) . . . "From the steaming jungles of the Amazon and the snow-capped mountains of Tibet. From the wind-swept wastes of the Sahara from the plains of Texas come strange assortments of hides destined to become smart shoes which women and men will wear in the hush of theatres and rustle of fashionable restaurants".

By the time the skins arrive at the tanneries where they will be made into leather they are already cured by the sun or by salting, which eliminates the danger of bacterial decay by removing the natural moisture of the skin or creating a medium in which the bacteria cannot live (q.v.).

Micro-organisms Encountered in the Industry[21]

Micro-organisms encountered in the industry may be divided into three groups viz. –
(a) moulds;
(b) yeasts;
(c) bacteria.

The moulds most frequently met with in the tanyard are as follows:

(1) *Mucor mucedo*, white mould.
(2) *Penicillium* (many varieties but chiefly) *glaucum*, green mould.
(3) *Aspergillus* (many varieties, but chiefly) *niger*, black mould.

Yeasts, notably *Saccharomycetes micoderma* which form the thick felt often observed on old tan liquors.

Bacteria: It will be remembered from the wide variety of bacteria normally encountered, the spores of *Bacillus anthracis* can survive both drying and biocidal treatments. If, therefore, hides and skins used as raw input to a tannery come from an area where anthrax is endemic, sodium hypochlorite should be added to the soak liquors to ensure a concentration of free chlorine of not less than 0,02 per cent at the end of the soaking period.

Halophilic Bacteria

The reliance placed on salt curing of hides and

skins in the past stemmed, possibly from the belief that, –

(1) The operation of salting is cheap and effected easily;
(2) Salt is comparatively inexpensive and readily obtainable;
(3) The effects of bacterial action are doubtful and acceptably non-existent;
(4) The process does not affect the final quality of the leather;
(5) The salted hide or skin has a fairly constant moisture content which is necessary for commercial reasons.

However, it must be realized that there are halophilic organisms which live in salt environments.

It has been known for some time that halophilic bacteria can live in the Great Salt Lake of Utah (USA) and in the Dead Sea of Israel.

Prior[22] has discovered an extreme hydrophilic bacterium and a moderate hydrophilic bacterium in a salt pan near Bloemfontein.

According to Rheinheimer[23] the most interesting halophiles are the extreme halophiles which have an optimum development at concentrations of salt of 20 to 30 per cent. He states that they all have red pigments and belong to the genera *Halobacterium* and *Halococcus*. They remain alive in salt crystals and when food (fish, meat, vegetables and skins) are pickled in salt the organisms may grow in the brine. Occasionally, the treated materials contain red stains which spoil the products (e.g. salted fish may be blemished by a red coccus which is halophilic).[24]

The halobacterium has the greatest salt requirement and grows in salt concentrations exceeding 12 per cent NaCl with an optimum of 25 to 30 per cent. Nevertheless, it can develop in saturated brine solution.

Whether halophilic bacteria can affect the quality of salted hides and skins does not seem to have been reported but, perhaps, it is a matter for consideration by the old-fashioned curers who are wedded to the use of salt. Certainly, high quality salt for domestic use requires to be free from halophilic bacteria.

Hide and Skin Preparations for Tanning (Beamhouse Operations)

Before tanning is conducted it is essential that skins and hides should be free from contaminating dirt such as blood, dung, adhering salt crystals (if salt-cured hides and skins are used). The first step in the tannery is soaking and washing of the skins and hides. This is followed by soakage in dilute milk of lime solution and in order to accelerate the softening and loosening of the hair sodium sulphide or sulphydrate is normally added to the milk of lime. Other accelerators used include amines such as dimethylamine. Another method of loosening hair and wool which is used for certain types of skin consists of painting the underside with a paste containing lime and sodium sulphide or lime and arsenic disulphide (As_2S_2 "Realgar").

Rideal[25] pointed out way back in 1898 that tannery liquors in the United States, at that time, contained sufficient arsenic after sedimentation to hinder bacterial treatment of tannery wastewater.

Hides which are to be used for the production of heavy leathers are usually treated in a weak solution of an acid. On the other hand, fine leather production requires treatment by "bating". The classical method of bating consisted of allowing the skins to remain in contact with water containing the faeces of dogs and birds (e.g. poultry) during which bating process the liquor underwent anaerobic fermentation. Today, pancreatic enzymes are used for bating.

A variation on the classical theme was the use of an infusion of bran which on fermentation gives rise to aliphatic acids. However, more easily controllable methods of de-liming can be used. Among the substances added to the de-liming liquors we have ammonia, pancreatin and lactic acid.

The processes indicated above, namely soaking, liming and de-hairing, de-liming and washing to prepare the hides and skins for tanning give rise to what are referred to as "beamhouse wastes" and the wastes arising from the subsequent tanning and finishing processes are known as "tanyard wastes".

The beamhouse processes are by far the largest source of effluent from a tannery and contain the fascia or fat which has been removed from adherence to the corium after de-liming and de-hairing. This solid waste can be collected separately and should not be included in the beamhouse waste as such.

Thus, it will be seen that the wastes from the beamhouse include aqueous effluents from all the operations cited and variously contain suspended and dissolved organic matter, curing chemicals (e.g. NaCl if used), grease, hide and skin trimmings, fleshings, etc.

Tanhouse Operations

Tanning essentially aims at stabilizing the collagen network of the derma. The oldest form of tanning was by the use of certain plant extracts (*vide ante*). Today this is not so and vegetable tanning has been displaced to a considerable extent by mineral tanning, more particularly by the use of solutions of basic chromium III sulphates and to a lesser extent by alum for white leather production.

A chrome liquor which has been in favour is made by reducing a mixture of sodium dichromate ($Na_2Cr_2O_7.2H_2O$) and sulphuric acid (H_2SO_4) in equal proportions, with glucose.

Another method consists in passing sulphur dioxide (SO_2) gas into a solution of dichromate to which sodium thiosulphate ($Na_2S_2O_3$) is added subsequently.

In every major producing country except Italy there has been a dramatic reduction in the output of vegetable tan industrial leather and sole leather as synthetic materials have become more attractive in quality and price.[26] Production of bovine leather for shoe uppers, furnishings, clothes, etc. has taken over the loss of markets for sole and harness leathers while sheep and goat leather have remained relatively static. However, the balance of production between countries of the European Economic Community (EEC) has changed. In West Germany and to a lesser extent in Holland, the output of these classes of leather has declined whereas Italy has increased its production by more than 200 per cent, although the bovine leather now shows signs of having stabilized.

In the tanhouse the hides are brought into an acid condition before tanning takes place with chrome salts in an acid medium. This treatment permanently stabilizes the collagen matrix. The hides are then designated "wet-blues". Alternatively, vegetable tanning agents may be used. Re-tanning, dyeing and the application of lubricants follow. The reagents *per se* provide the pollutional load at this stage.

Vegetable tanning procedures give rise to greater organic pollution than those where chrome tanning is practised.

Synthetic tanning agents ("syntans") and oil tannages are in use and, also, the use of aluminium, zirconium and iron salts but the only major non-vegetable, non-chrome process is the oil tannage used in the production of chamois leather.

The combined wastewater including beamhouse from both vegetable and chrome tanning processes usually has a pH value of about 10 to 12 and, of course, chromium will be present in the effluent from chrome tanning. This presents an environmental problem.

Finishing

On completion of the tanning of hides and skins to form leather it is usual to incorporate oil or fat to lubricate the fibres and so make the leather soft and pliable and waterproof. If oil or fat *per se* is employed the operation is referred to as "currying". Currying may be carried out by either of two methods namely "hand stuffing" or "drum stuffing". If an emulsion is used the operation is called "fat-liquoring".

A wide variety of animal and vegetable oils and fats are used for the currying procedures but for fat-liquoring sulphonated oils are more commonly used.

Oils and greases are used for the purposes indicated above but, additionally, oils are used in oil tannages (e.g. in the manufacture of chamois leather) where the oil or fat actually effects the tanning by converting the collagen of the hide or skin into leather; it has been postulated that the amino groups of the skin or hide proteins combine chemically either with oxidized fatty acids produced from the oils or with the aldehydes also formed as a result of oxidation of unsaturated oils. The main oil-tanned leather is chamois leather which is made from fleshes or inner layers of sheep skins by treatment with fish oils.

A further method of applying grease to leather is by the process of impregnation. This consists of immersing completely dry leather in hot melted greases or waxes.

Electro-endosmosis[27]

Attempts have been made to dehydrate and tan hides and skins by electro-endosmosis but, so far, without success. Electrolytic tanning failed due to the oxidation of the tannin at the anode though it was found that by enclosing the anode with a diaphragm helped.

TREATMENT AND DISPOSAL OF TANNERY EFFLUENTS

From the foregoing outline of tanning it will be realized that the main effluents to contend with are beamhouse wastes and tanhouse wastes. Of these two, the beamhouse wastes from a tannery constitute the major problem from the point of view of volume and pollutional load.

Also, it will be realized that the process is not a continuous one in the sense that the discharge of effluent is an even flow and uniform in composition. On the contrary, it is a summation of batchwise and continuous operations giving rise to an irregular daily flow of changeable composition. Hence, in any treatment process applied it is necessary to install a balancing tank or basin of adequate capacity to iron-out as far as possible, composition or pollutional-load peaks in the influent to the treatment plant throughout each working day or period and to ensure that the treatment plant is fed from the balancing tank or basin at an even rate.

Furthermore, the possibility arises of treating the beamhouse wastes and tanhouse wastes separately or combined. In most cases the combined wastes from the two sources are handled after separate settling or combined without prior individual settling.

If the tannery is outside a municipal area, the wastes will require to be treated to a standard suitable for discharge into a river as prescribed by the relevant laws or if land is available and the tannery is in an isolated area, the final effluent must be of such a quality as to make it suitable for irrigation or for discharge into an evaporation pond system which will not give rise to nuisance. Marine discharge is also possible for tanneries near the sea processing salted hides and skins.

Where a tannery is so situated as to be within the jurisdiction of a local authority which has a sewerage system within the municipal area and has an adequate sewage purification works, the final effluent will then have to be acceptable for discharge into the

sewerage system in conformity with the industrial effluents acceptance by-laws of the local authority.

Problems Arising

Beamhouse Wastes

These wastes are alkaline due to the lime added and they also contain sulphide (q.v.). This latter constituent must be eliminated for two reasons, viz. –

(1) to remove the odour and
(2) to prevent excessive corrosion of concrete sewers forming the municipal network: this corrosion takes place above the water-line.

Hydrogen sulphide (H_2S) released from the sewage by a process of desulphurication in a sewer in the presence of oxygen in the air above the water-line is oxidized by chemiautotrophic bacteria of the *Thiobacillus* type to sulphuric acid as follows:

$$2H_2S + O_2 \longrightarrow 2S + 2H_2O \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$2S + 3O_2 + 2H_2O \longrightarrow 2H_2SO_4 \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

The H_2SO_4 produced attacks the outer skin of the inner surface of the sewers and forms calcium sulphate crystals beneath the skin, which, as a consequence is ruptured and sulphuric acid thereafter has free access to the free lime in the cement and in due course the area of the sewers above the water-line becomes holed and the sewers have to be replaced. (This, of course, does not take place with salt-glazed eathernware or plastic pipes. But most outfall sewers of ample diameters are usually made of reinforced concrete.)

Tanhouse Wastes

Where chrome tanning is practised attention will require to be given to the elimination of or considerable reduction of chromium in the effluent.

pH Value of Effluent

The pH value of tannery effluent requires adjustment to conform with the municipal requirements in terms of the promulgated by-laws. Combining the beamhouse wastes (alkaline) with the tanhouse wastes (acid) does, in measure, achieve this end.

Treatability of Tannery Wastes

Hodgson[28] in a comprehensive report of inquiry commissioned by the Government of South Australia into methods of treatment of sewage and trade wastes and matters related thereto in America, great Britain, Holland and Germany concludes: "that a stable effluent can be obtained by the treatment of all the wastes from the tanning process together, employing chemical precipitation, followed by treatment on trickling filters, in humus tanks and on sand beds. The sludge may be dewatered on sand beds or by vacuum filters".

With regard to biological treatment by the activated sludge process he states it was found to be very sensitive to discharges of caustic liquors.

However, pilot plant studies at Grand Haven,[29] Michigan, USA, on the treatability of a tannery-domestic wastewater mixture have verified the effectiveness of the activated sludge method provided the chromium (Cr) content of the tannery effluent could be reduced to 5 mg/ℓ or less to avoid toxicity in the biological phase. This was achieved by blending lime from the tannery's beamhouse to aid in the precipitation of chromium hydroxide.

Therefore, it would appear that, provided the pH value and Cr content are regulated, it should be possible to treat the tannery-sewage mixtures by the activated sludge process.

In dealing with the combined wastes from a tannery (beamhouse and tanyard), we are presented with a complex dispersion where the dispersate contains organic matter in the form of colloidal particles and particles of coarser sizes and a dispersion medium containing a variety of ions in solution.

Initial consideration leant towards a solid/liquid separation step. But simple screening followed by sedimentation in a tank or modern clarifier will not result in an effluent of a quality that will be acceptable for discharge into a river or municipal sewer, even if coagulation chemicals are added prior to settlement. Nor is a pond system satisfactory for reasons already delineated in this section.

This will be realized from the fact that a typical analysis of the final mixed effluents from American tanneries has shown the following average values:[30]

Table I

Fats and grease	Trace up to 240 mg/ℓ
Sodium sulphide	25 mg/ℓ
pH Value	8,4 – 11,9
Total solids	2 200 – 3 000 mg/ℓ
BOD	226 – 600
Cr_2O_3	Trace – 0,3 per cent
Temperature	53 – 90°F
Turbidity	Grey – brown

By way of contrast the following results of analysis obtained for a South African tannery (Silverton Tannery, Pretoria) due to Hagger and Roets[31] are given, viz. –

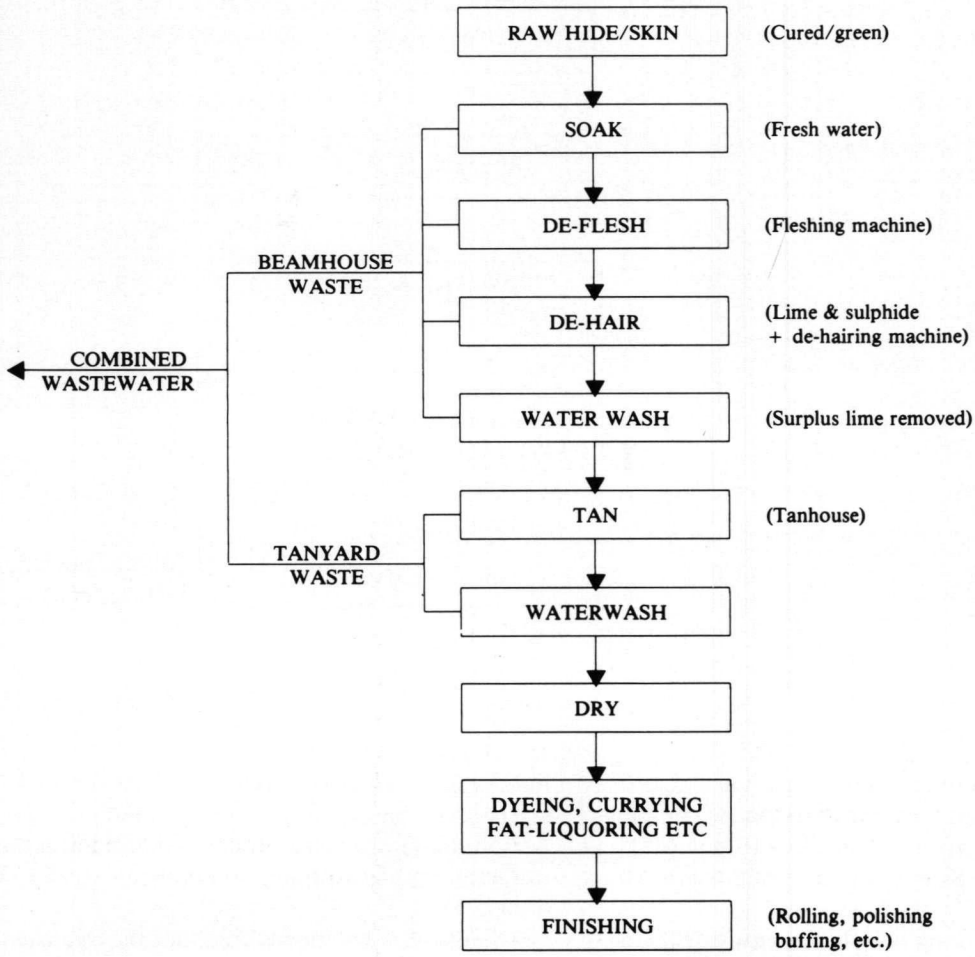
Table II

Date	Time (hours)	Oxygen Absorbed (4 h) mg/ℓ	COD mg/ℓ	pH	Total Dissolved Solids mg/ℓ	Suspended Solids (SS) mg/ℓ	Chloride (Cl) mg/ℓ	Sulphide (S) mg/ℓ	Chromium (Cr_2O_3) mg/ℓ	Conductivity mS/m²
18/1/80	1200–1400	1 560		9,1			520	128	134	880
	1400–1600	1 180		7,8			400	50	28	752
	1600–1800	540		7,2			600	8	44	432
	1800–2000	840		7,3			800	8	146	408
	2000–2200	216		7,7			400	6	44	
19/1/80	0700–1045	2 360	6 800	8,3	10 546	5 378	2 400	90	256,5	1 066
	1200–1830	2 460	5 600	8,4	4 879	3 510	900	78	99,6	697
	1830–0600	118	500	8,2	2 359	236	520	10	35,8	275
20/1/80	0800–1800	1 560	5 100	7,4	7 768	4 992	1 620	53	—	890
	1900–0600	210	700	6,7	1 592	1 082	520	3,2	—	267
21/1/80	0700–1500	460	1 800	7,1	3 484	1 038	740	3,2	—	472
25/1/80	–	1 500	9 400	9,3	11 648	4 256	3 500	226	314	1 252

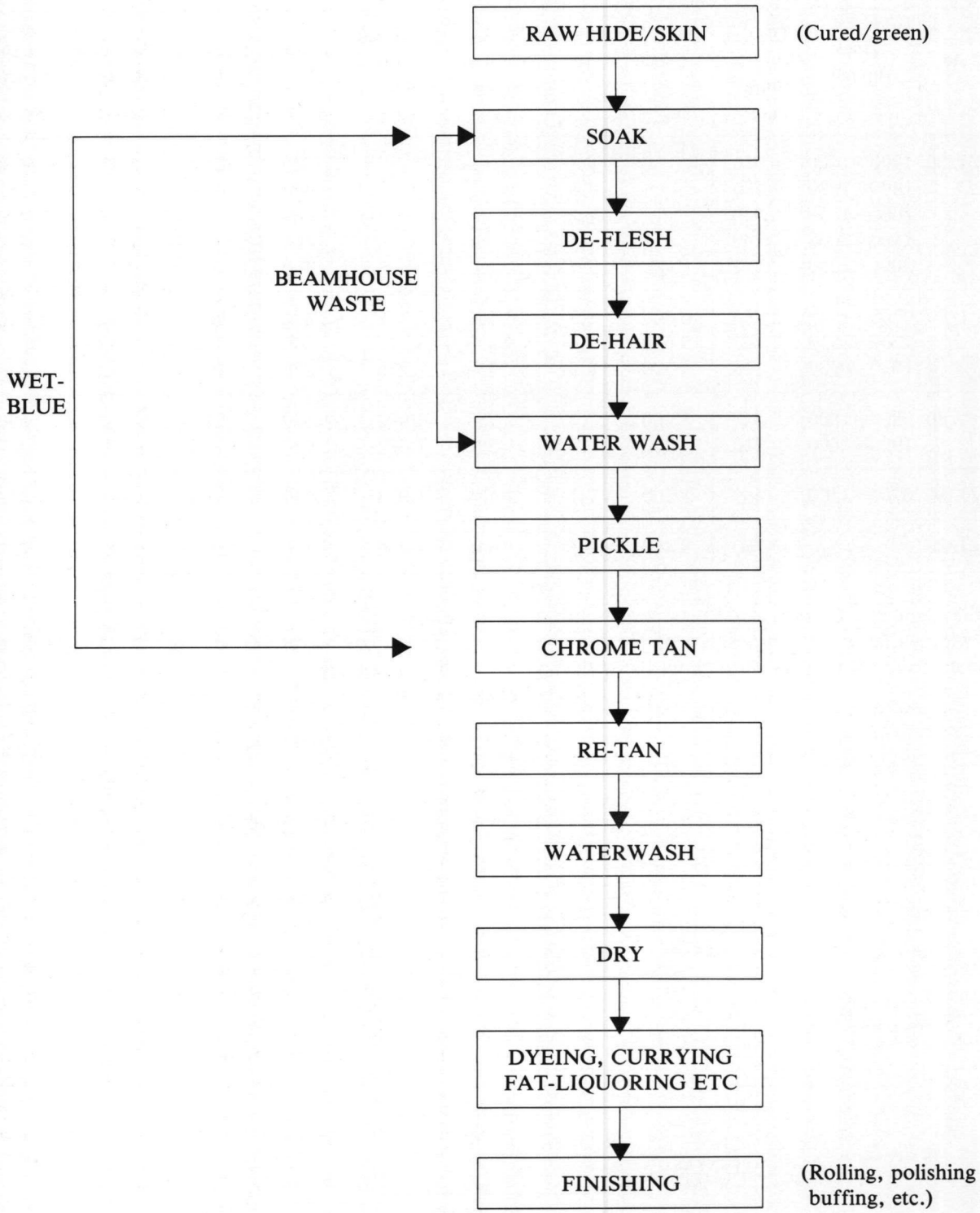
The results of Hagger and Roets clearly indicate the wide variation in composition of the combined effluent from the tannery throughout the periods investigated.

The following are flow sheets for vegetable and chrome tanning:

1. VEGETABLE TANNING



2. CHROME TANNING



The high suspended solids values shown in Tables I and II clearly indicate the unlikelihood of simple sedimentation to effectively reduce this to one of 25 mg/ℓ which would be acceptable for discharge into a watercourse.

Furthermore, in quoting population equivalents of industrial wastes it is reported that Imhoff[32] has stated that, based on the five-day BOD (= 54 g per person daily) one ton of hides produced at a tannery in Germany has a population equivalent of 1 000 to 4 000.

Therefore, it will be realized that the treatment and

disposal of tannery wastes is not easy and straightforward but in South Africa progress has been made due to the efforts of the Leather Industries Research Institute (LIRI) in Grahamstown assisted by the Water Research Commission.

Solid/Liquid Separations

In the case of combined tannery wastes it is not possible to obtain satisfactory removal of the dispersate from the dispersion medium by ordinary sedimentation and using centrifugation does not seem a proposition.

What other options are open then? Flotation, creaming up, flocculation?

Flotation

Flotation has been used for the recovery of economic minerals from ore pulps but applying this in the normal way as used by metallurgists would not be satisfactory. However, in recent years in South Africa dissolved air flotation has received attention for dewatering activated sludge and also, similarly, in the pulp and paper industry, for recovering fibre in the effluent. Flotation has been satisfactorily applied in the case of the Silverton Tannery in Pretoria.

Creaming Up[33,34]

In the transport of rubber latex dewatering of the latex is possible by the use of certain water soluble colloids such as gum tragacanth, carragheen ("Irish moss") and pectin to agglomerate or "cream up" the suspended solids. This process of concentration of the latex does not affect the properties of the latex particles (which remain suspended) whereas coagulation with electrolytes alters the rubber properties irreversibly.

Coagulation

Addition of flocculating agents such as mineral salt and polyelectrolytes is often practised with good effect.

Fellmongery

Sheep skin tannery effluents have not been studied to the same extent as those from bovine leather tanneries. In view of the fact that beamhouse processes are carried out the polluting load is less in the case of sheep skin tanneries.

Fellmongering involves removing the wool from the skins of sheep (and lambs) and preparing the skins for dispatch to a tanner. Consequently, fellmongery which is really a separate trade may be associated with a tannery. In fellmongering the principal processes involved are –

(1) soaking;
(2) loosening the wool by soaking the skins in a solution of lime, or painting them with a paste of lime and sodium sulphide or lime and arsenic sulphide (As_2S_2);
(3) removing the wool by scraping and
(4) soaking the skins in a strong solution of milk of lime or in dilute sulphuric acid. Wastewater amounts to about 90 to 136 ℓ per skin.

The total, unsettled, mixed effluent has a composition of the following order,[35] viz. –

Parameter	Concentration or Value*
BOD	1 100
COD	2 000 to 2 500
Suspended solids	2 000 to 2 500
pH Value	4 to 5
Chromium (III)	200
Salt (NaCl)	up to 5 000

*All expressed in mg/ℓ (with the exception of pH value).

PROGRESS IN THE PRODUCTION OF LEATHER

The Processing of Raw Hides and Skins

Clinton E Retzch,[36] after 44 years in the tanning industry in a talk to the "Westcoast Tanners" (USA) referred to the fact that many regarded the tanning industry as "an industry which is centuries old, set in its ways, reluctant to make changes and content to do things in the same manner as great grandfather".

However, he felt that there is, at present, more cooperation and less secrecy and the industry avails itself of technical services.

He pinpointed progressive steps including changes in the beamhouse such as the use of paddle-liming in place of pit and still liming and reduction in the time of beamhouse processing being speeded up from several weeks to a 24-h operation of dehairing, bating, pickling and tanning!

He also stated that interesting developments had taken place in the tanning field such as the introduction of masking agents such as formates and naphthalene syntans and self base-forming chrome tans for greater chrome utilization and the introduction of large automated programmed drums.

He mentioned other changes but a very significant statement was, – "For most of the twentieth century the bulk of leather has been produced from skins which were temporarily conserved by curing or drying, and this is still the pattern in Europe. The concept of processing fresh hides has been surprisingly slow to develop but the likelihood of environmental constraints on the use of salt, the re-location of slaughter units in the USA and the development of biocides for short-term conservation have ensured increased attention to this approach. The explosive growth of the leather industry in Latin America, now

equal to Europe's is, in Argentine and Brazil, almost entirely based on the processing of green hides".

The use of green hides in place of salted ones is now "coming home" to South African curers who were reluctant to release themselves from their middle man position as between abattoir (and livestock seller) on the one hand and tanner on the other. However, the substitution of biocides and refrigeration may release them from the addiction to the use of salt as the one and only method of curing/conserving.

It may not be possible to eliminate the use of salt entirely since game skins from animals killed in remote areas may continue to be cured with salt but, at least, the tanners of such hides or skins should remove physically, as much of the adhering salt crystals before soaking and such salt removed from the hides should be adequately stored to prevent salt egress into the water environment. Such salt can be re-used.

Good Housekeeping at Tanneries

The results of analysis for the Mountain View Tannery in Pretoria as reported for 1974 and 1975 are shown in Table III.

By recirculating chrome liquors, by sweeping excess salt (NaCl) from hides before soaking and dosing the effluent with polyelectrolyte and by generally exercising better all-round housekeeping as far as preventing the discharge of salt from the hide store was concerned, the quality of the effluent which discharges into the municipal sewer leading to the Rooiwal Sewage Purification Works (Pretoria) was improved to give the following values for the parameters quoted above:

PV 800; COD 2 460; pH Value 7,8; TDS 4 634; Suspended Solids 585; Cr_2O_3 54; Sulphide 128.

Not all that good but a big improvement for a little extra good housekeeping!

THE SOUTH AFRICAN SCENE

Developing Technology

At one time most tanners in South Africa used pond systems to dispose of their effluents. This method had many attendant drawbacks. A practice followed by some, contrary to Government Departmental policy, was to wait for the first big rain storm when the river adjoining a tannery was in flood and to breach the walls of the ponds and allow the contents accumulated during a long period to be swept away by the river in torrent. This surreptitious activity was hardly commendable but understandable!

However, in recent years the Leather Industries Research Institute attached to Rhodes University in Grahamstown has carried out a great deal of work under the sponsorship of the Water Research Commission to develop suitable methods for treating tannery wastes and tannery effluents in admixture with sewage.

In an interim study of the treatment of chrome tannery wastewater by dissolved air flotation followed by activated sludge or high-rate biological filtration the Leather Industries Research Institute (LIRI) has reported[37] for the period July 1980 to December 1980 that, – by adequately mixing the tannery wastewater, pre-aerating to remove sulphide, settling to remove easily settleable solids (sludge), coagulating with ferric chloride and a flocculant (Zetag 92) followed by dissolved air flotation to remove suspended solids – the Dissolved Air Flotation unit process is capable of removing c. 88 per cent of the suspended solids after the preliminary treatment indicated above. At the same time it was found that 53 per cent of the permanganate value (PV); 56 per cent of the Soluble COD and 20 per cent of the total dissolved solids (TDS) was removed.

After removal of suspended solids by Dissolved Air Flotation further treatment by the activated sludge process gave the following per cent reductions of chemical parameters as follows:

Permanganate value, 78;
Soluble COD 85;
Total dissolved solids, 39.

When high-rate biofiltration was used in the place of activated sludge treatment somewhat similar reductions were obtained viz. – 76; 84 and 37.

The final effluent from the above two related hook-ups of unit processes resulted in a final effluent of the following quality: Sulphide (S), nil; pH value,

Table III

Year	PV	COD	pH Value	Total Dissolved Solids	Suspended Solids	Cr_2O_3	Sulphide (S)
1974	2 078	5 796	7,3	6 677	1 755	51	—
1975	1 253	5 698	6,8	9 363	1 459	117	—

(All results expressed in mg/ℓ except pH value.)

7 to 8; PV, 70 mg/ℓ; soluble COD, 500 mg/ℓ and TDS, 7 300 mg/ℓ. These results represent a significant improvement from those of the influent from the tannery, viz. – PV, 340 mg/ℓ; soluble COD, 3 300 mg/ℓ and TDS, 12 000 mg/ℓ.

Arising out of the work done on behalf of the Water Research Commission in association with a consulting firm and the technical staff of the Pretoria City Council it has been possible to develop a process at the Silverton Tannery which now produces an effluent which is accepted for discharge into the city's sewerage system leading to the Rooiwal Sewage Purification Works (*vide ante*). The Silverton Tannery process is now traded under the proprietary name of "SILFLO" and plants have been installed at a number of tanneries.

However, this method of treatment would not have been evolved but for the fact that the tannery, on the advice of the Department of Water Affairs and the Water Research Commission cut down on the purchase of salted hides and replaced these with green hides thus ensuring that the NaCl content of the final effluent conformed with the industrial waste acceptance by-laws of the Pretoria City Council. The Department of Water Affairs for some time now has advocated the elimination of salt for curing hides. The curers are now realizing the necessity for using other means than the application of salt. The Leather Industries Research Institute (LIRI) has investigated the use of certain biocides, e.g. the antiseptic Busan 52 (active ingredients: 32 per cent N – hydroxymethyl – N – methyldithiocarbamate + 8 per cent sodium 2 – mercaptobenzothiozole). Busan 52 is widely used for hide and skins preservation.

LIRI[38] found, from laboratory-scale activated sludge experiments using domestic sewage, tannery beamhouse effluent and mixed chrome tannery effluent that for domestic sewage the tolerance level was between 100 and 250 mg/ℓ of Busan 52 while tannery beamhouse effluent and mixed chrome tannery effluent could tolerate 250 mg/ℓ of the biocide. The least affected was beamhouse effluent which showed tolerances approaching 1 000 mg/ℓ Busan 52.

Subsequently LIRI investigated the effects of Busan 72[39] and also boric acid[40] (Busan 72 contains 60 per cent of the active ingredient 2 – thiocyanomethylthiobenzothiozole).

It would appear that the biocide is closely bound to the hide and does not wash off to a great extent.

The presence of boron, to any extent, in the effluent would not be desirable as boron is inimical to the growth of crops irrigated with water of high boron content.

Re-cycling of Tannery Process Liquors

The Leather Industries Research Institute (LIRI) at Grahamstown has carried out numerous investigations on the re-cycling of processed liquors. These have included, –

(1) Reuse of sludge from vegetable tanning using wattle extract by re-dissolving the sludge with 4 per cent sodium sulphite under boiling conditions;
(2) Re-cycling lime-sulphide liquors. This results in a reduction of sulphide, lime, proteins and fats leaving the tannery;
(3) Re-cycling of chrome tanning liquors. It was found that savings in chrome salts were of the order of 28 per cent with no deterioration in the leather produced.

Therefore, it will be realized that by reusing processed solids and liquids advantages are obtained viz. – a saving in chemicals and an improvement in quality of the effluent without lowering the quality of the leather produced.

The Water Research Commission engaged the services of London and Local Consulting Engineers who have collaborated in a number of investigations of Water and Effluent Management in the Tanning and Fellmongering Industry and a number of reports have been published. These include, –

- *"Pretreatment of Tannery Wastes for Discharge into Sewerage Systems"*;
- *"An Acidification-Screening Process for the Treatment of Tannery Lime-Sulphide Liquors"*;
- *"Treatment of Fellmongery Wastewaters by the Activated Sludge Process"*;
- *"Water and Effluent Management in the Tanning and Fellmongering Industry"*.

From the work on tanneries it has been possible to formulate guidelines for the treatment and disposal of tannery wastes (cf.).

There seems little doubt that tanneries should recycle liquor and reuse sludges where possible; by so doing the pollutional load discharged from tanneries will be reduced.

Liritan Process: This is a minimum effluent tanning system which was developed by the Leather Industries Research Institute (LIRI) at Grahamstown. This involves treating the limed and bated hides for 18 to 24 h in a pit with a 5 per cent solution of "calgon" (sodium hexametaphosphate), a chemical commonly used in boiler water treatment. Sufficient sulphuric acid is added to achieve a pH value of 2,8 at the end of this operation. (A 2,0 per cent concentration of sulphuric acid is recommended at the start.)

The solution is reused daily, being regenerated by adding further calgon. This initial process prepares the hides and skins for wattle (mimosa) tanning which takes about 11 days or less. The tannin liquors are recycled and reused (q.v.). This process was introduced in 1960 and is now used in the Republic and overseas by major vegetable leather tanners.

Table IV
Tanneries and Fellmongeries in South Africa

Name	Location	Type of Process	Raw Materials kg/d	Water m^3/d	Usage ℓ/kg	Effluent Treatment	Effluent Disposal
1. Bachs Tannery	Huguenot, C.P.	Veg. Tan (Sole Leather)	1 000	5	5	nil	Municipal sewer
2. Edendale Tannery (Pty.) Ltd.	Edendale Natal	Veg. Tan (Sole Leather)	4 000	150	38	nil	Lagoon/ irrigation
3. Exotan (Pty.) Ltd.	Port Elizabeth C.P.	Chrome Tan (Exotic Skins)	?	32,5		Balancing Aeration	Municipal sewer
4. Hanni & Sons (Pty.) Ltd.	Nigel, Tvl.	Chrome Tan (Gloves)	2 000	60	30	Balancing Aeration	Municipal sewer
5. (a) Johannesburg Tanning Co. (Pty.) Ltd.	Krugersdorp Tvl.	Chrome Tan (Wet-Blue)	5 000	100	20	Balancing Aeration Mn^{++} Addition	Municipal sewer
(b) Johannesburg Tanning Co. (Pty.) Ltd.	Johannesburg Tvl.	Chrome Tan (Finishing)	6 000	100	17	nil	Municipal sewer
6. King Tanning Co. Ltd.	King William's Town, C.P.	Chrome Tan	35 000	1 000	28	Settlement	Irrigation
7. Mossop & Son (Pty.) Ltd.	Cape Town	Chrome Tan/ Veg. Tan (Finishing)	10 000	80	32	nil	Municipal sewer
8. Mountain View Tannery Ltd.	Hercules Pretoria	Veg. Tan Chrome Tan	2 500	60	24	Settlement Chemical addition	Municipal sewer
9. N.E. Cape Products (Pty.) Ltd.	Mafeking C.P.	Chrome Tan (Wet-Blue)	10 000	400	160	nil	Irrigation
10. S.A. Bata Co. Ltd.	Uitenhage C.P.	Chrome Tan	22 000	336	15	nil	Evaporation ponds
11. Silverton Tannery Ltd.	Silverton Pretoria	Chrome Tan Veg. Tan	34 000	545	16	Aeration "SILFLO" treatment	(a) Evaporation ponds (formerly) (b) Municipal sewer
12. Sutherlands Tannery Ltd.	Pietermaritz-burg, Natal	Chrome Tan Veg. Tan	8 000	500	62	nil	Evaporation, spray irrigation

Table IV *Continued*

Name	Location	Type of Process	Raw Materials kg/d	Water m^3/d	Usage ℓ/kg	Effluent Treatment	Effluent Disposal
13. Thorer Fur (Pty.) Ltd.	Cape Town	Chrome Tan (Skins)	2 000	125	62	Balancing Aeration	Municipal sewer
14. Urbans Inds. (Pty.) Ltd.	George C.P.	Chrome Tan Veg. Tan	350	60	171	Filter thro' sawdust	Irrigation
15. Velskin Products (Pty.) Ltd.	Hammans-kraal, Tvl.*	Chrome Tan (Sheepskins)	4 500	25	5	Coarse screening	Evaporation ponds (effluent to sewage works)
16. Western Tanning Co. Ltd.	Wellington C.P.	Chrome Tan	20 000	300	15	Aeration	Evaporation ponds
17. Pelt Products (Pty.) Ltd.	Port Elizabeth C.P.	Fellmongery (Lime-sulphide/ Enzyme-sweating)	not disclosed	250		nil	Sea discharge
18. Perseverance Wool Pullery Co.	Perseverance C.P.	Fellmongery (Enzyme-sweating)	12 000	136	11	Settlement	Evaporation ponds
19. Pinetown Processing (Pty.) Ltd.	Pinetown Natal	Fellmongery (Lime-sulphide)	5 000	100	20	Settlement	Municipal sewer
20. SA Cape Fellmongers (Pty.) Ltd.	Port Elizabeth C.P.	Fellmongery (Lime-sulphide)	17 000	300	17	Balancing Aeration	Municipal sewer
21. Klein Karoo	Oudtshoorn C.P.	Tannery (Ostrich skins)	?	?		Balancing Aeration	Evaporation
22. General Hide Corporation	Harrismith O.F.S.	Chrome Tan (Wet blue)	480 000 hides per annum				

*Now Bophuthatswana.

REFERENCES

1. British Standard BS2780: 1972 (2).
2. Waste Management Paper No. 17, Department of Environment, H M Stationery Office, 1978, p. 1 (1.3).
3. (a) Procter, H.R. *"Colloid Chemistry and Tanning"*, Department of Scientific and Industrial Research, H M Stationery Office, London, 1917, pp. 5-19.
3. (b) Procter, H.R. and Wilson, J.A. *"Report on Collagen and Gelatin"*, Department of Scientific and Industrial Research, H M Stationery Office, 1923, pp. 13-31.
4. (a) Shuttleworth, S.G. *J. Amer. Leather Chemists Assoc.*, 1952, **47**(9), 603.
4. (b) Shuttleworth, S.G. *"The Mechanism of Chrome Tannage"*, A.C.S. Monograph No. 134, Vol. 2, 1958, *"The Chemistry and Technology of Leather"*.
4. (c) Shuttleworth, S.G. and Cunningham, G.E. *J. Soc. Leather Trades Chemists*, 1948, **32**, 183.
4. (d) Shuttleworth, S.G. *J. Soc. Leather Trades Chemists*, 1959, **34**, 410.
5. Maximow, A.A. and Bloom, W. *"A Textbook of Histology"*, W R Saunders Co., Philadelphia and London, 1942, p. 335.
6. Lewis, W.K., Squires, L. and Broughton, G. *"Industrial Chemistry of Colloidal and Amorphous Material"*, The Macmillan Co., New York, 1943, p. 379 et seq.
7. Burton, D. and Reed, R. Discussions of the Faraday Society, 1954, No. 16, p. 195.
8. Day, T.D. *J. Physiol*, 1952, **117**, 1.
9. Meyer, K. *Ann. N.Y. Acad. Sci.*, 1950, **52**, 961; *Advances in Enzymology*, 1952, **13**, 19.9.
10. Loeb, J. *"Proteins and the Theory of Colloidal Behaviour"*, McGraw-Hill Book Co. Inc., New York, 1924, p. 42.

11. Northrup, J.H. *J. Gen. Physiol.*, 1920–21, **3**, 211.
12. Karrer, P. *"Organic Chemistry"*, Elsevier Publishing Co. Inc., New York, 1946, p. 529.
13. (a) Desha, L.J. *"Organic Chemistry"*, McGraw-Hill Book Co. Inc., New York and London, 1936, p. 691.
13. (b) Roux, D.G. and Evelyn, *Biochem. J.*, 1958, **69**, 530.
13. (c) Roux, D.G. *"Mimosa"*, African Territories Wattle Industries Fund, London, 1980.
14. Riegel, E.R. *"Industrial Chemistry"*, Reinhold Publishing Corp., New York, 1942, p. 637.
15. Richards, L.A. (ed) *"Diagnosis and Improvement of Saline and Alkaline Soils"*, US Department of Agriculture, Handbook No. 60, 1954, 160 pp.
16. Hirsh, L. *"Irrigation with Reclaimed Wastewater"*, Proc, Jerusalem Conference on Water Quality and Pollution Control, Ann Arbor Science Publications Inc., Michigan, 1971, p. 254.
17. Zsigmondy, R. *"The Chemistry of Colloids"*, 1st Edn., John Wiley and Sons, Inc., New York, 1911, p. 262.
18. Procter, H.R. *Koll Chem. Beihefte.*, 1911, **2**, 243-284.
19. Von Meyer, E. *"A History of Chemistry"*, Macmillan and Co., London, 1981, 519.
20. Southgate, B.A. *"Treatment of and Disposal of Industrial Wastewaters"*, Department of Scientific and Industrial Research, H M Stationery Office, London, 1950, p. 208.
21. Atkins, W.R. and Thompson, F.C. *"Procter's Leather Chemists Pocket Book"*, E and F N Spon, London, 1937, p. 377 et seq.
22. Prior, B.A. *"Properties of Two Halophilic Bacteria from a Salt Pan"*, *Water S.A.*, 1978, **4** (3) 119.
23. Rheinheimer, G. *"Aquatic Microbiology"*, 2nd Edn., John Wiley and Sons, 1980, pp. 106-108.
24. Scott-Wilson, H.W. *"Aids to Bacteriology"*, Ballière, Tindall and Cox, London, 1946, p. 249.
25. Rideal, S. *"Sewage and the Bacterial Purification of Sewage"*, The Sanitary Publishing Co, London; John Wiley, New York, 1901, p. 293.
26. Urwick Technology Management Ltd., *"Environmental Impacts and Policies for the EEC Tanning Industry"*, Graham and Trotman, Ltd., London, 1977, p. 3.
27. Bancroft, W.D. *"Applied Colloid Chemistry"*, McGraw-Hill Book Co. Inc., New York and London, 1932, p. 280.
28. Hodgson, H.J.N. *"Sewage and Trade Waste Treatment in America, Great Britain, Holland and Germany"*, Frank Trigg, Government Printer, North Terrace, Adelaide, 1938.
29. Van Dam, Doris *"Deeds and Data"* (Water Pollution Control Federation), August 1977, p. 10.
30. Shuttleworth, S.G. *"The Problems of Tannery Effluent Disposal in South Africa"*, CSIR Conference, Pretoria, 1963.
31. Hagger, M.J. and Roets, S.D. *"Physical and Chemical Treatment of Combined Tannery Wastewater to Achieve Acceptance for Discharge to Municipal Sewer"*, Paper presented at a Conference of the Institute of Water Pollution Control (Southern African Branch).
32. Imhoff, K. Reported in *"Treatment of Mixed Domestic Sewage and Industrial Wastewater in Germany"*, Organisation for Economic Co-operation and Development, Paris, 1966.
33. Dean, R.B. *"Modern Colloids"*, D van Nostrand Co. Inc., New York, 1948, p. 232.
34. Stevens, H.P. and Stevens, W.H. *"Rubber Latex"*, Paper read at a symposium held in London, December 7, 1934 under the auspices of the British Section of the International Society of Leather Trades Chemists, Published by A Harvey, London under the title *"Technical Aspects of Emulsions"*, 1935, p. 115.
35. Urwick Technology Management Ltd. *"Environmental Impacts and Policies for the EEC Tanning Industry"*, Graham and Trotman Ltd., London, 1977, p. 26/38 C.I. (Appendix II).
36. Retzch, Clinton, E. *"My 100 years in the Tanning Industry"*, Leather and Shoes, 1980, pp. 4 and 27.
37. LIRI, Research Bulletin No. 88, *"Purification of Chrome Tannery Wastewater by Dissolved Air Flotation Followed by Activated Sludge or High Rate Biofilter Treatment"*, Rhodes University, Grahamstown, October 1981.
38. LIRI, Research Bulletin No. 818, *"The Effects of Antiseptics on the Activated Sludge Treatment of Domestic Sewage, Tannery Beamhouse Effluent and Chrome Tannery Effluent"*.
39. LIRI, Research Bulletin No. 827.
40. LIRI, Research Bulletin No. 826.

15(5) THE TEXTILE INDUSTRY: A DIVERSE ACTIVITY WITH AN ARRAY OF MANUFACTURED PRODUCTS AND AN OLLA PODRIDA OF EFFLUENTS

INTRODUCTION

Historical

The weaving of natural fibres originated in different parts of the world. However, due to the fact that textiles can be eaten by insects, decomposed by bacteria, destroyed by fire, etc., their existence has had to be assessed by objects associated with their manufacture such as spindle whorls, loom weights and weavers' combs. In West Yorkshire (England) there is evidence in the remains of a dyed woollen garment or cloak wrapping a body in an Early Bronze Age burial, 1 600 – 1 400 BC.[1] On the other hand, linen textiles dating to about 5 000 BC have been found in Egypt.

Also, the art of dyeing and bleaching seems to have been developed at an early date. The Romans wore togas of wool or linen. Silk was woven in China about 100 BC and cotton in India about 3 000 BC.

In Britain linen manufacture was introduced during the Iron Age about 500 BC.[2] Flemish textile weavers, fullers and dyers by invitation of King Edward III came to the village of Worsted in Norfolk and their skills improved the textile industry in Britain. The term "worsted" has since been associated with the manufacture of fine wool cloth. Worsted yarns are made solely from the longer fibres and are used for suiting.

Fibre Processing Techniques

The processing of fibres involves, –

(1) removal of natural and acquired impurities;
(2) imparting desirable qualities to such fibres.

In giving effect to the above, the following procedures are given, in attenuated form, by way of illustration, for wool.

Wool Processing: Natural impurities are those due to glandular secretions (sweating) from the sheep

adhering to the fleece. These include the water-soluble "suint" and the water-soluble "wool-grease".

Acquired impurities include dust and soil, adhering organic and vegetable matter such as straw, burrs, seed pods, excrement, etc.; chemicals applied for treatment of disease and insect pests and materials such as paint used for identification purposes. Wool, which is basically keratin, is insoluble in water at ambient temperature.

The first operation after sorting of wool is scouring. Scouring is carried out in two stages, viz. –

(1) using hot water to remove water-soluble impurities, followed by
(2) using detergents or solvents.

After adequate scouring the wool is rinsed. Finishing operations include bleaching and dyeing.

Eldridge[3] has stated "The waste liquor from wool scouring constitutes one of the strongest wastes produced by the textile industry". However, when suint and wool grease removal is practised the pollutional impact of the waste is considerably attenuated.

Southgate[4] records that for some wool the proportion of impurities associated with wool may be as high as fifty to sixty per cent of the total weight.

The South African Scene

The textile industry in South Africa has developed to the stage where there are more than 600 textile companies active in the textile field using a spectrum of fibres and fibre combinations including wool, cotton and synthetics and producing a wide range of products, viz. – blankets and rugs, carpets and carpeting, cloth and cloth sheeting, knitted cloth, industrial cloth, wool yarn, worsted yarn, blended yarns, carpet yarns, cord, cotton lint and cotton waste, knitwear apparel, household textiles including bedspreads, dish cloths, duvets, pillow cases, towels, sleeping bags, nets, tents, rope, sewing thread, twine and felt.

In 1981, 118 400 persons were employed in the textile industry in the Republic of which 10 300 were Europeans[5] (Whites). A still greater number of people in the clothing industry are supported by the products from the textile industry.

Some of the processes involved in the textile industry are water intensive. In fact, the Water Research Commission reported[6] that the estimated total water consumption of the industry was of the order of 30 million cubic metres per year. Therefore, it will be realized that in a country like South Africa where water resources are limited, a close check needs to be kept on the use of water by this nationally important industry.

However, it is not the purpose of this section to deal with in-plant process control and well-defined steps aimed at a reduction in water use. Naturally, good housekeeping would include the reporting and stopping of leaks expeditiously whenever they occur, counter-current washing, replacing of batch with continuous process equipment, recycling of effluent, where possible, and, generally instituting measures to prevent or reduce the abuse of water by employees.

From a pollution point of view the textile industry, as a whole, represents a somewhat complex problem since textile wastes are as varied as the types and colours of the materials being processed and one can but agree with the findings of Schlesinger, Dul and Fridy[7] who have stated from a wastes survey that – "no two plants used the same processing chemicals and quantities, production rate, productive equipment, or operators . . .".

Fibre Types: Fibres used in the textile industry fall into two main groups, viz. – natural fibres and manufactured fibres. Natural fibres can be either of animal origin (e.g. wool, hair, silk) or of vegetable origin (e.g. cotton, flax, jute, hemp, sisal). Mineral fibres are represented by asbestos.

Manufactured fibres are of two kinds, viz. – those manufactured synthetically (e.g. rayon, nylon, acrylic, polyester fibres as well as the so-called "Man Made Mineral Fibres" (M.M.M.F.) which include glass, rock and fusible slag) or by chemical treatment of natural products i.e. semi-synthetic. The materials cited may be used mainly in the textile industry although some (e.g. mineral fibres) may be used for re-inforcement of resin, rubber or cement. In South Africa the principal fibres used are wool, cotton and synthetics or mixtures of these.

The processes used in textile manufacture can include, *inter alia*, such basic ones as washing, detergging or scouring, kiering, bleaching, desizing, mercerizing and dyeing. Invariably the effluents from the industry contain dyes which are difficult to decolorize economically, show high Chemical Oxygen Demand (COD) values and high sodium (Na) contents and, in some cases, chloride (Cl).

In order to create a better understanding of the processes cited above the following information is supplied in desiderative explanation thereof.

These processes are necessary to treat the raw material effectively to produce a satisfactory end product be it fibre for spinning or the resultant cloth. Raw wool as has been previously stated consists of about 50 per cent wool fibre and about 50 per cent of a variety of adhering materials/impurities e.g. natural wool fats and waxes, dried perspiration (suint), dirt such as sand, clay, excrement, vegetable debris and burrs. Valuable materials can be produced from the wool grease e.g. lubricating greases, lanolin and potash from the suint.

The impurities are removed by agitation or by counter-current washing in solutions containing scouring agents such as soap, soda ash and detergents – hence the terms scouring and deterging. Naturally, the resulting wastewater from this cleansing process

will be considerably polluted but will contain valuable substances such as wool grease and suint indicated above. In many cases attempts are made to improve the recovery of these two constituents and "SAWTRI" (South African Wool Textile Research Institute) under the sponsorship of the Water Research Commission has been investigating this problem to improve the recovery of these two constituents in scouring wastes. Since suint contains potassium it has fertilizing properties.

Miscellaneous Operations

Bleaching: Commonly used bleaching agents include sodium hypochlorite, calcium hypochlorite and hydrogen peroxide. To eliminate excess reagents subsequent treatment by washing with sodium bisulphite reducing agent may follow.

Desizing: In order to protect and make thread more amenable to weaving operations the thread is coated with the size by passage through a solution of sizing material and this has to be removed subsequently after weaving.

Commonly used size materials are starch and polyvinyl alcohol (PVA). In some cases (e.g. synthetics and mixed thread weaving) it is also necessary to add antistatic oils to facilitate weaving.

Desizing can take the form of treatment with dilute sulphuric acid followed by kiering or steeping of the woven cloth in an enzyme bath followed by acid treatment.

The volume of desizing wastes is not large by comparison with the total volume of wastes from a textile plant. Consequently, if the solids in desizing wastes can be isolated by a suitably arranged physicochemical process such recovered solids can be disposed of without too much difficulty.

Deterging may be broadly defined as any procedure for the removal of soil or dirt from the surface of a solid by means of a liquid. The development of detergents as we know them today arose from the desire to improve the efficiency of the detergent process and also in view of fat shortages; the soaps being made from this source material. Today it is possible to tailor surface-active agents to serve as detergents for specific purposes.

As far as sewage purification and industrial effluent disposal is concerned soft or biodegradable detergents are the only acceptable ones. However, the use of hard or non-biodegradable detergents used for grease removal in the mechanical and motor industries, if used, should not be allowed to discharge into a sewerage system leading to a sewage purification works.

Emulsification may be very important in wool scouring and salts which greatly reduce the interfacial tensions of oils and water usually enhance the scouring action.

Cotton kiering is the boiling of woven goods in water containing 0,5 to 3,0 per cent sodium hydroxide and sodium carbonate. In this treatment gums, pectins, vegetable impurities and sizing matter are separated from the fibre. Sizing is a necessary process to enable spinning of fibres and consists in the application of a gelatinous coating (e.g. starch) to the fibres prior to spinning and this has to be subsequently removed from the woven cloth. This removal treatment is called desizing.

The wastewater from cotton kiering is highly alkaline and has a very high BOD (Biochemical Oxygen Demand) value. Thus, if discharged into a river, it will rapidly remove dissolved oxygen from the water in the river or lead, *inter alia*, to fish kills and pollution.

Mercerization: Concentrated sodium hydroxide (NaOH) solutions cause cotton fibres to swell and the walls of the fibre to become cylindrical. If the alkali treatment is performed while the cotton is under tension so that length-wise shrinkage is avoided the cotton develops a silk-like lustre. The process is called mercerization. Mercerized cotton has a greater affinity for dye than non-mercerized cotton.

In mercerizing cotton cloth the treatment with sodium hydroxide is followed by rinsing and treatment with dilute acid.

Mercerization, as practised, resulted from the observation of John Mercer who first noted the swelling effect in 1844 and H H Lowe who, while investigating shrinkage, discovered the effects of tension on the swollen fibres.

Bleaching of cotton aims at producing whiter cotton by the aid of chemicals such as sodium hypochlorite (NaOCl) and hydrogen peroxide (H_2O_2). This treatment follows desizing and kiering and may be followed by dyeing.

Dyeing: Dyes, in the context of the textile industry, are compounds which colour wool, cotton, linen, silk, etc. In order to be of value as a dye the coloured compounds must unite with the substance to be dyed in such a way that the resulting product is not materially affected by the treatment to which it is subjected in the dyeing process. The dyestuffs include an enormous number of substances having very different properties.

Direct dyes (e.g. indigo and Congo red) are those which dye fibres permanently without the aid of another substance. However, in the case of many dyes, the textile being processed requires to be initially treated with a mordant before the dyeing stage. The term mordant is derived from the Latin mordere, to bite, and suggests a substance which bites into the fabric on the one hand and into the dyestuff on the other hand. Mordants used include a variety of substances. These include salts of aluminium (e.g. hydrated oxide and acetate), iron, chromium, tin (e.g. stannic chloride), tannic acid, finely divided

silica, sulphur, calcium phosphate, albumen.

Formerly, dyes were obtained from natural sources but, today, are predominently synthetic in origin. They are mainly chemical compounds and differ widely in type, consequently dyeing is a specialized activity but, by the same token, it will be realized that the complexity of many dyebath wastewaters will prove formidable pollution problems in certain circumstances.

The first group of dyes are the direct or substantive dyes which are soluble in water and are taken up selectively by various fibres. Then there are the so-called acid and basic dyes which are also water soluble. Yet, another group of dyes consists of insoluble dyes which can be deposited within the fibre itself or by chemical conversion be produced in soluble form.

Colloidal Electrolytes: Many dyestuffs (e.g. Congo red) are colloidal electrolytes. Other colloidal electrolytes include soaps, detergents, alkyl sulphonic acids, alkyl sulphates, quaternary ammonium salts, clays, and gum agar. As the name implies these compounds form colloidal solutions (very fine particles in suspension – invisible to the naked eye) and at the same time exhibit the behaviour of electrolytes by being ionized in water.

Colloidal electrolytes may be defined as electrically dissociated compounds; one of whose ions is of colloidal dimensions.

The Water Research Commission has solicited the advice and experience of local and overseas authorities in the field and has sponsored investigational work carried out on its behalf by the National Institute for Water Research and the Chemical Engineering Department of the University of Natal, as well as creating a study group for the co-ordination of research projects. Investigations have been concerned, *inter alia*, with water usage, problem areas, methodology and investigational procedure to solve problems.

Methods of Treatment of Textile Effluents

When considering (1) the pretreatment of textile wastewater for discharge into the sewerage system of a local authority or (2) the complete treatment of textile effluents for direct discharge into a watercourse, we are confronted with five basic problems in each case, viz. –

(1) pH Correction;
(2) Reduction in the organic load: this will be conditioned by the nature of the fibres processed and the processing methods used in the factory;
(3) Elimination of colour;
(4) Reduction in sodium (Na) and/or chloride (Cl) content;
(5) Removal of toxic materials (both organic and inorganic).

Additional problems arise from the fact that wet batch processing of textiles results in considerable variations in the flow and composition of the effluent from a factory. Surges of variable composition are naturally undesirable from a pollution control point of view.

Furthermore, whilst suspended particles arising, for instance, from wool scouring may be removed by mechanical and physical means, the presence in effluent of organic colloids and colloidal electrolytes in the form of dyes constitute added difficulties.

Primary Methods of Treatment

These include methods for the removal of the grosser hydrophobic constituents by such methods as screening, settlement, flotation, filtration, centrifugation, etc.

The practice of such physical methods does not result in the total removal of the solids. For instance, in the case of wool scouring wastewaters only up to fifty (50) per cent of the wool grease can be removed by industrial centrifugation practices leaving a large amount of wool grease and suspended solids to be dealt with.

Secondary Methods of Treatment

After removal of the grosser solids, textile effluents consist of a suspension of finely divided solids made up of colloids, colloidal electrolytes as well as organic and inorganic matter in solution. The organic compounds present can be of macromolecular dimensions whilst the inorganic compounds may include sodium hydroxide and sodium chloride depending on the type of textile being processed and dyed – and, also, the remains of agents used in the bleaching process such as sodium peroxide, sodium hypochlorite, sodium silicate, sodium phosphate, surface active and chelating agents.

Chelate Formation: The word chelate is derived from the Greek chela, a crab's claw. Chelate compounds are formed when a molecule or a chemical group attached to a molecule has two points of attachment to the centre atom, e.g. Be (beryllium), Co (cobalt) and Ni (nickel), giving rise to a ring molecular structure. Chelation can occur with a number of organic compounds notably ethylenediamine and complex salts derived from oxalic acid.

The strength of chelate linking depends on the constitution of such substance. It exerts a great effect on the physical properties such as solubility.

Surface Energy: A surface active agent is one which alters the surface tension of a liquid or the interfacial tension between liquids. If two liquids are completely miscible the interfacial tension will be zero.

Surface tension is the property, due to molecular

forces, existing in the surface film of all liquids which tends to contract the volume into a form of the least surface area. The particles in the surface film are inwardly attracted thus resulting in tension.

The surface tension of pure water against air at 25°C is c. 72 dynes per centimetre. This value decreases with increased temperature and likewise increases at lower temperatures. If soap, for instance, is present in water the surface tension is lowered.

Surface active agents play an important part in deterging or washing of fabrics since they have the power of lifting impurities from a surface and thereafter their function is to ensure that these are emulsified or otherwise caused to remain in suspension and so are prevented from re-depositing on the fabrics.

To remove or otherwise transform the finely divided suspended material and the matter in solution constitutes the "pons asinorum" of the problem of disposal of the effluent into a sewerage system of a local authority or, more particularly, into a watercourse. Towards this end the following processes have been suggested, viz. – flotation – with and without the addition of conditioning, collecting and frothing agents, dissolved air flotation, electroflotation, reverse osmosis, ultrafiltration, activated carbon and clay adsorption, ion exchange as well as activated sludge treatment.

However, it must be remembered that the textile industry is a highly competitive one and some of these processes may well be beyond the financial reach of an individual small textile plant.

Nevertheless, progress has been made in South Africa and this is illustrated by the following case histories of textile factories where the respective managements have endeavoured to solve their respective effluent disposal problems.

CASE HISTORY NO. 1

Symbiotic Treatment of Textile Wastewater, Municipal Tanker Sewage and "Night Soil"

This concerns a public company established in a municipal area of a small town on the banks of a substantial river.

The town does not have a sewerage system but provides sanitary pail and conservancy tank services.

The Borough Council and the management of the textile plant have devised a scheme whereby the textile waste water, the tanker sewage and "night soil" of the town are treated jointly in a wastewater treatment plant which has resulted mainly from the investigations and recommendations of the National Institute for Water Research (NIWR).

The two bodies, namely the textile company and the local authority – as far as the joint treatment of their respective wastewaters is concerned – live virtually in symbiosis with one another. That is to say that each needs the other for the satisfactory treatment of their waste waters – the local authority finding it economically advantageous for the textile factory to treat its sanitary wastes and the factory, from its side, needing the local authority's sanitary wastes to ensure the satisfactory functioning of the wastewater purification plant since it has proved difficult to purify textile wastes, of the nature produced at this factory, without the addition of nutrients such as are inherent in sanitary sewage wastes.

Particulars of the Treatment Works

The treatment works is situated near the river as is also the factory which abstracts water from this river and, in turn, discharges the final effluent from the treatment works into this river.

The factory produces cotton, polyester/cotton and polyester/viscose yarns and cloth for domestic and industrial use.

In the desizing, scouring and bleaching processes soluble starches, sodium hydroxide and hydrogen peroxide plus small quantities of retardants and stabilizers report in the effluent. Sodium hydroxide in the waste liquor from mercerization is recycled.

The dyeing processes give rise to dyes, soaps, sulphuric acid, sodium nitrate, sodium hydroxide and sodium hydrosulphite. The different finishes used to meet the requirements of customers result in effluents containing about two (2) per cent of starch and resins.

Sodium chemicals used at the factory include hydroxide, hydrosulphite, sulphate, hypochlorite, carbonate, bicarbonate, nitrite, silicate, tripolyphosphate, chloride, sulphide, sulphite and alginate.

Basically, the end of the line method of purification consists in treating the mixture of textile wastewater, "night soil" and tanker sewage in a pond system followed by activated sludge treatment, maturation pond treatment and finishing up with algal ponds before discharge into the river.

The first pond of the system acts as a mixing mechanism for the combined wastes. The second pond which is a large one serves, *inter alia*, as a means of overcoming shock loads and evens out the flows. In this second pond anaerobiosis occurs. The effluent arising therefrom is then treated in an activated sludge plant provided with surface aerators. The effluent from the activated sludge plant is "polished" further by passage through maturation ponds and a series of algal ponds.

This combined textile wastewater, domestic tanker sewage and "night soil" plant has been achieving results of General Standard quality as set out in Government Notice R553 of April 5, 1962* with the exception of the sodium (Na) content. However, a relaxation up to a value of 250 mg Na/ℓ was granted by the Department of Water Affairs in consultation

*Superseded by R991 of 18 May 1984.

with the South African Bureau of Standards.

Through in-plant measures the company has been able to reduce the amount of sodium previously present in the effluent to come within the limit specified. The final effluent is allowed to discharge into the adjoining river where a great deal of dilution occurs.

CASE HISTORY NO. 2

Electroflotation

This relates to a textile factory which has manufactured worsted textiles for some 30 years and is well established in the industrial area of a medium-sized town.

The purpose of the factory is to manufacture worsted textiles and the fulfilment of this objective involves raw wool scouring, combing, spinning, weaving, dyeing and finishing. Apart from the processing of worsted wool, synthetic mixtures of wool and polyester fibres are also handled.

The factory obtains its water requirements from the local authority and disposes of its effluent by spray irrigation on an area of land set aside for this purpose.

Originally, the effluent from the factory was discharged into the municipal sewerage system for treatment in the town's sewage purification works which is a conventional one using biofilters for aerobic purification of settled sewage and digesters for the alkaline anaerobic digestion of the sludge.

Due to the fact that the textile factory discharged sulphuric acid in the effluent, at that time, corrosion of the benching and mortar joints of the salt-glazed industrial sewer resulted. Subsequently, due to representations by the local authority the factory management disposed of the industrial effluent on land. The domestic sewage from the factory has continued to be discharged into the municipal sewers. In due course the area of land for the disposal of textile wastewater proved inadequate and further land was put under irrigation.

However, this can only be regarded as a short-term solution since, in the long-term, the soil will be adversely affected. This is borne out by the high salinity of the effluent, a Sodium Adsorption Ratio (SAR) value of about 10 and the presence of a not inconsiderable amount of chromium. In this connexion it should be noted that the effluent from the dyehouse which constitutes some 75 per cent of the total water used by the factory contains 5,5 mg Cr/ℓ.

Electroflotation: The effluent from the dyehouse is now treated in one electroflotation unit.

The electroflotation equipment consists of a number of pairs of electroflotation cells provided with aluminium electrodes. The process is a continuous one, the cells operating in parallel, each treating an aliquot of the flow. Before admission to the electroflotation unit the component flows of the combined effluent are subjected to one or more of the processes of screening, sedimentation and air flotation. The aim is to remove all suspended and settleable solids such as fibre, soil, fats, etc.

After this preliminary treatment the effluent flows to an earthern dam. After adjustment of the pH value of the contents of the dam to pH 8,0 (approximately) the effluent is caused to flow through the electroflotation plant.

The principle of operation of the electroflotation process is as follows:

Application of an electrical potential and the resulting passage of an electric current between the aluminium electrodes causes the release of Al^{3+} cations by anodic oxidation. Upon hydrolysis, a voluminous floc forms which adsorbs dyestuffs and tends to sink to the bottom of the electroflotation cells.

However, while this electrode process is taking place, hydrogen (H_2) and oxygen (O_2) gases are evolved at the electrodes and these two evolved gases float the floc plus any oil or grease to the surface where it forms a thick mat which is suitably removed. The extent of purification is proportional to the duration of electrolysis.

At this factory the electroflotation unit has produced a clear effluent with the following measured properties, viz. – pH value 8,6; conductivity 22 m S/m; 4 hours oxygen absorbed 12,6 mg/ℓ; chemical oxygen demand 214 mg/ℓ; Na 36 mg/ℓ.

The following is an analysis of the combined pretreated effluent before electroflotation:
pH value 8; total dissolved solids 1 137; suspended solids 478; chemical oxygen demand 2 020; 4 hours oxygen absorbed 147; Na 145; Cl 64; fat, oil and grease 1 200. With the exception of pH all the above parameters are expressed as milligrams per litre (mg/ℓ).

The per cent removal of impurities is as follows:
Total dissolved solids 50; suspended solids 90; fat, oil and grease 90; chemical oxygen demand 85; 4 hours oxygen absorbed 85.

The solids removed by electroflotation and pretreatment processes are discharged as a slurry to earthern dams where evaporation of the liquid phase takes place. The dried-out solids are subsequently disposed of by landfill.

Comment: The use of electroflotation in treating effluent from a textile plant processing textiles consisting mainly of wool fibres is promising. However, its application for the treatment of effluent from textile plants processing synthetic fibres does not appear to be economically satisfactory although its wider application in the textile industry could well be investigated.

However, it will be realized that in this cited case the treatment processes produced an effluent suitable for irrigation or discharge into a municipal sewerage system but such effluent does not conform with the

requirements of the General Standard – which requirements have to be met for discharge into a watercourse.

CASE HISTORY NO. 3

Elimination of Mercury

This illustrates how a problem of mercury in a textile effluent has been dealt with by a textile factory established in a special industrial area provided with a combined industrial wastewater/sewage treatment works.

The textile plant in question is concerned with the following activities: Spinning of new cotton yarn, weaving of cotton, flax-cotton and flax; dyeing, rot-proofing, water-repellent proofing and finishing of woven materials. The materials produced are used for making tents, tarpaulins and awnings.

In order to prevent rotting of woven material and ensure resistance to wear and tear while in use, treatment with mercury compounds is resorted to.

During processing of the materials the following reagents are used, viz. –

(1) Laurylchloropentaphenol (Na salt).
(2) Phenyl-mercury-acetate.
(3) Phenyl-mercury-nonane-2-ol.
(4) Cu-8-hydroxy-quinolate.
(5) Salicylanilide.

These compounds were chosen by the company for their known germicidal effects.

Unfortunately, organo mercury compounds are extremely poisonous to human, animal and biological life as was evidenced by the poisoning of cats, dogs, fish, infants, children and adults at Minamata Bay in Japan some years ago.[8,9] Therefore, it is important that such mercury compounds should not be released to the water environment.

There are basically two significant effluents arising from the factory, viz. –

(i) one containing phenyl-mercury-nonane-2-ol together with copper and chromium chemicals;
(ii) the other containing phenyl-mercury-acetate, soap, wax and other organic material.

The method of treatment of the effluents under normal operating conditions is as follows:
The second "soapy" effluent is acidified and heated to break the emulsion. Thereafter, on cooling, the water-insoluble phase containing a high concentration of mercury, is separated off and stored in drums for later disposal.

The water-soluble phase of this second effluent together with the first effluent are then treated successively with alum zinc powder and sodium hydroxide. The zinc/mercury toxic amalgam sludge formed is then separated from the mixture by filtration and dried in a specially fabricated stainless steel evaporator using high-temperature steam. The dried solids are set aside in steel drums and disposed of from time to time in an approved toxic waste disposal site by a toxic waste disposal firm.

The filtrate is recycled back to the impregnation system for re-use.

Unfortunately many teething troubles have been experienced with the evaporator, more particularly in respect of the putty-like nature of the final solids formed and certain corrosion problems were encountered. This being so, the management of the textile factory resorted to an alternative method of treatment of the toxic portion of their effluents. This is done by way of the judicious use of two treatment ponds and by working in close liaison with the manager of the sewage/wastewater treatment plant of the industrial township.

The *modus operandi* of this alternative processing is as follows:
The contents of a pond are circulated by means of a portable pump and acidified with sulphuric acid to a predetermined pH value after which lime is broadcast over the pond and then calcium sulphide added – the aim being to precipitate the mercury and ensure a supernatant liquor with a pH value and Hg (mercury) content acceptable to the sewage/wastewater works manager at a time of discharge designated by him.

The ponds are normally used in series – the supernatant liquor from the second pond being discharged to the sewer. The more heavily sludged-up pond is allowed to dry out from time to time and the dried solids scraped from the bottom of the particular pond and set aside for disposal by the toxic waste disposal firm.

The ponds have been maintained as a standby facility for treating the toxic wastes when the evaporator fails.

Naturally, it is expedient to isolate the toxic wastewater from the factory to reduce the volume that has to be treated. This being so the non-toxic effluents, including domestic sewage, are released to the sewerage system of the township without pretreatment.

CASE HISTORY NO. 4

Too Much Textile Waste, too Little Nutrient Material

It is commonly accepted that the effluent from textile plants after cooling, addition of chemicals to facilitate flocculation, (or cracking with sulphuric acid in the case of wool wastes), subsequent removal of flocculated solids and scum (by mechanical or other means) followed by pH adjustment of the final aqueous effluent may be satisfactorily treated by biological filtration or by the activated sludge process.

However, with the increasing use of synthetic

fibres and the employment of new dyes and dyeing procedures problems have arisen – two of these may be mentioned, viz. –

(1) The use of sodium chloride (NaCl);
(2) The use of dyes which are difficult to decolorize.

The presence of sodium hydroxide (NaOH) from the mercerizing of cotton goods, sodium chloride (NaCl) used in processing certain synthetic fibres and the use of intractable dyes present problems. The presence of Na^+ and Cl^- ions in solution in an effluent create difficulties when such effluent is discharged into a river – the water from which is used for domestic or agricultural purposes. Likewise the presence of dyes in river water used as a raw-water supply to a waterworks may create problems and extra expenditure to decolorize the effluent and eliminate any other concomitant effects.

The general tendency has been to encourage the discharge of textile wastes, particularly wool-washing liquors, after certain pretreatment, into the sewers of local authorities in the belief that in admixture with sewage these wastes can be satisfactorily treated at the municipal sewage purification works.

This would seem to be a better policy than to attempt treatment of the effluent alone without the addition of the requisite nutrients to adequately support biological degradation.

In illustration of this we have the case of an industrial township where a number of textile plants have been established and the plant to treat this combined wastewater – mainly effluent from textile factories – was originally a conventional-type sewage purification works consisting of screens, detritus channels, sedimentation tanks, biological filters, humus settlement tanks, digesters and rapid sand filters.

The wastewater received at the purification works results from contributions by at least ten textile plants processing a variety of textiles including cotton, woolen and synthetic fibres. The textile wastes contain as normal concomitants, dyes, sodium salts and detergents. In addition to the domestic sewage, effluent from a large chicken abattoir also forms an integral part of the daily flow to the wastewater treatment works. The chicken abattoir was established at a later date than most of the textile plants.

The combined wastewater arriving at the works contains significant amounts of metal ions, e.g. chromium, nickel and mercury. The 4 hours oxygen absorbed and chemical oxygen demand values are substantial.

The lack of adequate nutrients to sustain biological activity was considered to have caused malfunctioning of the wastewater treatment plant: later, the situation was somewhat improved by the establishment of the chicken abattoir.

The presence of metal ions such as nickel and copper may have adversely affected sludge digestion.

At an early stage it became evident that the wastewater works was not responding in the manner anticipated.

Difficulties arose in the settling of suspended material and also in biological filtration. The digesters lost their effectiveness and the sludge produced was difficult to de-water and lacked fertilizing properties acceptable for disposal on farm land.

Added to these difficulties, was the necessity to exercise increased surveillance of the operation of the sand filters and greater attention had to be paid to the back-washing of these.

In order to alleviate conditions, alteration of certain units and changes of their functions had to be resorted to in order to produce an effluent of General Standard quality.

In order to initially improve solid/liquid separation the wastewater was caused to flow through two balancing lagoons which were provided at the intake to the works. Surface (floating-type) aerators were installed in the lagoons and flocculants used were aluminium sulphate and "floccotan" – a flocculant prepared from wattle extract. Later other flocculants were employed.

The function of the sludge digesters was altered – these being converted to settlement in order to improve the functioning of the sand filters.

The settled sludge which was gelatinous in character was difficult to de-water and was disposed of on land.

The modifications to the plant units and their function were carried out through necessity and were aimed at ensuring an effluent of satisfactory quality.

The stage has been reached where extension of the works has been provided in the form of a bubble-cap aeration activated sludge plant.

This plant was also designed to provide for the biological removal of phosphate. This is aimed at preventing eutrophication of a large water impoundment downstream of the point of discharge of the final purified effluent into the river. However, this new plant (extension), so far, has not proved to be the panacea hoped for.

Comment: The problems which arose at this wastewater treatment works and the methods used to overcome them clearly draw attention to the undesirability of over-powering with textile effluent a wastewater purification works designed in accordance with accepted sewage purification practice. It would seem clear that in planning industrial townships and growth areas it is undesirable to have a preponderance of textile plants unless their combined effluent load and concurrent ill effects are satisfactorily counterbalanced by an adequate volume of other effluents containing nitrogenous matter (e.g. sewage). In this connexion it should be noted that even with wool scouring wastes Petru[10] has found that after pretreatment with calcium hydroxide or calcium chloride followed by removal of grease, as

far as possible, by centrifugation, the resultant waste could be treated in admixture with sewage by the activated sludge process provided the rates of scouring waste to sewage was 1:10. Initially, the ratio at start-up, should be 1:30; a little later 1:20 and finally 1:10.

CASE HISTORY NO. 5

Problems of Colour and Salt

Problems have arisen with a textile plant situated in a small town provided with a sewerage system and a sewage purification works discharging purified effluent into a river. This river (or stream) is a tributary of another river from which a popular seaside resort abstracts water downstream by a well-point system in the river.

Both rivers flow through sugar-cane fields, the river water being used for irrigation of the sugar-cane.

The textile factory management have effected in-house changes to reduce the quantity and pollutional load of the effluent and have installed a surge tank and metering arrangements to meet the requirements of the municipality into whose sewerage system the factory effluent discharges.

The factory processes texturized polyester and polyester/viscose cloth. The wet processing operations are scouring and dyeing. No sizing agents are used in the weaving process. The cloth produced is scoured before dyeing and the fact that salt (NaCl) is used in viscose dyeing gives rise to a high Na^+ value (c. 250 mg/ℓ) in the final effluent. Organic pollution arises from the dispersing and dye-fixing agents. The wastewater from scouring contains spinning and anti-static oils, detergents, and sometimes, sodium carbonate.

The final effluent has a 4 hours oxygen absorbed value of the order of 50 to 60 mg/ℓ and the Chemical Oxygen Demand (COD) is of the order of 500 to 600 mg/ℓ.

The daily volume of effluent discharged into the municipal sewerage system by the factory constitutes a large portion of the daily flow arriving at the sewage purification works.

The Municipal sewage purification works is of modified conventional design incorporating the following units: screen, detritus channels, "night soil" and conservancy tank sewage intake with wedge-wire screen, high-rate (roughing) biological filter (with 3,6 m depth of plastic media), humus settlement tank, secondary biofilter (with 1,8 m depth of stone media), clarifier, upward flow pebble filters, chlorine contact tanks, sludge digester and sludge drying beds.

"Night soil" and tanker contents constitute supplementation from a neighbouring built-up area in an attempt to improve the work's performance necessitated by the disproportionate amount of textile effluent in the sewage arriving at the sewage purification works.

It has been found that the final effluent from the sewage purification works does not conform with the requirements of the General Standard, more particularly in respect of colour and sodium content.

In an endeavour to eliminate colour and sodium salts at the textile plant a number of methods have been considered. These have included:
Separation of dyebath wastewater and rinse-water and disposal of the former by the following methods viz. –

(1) Evaporation, both natural in shallow ponds and by means of suitable evaporators (e.g. multiple-effect, vapour re-compression);
(2) Reverse osmosis;
(3) Ultrafiltration;
(4) Electroflotation;
(5) Activated carbon treatment;
(6) Discharge of saline dyebath water (after decolorization) to the sea by pipeline.

The first four of these methods were originally rejected for a number of reasons including being beyond the financial capability of the factory. However, the feasibility of the last method was under review. The factory provides quite a number of work opportunities for the townsfolk and the municipal council receives revenue by way of rates and the extra charges made for acceptance of the textile plant effluent to the sewers. Therefore, to re-site the factory would constitute a hardship to the owners and the municipality alike.

The possibility of extending the present works and incorporating an activated sludge plant in concert with an extension of the town's sewerage system has been actively canvassed. The financing of this project – in the main – would have to rest with the textile company. It is considered that with the extra activated sludge treatment the quality of the effluent would be considerably improved and the colour eliminated or satisfactorily diminished. It has been proposed that with the extra treatment units to be incorporated the effluent will conform with the quality requirements of the General Standard save in respect of Na^+ content, 4 hours oxygen absorbed, Chemical Oxygen Demand (COD), total dissolved solids, chloride and *E. coli*. The average composition of the raw sewage entering the works is approximately as follows: pH value 7,0 to 9,5; suspended solids 100 mg/ℓ; Chemical Oxygen Demand (COD) 450 mg/ℓ; free and saline ammonia as N: 6 mg/ℓ; chloride as Cl: 350 mg/ℓ.

The composition of the final effluent produced from the above influent sewage was of the following order: pH value 8,3; suspended solids 17 mg/ℓ; 4 hours oxygen absorbed 50 mg/ℓ; Chemical Oxygen Demand (COD) 250 mg/ℓ; free and saline ammonia as N: 2,5 mg/ℓ; chloride as Cl: 350 mg/ℓ; sodium as Na: 220 mg/ℓ.

Dilution of this effluent by the tributary water dur-

ing periods of normal flow reduces the 4 hours oxygen absorbed value to 30 mg/ℓ (General Standard requirement 10 mg/ℓ) and the Chemical Oxygen Demand (COD) value to 120 mg/ℓ (General Standard requirement 75 mg/ℓ).

Sodium (Na^+) Content of the Effluent: The main objection to an effluent containing a high Na^+ content is from the point of view of irrigation – in regard to the deleterious effect it has on soil conditions and plant growth.

Gypsum ($CaSO_4.2H_2O$) was applied to tracts of grassland in Germany well before the end of the last century (19th century) with success. Its use on land in other countries e.g. France and the USA for a variety of crops was also a success.

Gypsum was considered by agricultural scientists at the time that its chief value lay in the fact that it acts on the potash present in the soil and so renders that available for plant needs. However, today it would be considered more efficacious to use a potash-containing fertilizer.

Yet, in effluent disposal, gypsum has a distinct use and it is recommended for application to irrigated land to ensure efficient drainability of the soil.

To evaluate the suitability of an effluent for irrigation on a soil the Sodium Adsorption Ratio (SAR) requires to be known. This is calculated from the following formula:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where the cation concentrations Na^+, Ca^{++} and Mg^{++} are expressed in milli-equivalents.

In most cases a SAR value not exceeding 8 should be aimed at. Permeability problems are also related to the carbonate (CO_3) and bicarbonate (HCO_3) content in the irrigation water which, of course, has been disregarded in the SAR formula above. When drying takes place between periods of irrigation a certain amount of CO_3 and HCO_3 reacts with the soil water to precipitate $Ca - MgCO_3$ thus removing available Ca and Mg from the soil water and thereby increasing the sodium hazard. As a result, the Residual Sodium Carbonate (RSC) has been used in some cases for assessing the suitability of an irrigation water.

The former concepts of SAR and RSC have been refined to give what is referred to as the adjusted Sodium Adsorption Ratio (adj. SAR) which is given by the following formula:

$$\text{adj. } SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \; [1 + (8{,}4 - pHc)] \ldots\ldots \quad (2)$$

where pHc is the calculated pH value of the irrigation water in contact with lime in equilibrium with soil CO_2.

Na, Ca and Mg are in milliequivalents per litre and pHc is calculated from the analyses values, viz. –

$pHc = (pK'2 - pK'c) + p\,(Ca + Mg) + p\,(Alk)$

Where, in turn –

$(pK'2 - pK'c)$ is obtained from using the sum of $Ca + Mg + Na$ in meq/ℓ;

$p\,(Ca + Mg)$ is obtained from using the sum of $Ca + Mg$ in meq/ℓ;

$p\,(Alk)$ is obtained from using the sum of $CO_2 + HCO_3$ in meq/ℓ.

Values of pHc above 8,4 indicate a tendency to dissolve lime from the soil through which the water moves; values below 8,4 indicate a tendency to precipitate lime from the water applied in irrigation.

In order to maintain the state of aggregation of the soil (tilth) and ensure good permeability thereby, the practice usually followed is to add gypsum ($CaSO_4.2H_2O$) in controlled amounts to ensure that the SAR [according to formula (1)] does not exceed 8,0.

Should an area of land be over-irrigated or the permeability allowed to deteriorate by non-application of gypsum or skimping thereof the situation created from an effluent disposal point of view would be one of potential pollution danger by allowing runoff into a river apart from ruining the soil and crops or pasturage for animals.

Purified domestic sewage effluent has proved satisfactory as irrigation water. However, industrial effluents *per se* or in admixture with purified sewage and having a high concentration of sodium salts are unsatisfactory in many cases.

Irrigation water containing a high sodium content can cause severe soil permeability problems giving rise to ponding and runoff with resultant deterioration in crop germination, soil aeration and causing a proliferation of weeds and disease of crops.

During rainy periods considerable dilution of the effluent in the river takes place. However, during dry periods of low river flow it would be necessary to observe the SAR values carefully.

Removal of Colour: During a recent year's dry period (1980) the seaside town mentioned has had reason to complain about the quality of the water abstracted from its well-point system in the river and in order to ameliorate conditions, particularly in respect of colour and taste for users of the municipal water supply, has had to resort to treatment with extra chemicals and with activated carbon. This means that someone other than the polluter is paying for the effects of pollution!

During periods of normal rainfall the seaside town's waterworks has been able to cope satisfactorily with the raw water abstracted from the river without additional expense and effort. To avoid similar difficulties in the future a new well-point system has been placed in the main river upstream of its confluence with the tributary which receives sewage

purification works effluent.

Comment: So far progress in this case has not been positive. Most options which appeared to offer a solution have been eliminated. However, due to developments which have taken place in ultrafiltration membrane technology the course likely to be followed by the company will be ultrafiltration and evaporation.

However, if it is found possible to alter the ingredients for dyeing thereby eliminating the use of sodium chloride and switching to dyes which can be decolorized inexpensively the textile factory will have achieved a breakthrough. This, however, would call for research and an ability to innovate on the part of the textile factory management.

Rationale

In considering progress in this field of pollution control recourse has been had to problems which have been encountered at five (5) selected textile factories and the means used, in each case, to achieve a solution. The five case histories cited illustrate a reasonable array of problems met with in the industry.

The textile industry is a highly competitive one and entrepreneurs and managements have to actively address themselves, on a continuing basis, to new market objectives and in doing so, from time to time may make decisions which create difficulties from the point of view of disposing of the effluent.

To know whether pollution difficulties are likely to arise with the use of new dyes and other chemicals as well as new and novel procedures calls for a great deal of foresight on the part of the individual innovators in the field and an even greater prescience on the part of those who have to deal with the effluents from such innovative processes discharged from factories.

It will be realized that where a textile plant of reasonable size is established within the municipal area of a large local authority possessed of adequate sewage purification facilities such textile wastewater can be conveniently disposed of by discharge into the municipal sewerage system. However, effluent discharged into a municipal sewer must conform with the requirements set out in the effluent acceptance by-laws of a particular local authority.

Naturally, the dilution which the textile effluent receives before reaching a sewage purification works is an important factor thereby attenuating the colour and salt concentrations.

The case histories selected indicate that textile waste, after pretreatment to remove useful recoverable material (e.g. wool grease in the case of effluents from worsted factories), to adjust the pH value and to remove toxic metal ions (e.g. mercury), may be added at a controlled rate, to sewage. Such mixture may be satisfactorily dealt with by a large sewage purification works. Treatment of textile effluent in admixture with sewage at a large and efficiently operated sewage purification works may lead to the elimination of colour but the inorganic salts will remain though their concentration will be lessened in the final effluent from the sewage purification works.

Sodium (Na) and chloride (Cl) ions will report in the purified effluent from the sewage purification works and it is important that the concentration of these shall not render the (sewage) effluent or the water in the river into which the effluent discharges unfit for agricultural, industrial or domestic purposes.

On this account the management of textile factories should be encouraged to recover, where possible, sodium-containing salts and support any move in the dyeing processes towards using satisfactory substitutes for chemicals containing sodium and chloride ions.

Where suitable land and sufficient of it is available effluents from textile plants, after pretreatment, may be irrigated on such land provided certain conditions are fulfilled.

In order to discharge effluent from a textile factory into a municipal sewer it is important to provide for a large surge tank and flow metering device at the factory effluent discharge point to ensure a fairly uniform and even discharge and metering of effluent into the sewer.

The importance of avoiding a preponderance of textile effluent in relation to the amount of sewage being treated has been indicated.

In cases where a larger volume of textile effluent has to be treated in relation to that of the sewage the importance of mixing followed initially by anaerobiosis and finally aerobic treatment has been clearly shown.

The prospective unsatisfactory denouement of a textile manufacturing venture, where the factory is set in a small town with a small sewage purification works discharging effluent into a tributary of a river forming the drinking water supply of a town, has highlighted the necessity for the correct siting of a textile plant from a pollution control point of view. In this instance the considerations of the economics of the venture were probably sound but those of effluent disposal were of a more evanescent and hopeful nature.

REFERENCES

1. Raistrick, A. *"Industrial Archaeology"*, Granada Publishing, London, Toronto, Sydney, New York, 1912, p. 95.
2. *"British Industry Today, Textiles and Clothing"*, H M Stationery Office, London, 1978, p. 2.
3. Eldridge, E.F. *"Industrial Waste Treatment Practice"*, McGraw Hill Book Company Inc., 1942, p. 238.
4. Southgate, B.A. *"The Treatment and Disposal of Industrial Wastes"*, H M Stationery Office, London, 1948, p. 183.

5. Information supplied by the Central Statistical Services, Department of Constitutional Development and Planning (S. Africa).
6. "IMIESA", *J. Instn. Municip. Engnrs. S.A.*, July, 1982, p. 43.
7. Schlesinger, H.A., Dul, E.F. and Fridy, T.A. *"Industrial Pollution Control Handbook"*, Herbert F. Lund (Editor-in-chief), McGraw Hill Inc., 1971, pp. 15-27.
8. Irukayama, K. *"The Pollution of Minamata Bay and Minamata Disease"*, *"Advances in Water Pollution Research"*, Proc. 3rd Internat. Conf., Munich, Germany, Sept. 1966, Vol 3, pp. 153-174. (Pub. by Wat. Pollut. Control Fed.)
9. Tucker, A. *"The Toxic Metals"*, Earth Island Limited, 3 Grays Inn Place, London W.C.1, 1972, p. 15 et seq. (*"Mad Cats and Dead Men at Minamata"*).
10. Petru, A. *"Combined Treatment of Wool-Scouring Wastes and Municipal Wastes"*, *J. Proc. Inst. Sew. Purif.*, 1964, 5, 497.

15(6) WASTEWATER PROBLEMS IN THE BREWING INDUSTRY

I BEER

"Ale is the natural drink of Englishmen and made of malt and water. Beer which is composed of malt, hops and water is the natural drink of the Dutchmen and of late is much used in England to the great detriment of many Englishmen" . . . Sixteenth Century definition of ales and beers.[1]

Introduction

Beer is a beverage containing 3 to 6,5 per cent alcohol (C_2H_5OH) prepared from grain (usually barley) which has been allowed to germinate and produce the enzyme diastase. The germinated grain is then dried and cured at a gentle heat (torrefied). The product thereby resulting is called malt. The malt has the power of converting the starch in the grain into malt sugar or maltose. This is then converted by the growth of yeast in it into alcohol and carbon dioxide. Hops extract is added as an adjunct to impart a bitter flavour to the beer and also to prevent the growth of undesirable organisms. Further, the tannic acid in the hops aids in precipitating proteins which would otherwise impair the quality of the final product.

Malting: Many breweries do not make their own malt but purchase it from recognized maltsters or malt supply houses.

Lager, Ale, Stout and Porter: Brewing of lager beer employs bottom yeasts – so-termed due to the employment for fermentation of yeasts which settle to the bottom of the fermenter. On the other hand yeast selected for the production of ale rises in a relatively thick foam to the top of the fermenting ale in the fermenter.

In the brewing of stout a portion of specially roasted malt is included. This imparts the dark colour and particular flavour to the stout but care must be taken in the method of roasting to prevent contamination from fumes if the heat source is a coal fire.

A point to remember in the manufacture of beer is the quality of the water used and many beers depend for their popularity on the nature of the water used.

The word "beer" can be regarded as including all malt liquors while the term ale includes all but "stout" and "porter".

Porter[2] originates from the fact that this beverage was drunk mainly by porters: it became well accepted in the early part of the 18th century since it was largely imbibed by porters who were in the habit of drinking "Three Threads", i.e. one-third ale, one-third beer and one-third "twopennies", so a beer was prepared with the flavour of the mixture which saved the bartender the inconvenience of going to three casks to prepare the mixture for a client.

Historical

The art of making beer was discovered as far back as 4 000 to 7 000 BC having probably spread from the valleys of the Tigris and Euphrates to the Nile.[3] Archaeological evidence suggests that there was a well-developed and nationalized industry in the Nile Valley c. 6 000 BC. From Egypt the art spread to Greece and thence onward throughout the whole of Europe – but never became firmly established in the vine growing centres bordering the Mediterranean[4] where wine was produced.

Anderson[3] considers that the Phoenician Traders who came to England may have taught the English the art of beer making in addition to their normal practises of fermenting honey to make mead and apples to make cider.

The word beer is said to be derived from the Saxon word "baere" meaning barley. During the Roman occupation of England the drink rivalling imported wine was beer (Cervesa[5]) (cf. Latin cer(e)visia – beer; cerevisiae coctor – brewer).

It is well to remember that though brewers yeasts, e.g. *Saccharomyces carlsbergensis* (bottom yeast) and *S. cerevisiae* (particularly the latter) give rise to ethanol and carbon dioxide as the major products of sugar dissimilation: brewers yeasts are unable to ferment the polysaccharides of barley grain and so these have first to be hydrolysed to simple sugars. The hydrolytic breakdown is initiated during the malting stage. The barley corns after steeping in water for 2 to 2,5 days are spread out on the malting floor to a

depth of about 1 foot (30 cm) or, in modern malting houses, placed in slowly revolving drums or in aeratable boxes. Germination as evidenced by sprouting is allowed to proceed for 5 to 7 days during which time each barley corn produces a short rootlet and a short acrospire. Additional hydrolytic enzymes are formed during malting, notably α-amylase, proteolytic enzymes as well as extra β-amylase. Germination is stopped at an appropriate stage by "kilning" the grain, the temperature being raised to about 80°C.

Malting Procedure

In malting, the barley is cleaned and soaked in water so that the grain can take up the moisture needed for germination (sprouting). The water is then drained off and sprouting continued for 5 to 7 days (refer to Figure 1). During this germination process the malt requires to be turned over frequently to prevent overheating and to ensure uniform growth. When growth is complete as noted by the length of the acrospire (or germ) and the hardness of the endosperm the sprouts are killed by kilning the malt, the sprouts and rootlets removed physically and the malt aged for several weeks, after which it is ready for use in a brewery.

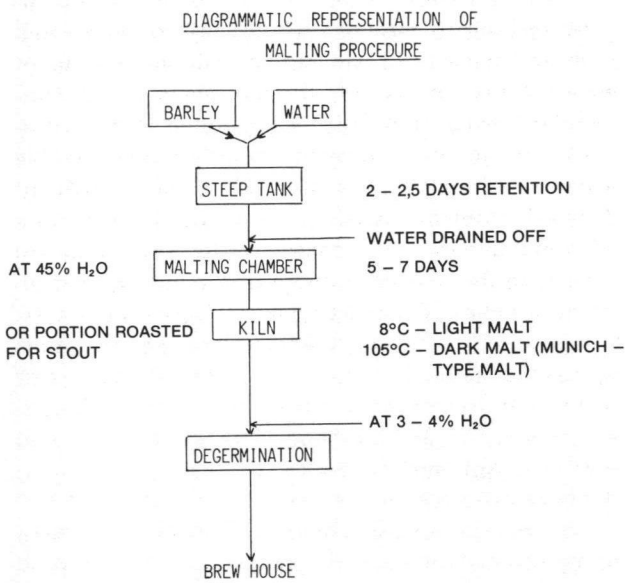


Figure 1

During the malting process, the amounts of certain enzymes are increased and new ones formed. Important enzymes present are α-amylase and β-amylase.

An average malt has the following composition calculated on the dry weight:[6]

Constituent	Per cent
Starch	59
Sugars	10
Gums	10
Cellulose	5
Protein	19
Fat	2,5
Ash	2

Anderson[3] has illustrated the process and materials used in brewing beer substantially as follows (Figure 2):

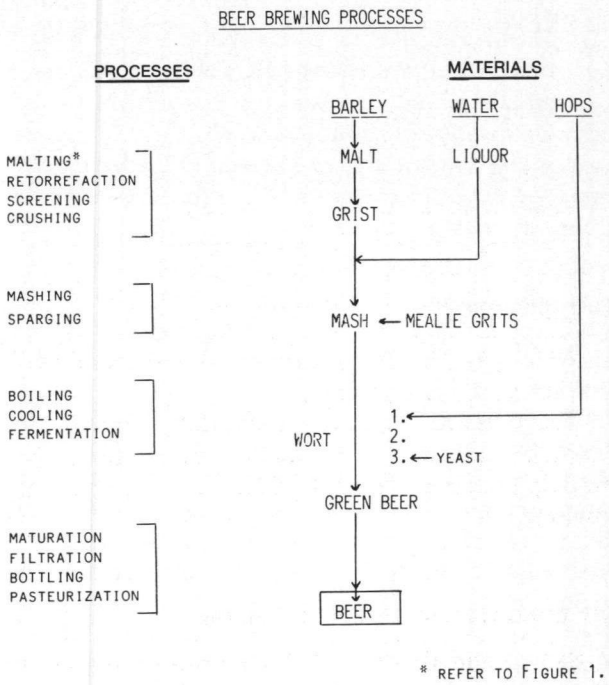


Figure 2

Hops

The hop is a perennial plant botanically considered as being allied to the Canabinacea or hemp family. The common variety is referred to as *Humulus lupulus*. The plant is dioecious i.e. the male and female flowers are produced on separate plants. It is the female flowers that are used by the brewers. The female flowers grow together to form cones which develop a yellowish powder known as lupulin which contains resins and essential oils.

Hops impart a flavour, act as a preservative and aid in clarifying the wort. Tannin, which is extracted from the petals assists in precipitating suspended matter in the wort.

After hop treatment the wort is sterile and enzymic activity has ceased. Subsequently yeast is added to the wort and fermentation allowed to proceed – either top or bottom yeasts being employed.

Beer Qualities Favoured: Apart from the flavour which is a property subjective to individual palates two other properties are sought after, viz. –

(1) Clarity;
(2) Frothing properties.

Cloudy barrels of beer may be clarified by the well-known physico-chemical process of sensitization by adding a small amount of protein material such as isinglass, gelatin or egg albumin in the form of the contents of a broken egg to a barrel of beer.

Frothing can be accentuated by the addition of artificial frothing agents such as saponin* (H Fruendlich in his book *"Colloid and Capillary Chemistry"*, Methuen, London, 1926, p. 792 states that . . . "A solution containing 0,01 g saponin per litre froths very strongly").

Brewery Wastes

The chemical constitution of brewery waste has been determined by Thiel and du Toit[7] of the National Institute for Water Research of the South African Council for Scientific and Industrial Research (NIWR).

Detailed chemical analysis of a number of samples of combined effluent from the brewhouse and cellars of a brewery (within the South African Breweries Limited Group) with a daily wastewater flow of c. 500 000 gallons (2 273 m^3) are given by these authors in which attention was paid to possible deficiencies of nitrogen and phosphorus-containing compounds and the impact such deficiencies might have on the treatability of the wastewaters.

*Saponins are natural glycosides and though toxic to fish and also warm-blooded animals when injected into the blood stream they are not absorbed from the intestines. Hence fish killed by or caught by the aid of saponins and beverages containing saponins e.g. root beer and beer when ingested by man are not toxic.

Composition and Nutrient Value of Beer

A beer of 4 per cent alcoholic content could have the following composition [Table I(A)]:[8(a)]

Table I(A)

Constituent	Per cent
Water	90
Ethyl alcohol	4
Carbohydrate	4,4
Protein	0,6
Calcium	0,004
Phosphorus	0,026
Riboflavin	0,0003
Niacin	0,0002
Thiamin	Trace

Wilson, Fisher and Fuqua[8(b)] in dealing with the constituents in foods give the following values for beer [Table I(B)]:

Table I(B)

Approx. Measure	Weight g	H_2O %	Energy Kcal	Protein g	Fat	Fatty acids			Carbohydrate g	Ca mg
						Saturated	Oleic	Linoleic		
12 fl. oz.	360	92	150	1	0	—	—	—	14	

Fe mg	Vitamin A Value I.U.	Thiamin mg	Riboflavin mg	Niacin mg	Vitamin C mg
Trace	—	0,01	0,11	2,2	—

— No results available

Bingham[8(c)] gives the average nutrients in 300 mℓ (0,5 pint) of beer as follows [Table I(C)]:

Table I(C)

Nutrients	Bottled			Draught	
	Pale Ale	Stout	Mild	Bitter	Strong
Alcohol	10	8	8	9	20
Energy (kilojoules)	405	465	315	390	920
(kilocalories)	95	110	75	95	220
Protein (grams)	1	1	0,5	0,75	2
Carbohydrate (grams)	6	12	5	7	18
Potassium (milligrams)	145	135	100	120	330
Other minerals		Small		amounts	
B Vitamins:					
Thiamin (milligrams)			average 0,012		0,03
Riboflavin (milligrams)			average 0,15		0,3
Nicotinic acid (milligram equivalants)			average 2,1		4,5
Pyridoxine (milligrams)			average 0,18		
Pantothenic acid (milligrams)			average 0,3		
Biotin (micrograms)			average 1,5		
Others	—	—	—	—	—
Vitamin A and C	0	0	0	0	0
Vitamin E	—	—	—	—	—

— No results available

Bingham states that beer contains alcohol and sugar [cf. Table I(C)], both of which supply energy. Most beers, she states, contain from 75 to 120 kilocalories per half pint (300 ml); from 6 to 13 grams alcohol (C_2H_5OH) for the same volume (300 ml) and from 4 to 13 grams carbohydrate for a similar aliquot.

Beer, though a good source of B vitamins, is poor in thiamin (vitamin B), which is retained in the brewer's yeast. It is also lacking in vitamins A and C.

Composition of Brewery Wastewater

pH and COD values reported for hourly samples and seven daily composite samples of combined brewhouse and cellars effluent have been reported by Thiel and du Toit (Table II):[7]

Table II

Sample No.	pH Value			COD		
	Max	Min	Composite	Max	Min	Composite
1	9,5	3,9	5,3	69 800	600	7 000
2	8,3	2,0	6,5	34 600	500	6 000
3	11,1	3,3	5,7	13 800	900	7 000
4	13,0	2,5	12,3	36 500	100	7 200
5	11,1	6,0	7,1	3 400	50	500
6	8,2	7,3	7,2	2 800	150	500
7	11,1	3,8	6,4	41 000	160	4 700

From Table II it is abundantly clear that wide variations of pH values and COD values occur throughout each day and from day to day.

Thiel and du Toit have given results of more comprehensive analyses of seven consecutive daily composite samples of combined brewhouse and cellars effluent; of these, 3 consecutive daily composite samples have been taken – this number being considered sufficient for discussion of results.

It will be seen from the results given in Table III that 29 per cent [actually nearer 1/3 (33,33 per cent) for the seven samples] of the COD can be removed by settlement.

The authors state that Helmers, Frame, Greenberg and Sawyer[9,10] have indicated that the optimum C/N ratios lie within the range 10/1 to 20/1. It will be observed in Table III that the C/N ratios are well beyond this range which may indicate nutrient deficiency and consequent difficult treatability unless the deficiency is made good.

Thiel and du Toit have given references to a number of investigators who have encountered "bulking" troubles in their attempts to treat brewery wastes by the activated sludge process and to others who encountered difficulties with biofiltration methods of treatment.

In dealing with breweries Ruffer[11] has stated that due to the high concentration of carbohydrates in solution and undissolved protein the BOD of brewery wastewater is of the order of 1 000 to 4 000 mg/ℓ. As a result the aerobic biological treatment of the wastewater, *per se*, or in admixture with sewage has

Table III
Analysis of Combined Brewhouse and Cellars Effluent
Composition of three consecutive daily composite samples

Parameter	1			2			3		
	W	S	C	W	S	C	W	S	C
pH Value	—	—	5,3	—	—	6,5	—	—	5,7
Conductivity (μmhos at 20°C)	—	—	460	—	—	520	—	—	410
Total solids (mg/ℓ)	4 950	4 500	4 180	3 910	2 800	2 670	3 250	2 680	2 580
Volatile solids (mg/ℓ)	4 630	4 090	3 830	2 710	2 380	2 280	2 880	2 390	2 230
Volatile solids % of Total solids	94	91	92	69	85	85	89	89	87
COD (mg/ℓ)	7 000	4 900	4 700	6 000	4 000	2 300	7 000	5 300	5 100
Organic carbon calcd. from COD (mg/ℓ)	2 630	1 840	1 770	2 260	1 500	865	2 630	1 990	1 920
Ammoniacal nitrogen (mg/ℓ)	—	—	<2	—	—	<2	—	—	<2
Organic nitrogen (mg/ℓ)	88	48	28	61	36	18	79	46	28
Volatile fatty acids (mg/ℓ as acetic acid)	—	—	270	—	—	250	—	—	220
Free amino acids (mg/ℓ as leucine)	—	—	75	—	—	30	—	—	50
Total amino acids (mg/ℓ as leucine)	400	250	140	330	160	80	425	200	125
Free reducing sugars (mg/ℓ as glucose)	—	—	1 500	—	—	600	—	—	500
Total sugars (mg/ℓ as glucose)	3 660	3 100	2 900	1 870	1 790	1 720	2 200	1 970	1 750
Orthophosphate (mg/ℓ as P)	—	—	6,5	—	—	3,9	—	—	6,2
Total phosphate (mg/ℓ as P)	20,6	16,3	14,4	18,3	12,7	10,1	23,2	18,9	14,0
Sodium (mg/ℓ)	—	—	30	—	—	60	—	—	30
Potassium (mg/ℓ)	—	—	25	—	—	20	—	—	40
C/N ratio	30	38	63	37	42	48	33	43	68
C/P ratio	130	110	120	120	120	86	110	110	140

Legend
W = Whole sample;
S = Supernatant liquor after settling for 2 h;
C = Supernatant liquor after centrifugation.

often given rise to failure.

In this connexion he emphasizes the fact that frequently bulking of activated sludge occurs and states that the main cause of bulking is the unfavourable ratio of available nitrogen to BOD and C-compounds as pointed out by Thiel and du Toit.[7]

He points out that Imhoff[12] recommends a nitrogen increase to 10 per cent of the BOD.

Miles and Southgate[13] have indicated that a ratio commonly adopted for wastes to be treated by the activated sludge process is BOD:N:P of 100:5:1. In biological filtration, they state, the necessary proportions of nutrients are rather less, since biological film remains in a filter bed for long periods, and on decaying releases nutrients previously assimilated. Brewery wastes they state, further, unlike those from maltings are usually deficient in nutrients.

They contend, further, that "with a favourable nutrient balance the organic constituents from brewing are decomposed by aerobic treatment processes at least as readily – indeed, probably more readily – than those of domestic sewage".

Treatment and Disposal of Brewery Wastewater

It is obvious that we have two situations to contend with, viz. –

(1) Where the brewery wastewater has to be dealt with on its own; and
(2) Where the brewery wastewater is treated in admixture with sewage at the sewage purification works of a local authority (or other body).

Invariably, situation (2) is the order of the day. A brewery is not a noxious industry and so can operate

in a built-up area where it is close to its customers and transport is satisfactory.

However, a large brewery operating in a small town, in all probability will upset the municipal sewage purification works if the brewery wastewater is accepted for discharge into the municipal sewerage system unless certain conditions are adhered to.

For successful operation of the sewage purification works the following matters are important, viz. –

(i) The content of nitrogen and phosphorus-containing material in the mixed sewage-brewery wastewater must be adequate to ensure satisfactory biological activity and the C/N ratio of the brewery wastewater should be in the range 10/1 to 20/1.

(ii) The yeast content of the wastewater should be low and live yeast cells absent. The presence of live yeast can cause clogging of sewers and undesirable side-effects at the sewage purification works – particularly in the clarifiers.

(iii) The provision at the brewery of a balancing tank of adequate size (In a Yorkshire (England) brewery a settlement tank of 24-h capacity of effluent has been used). However, a settlement tank with a retention period of 2 h (average daily flow) followed by a balancing tank of 6 to 8-h capacity should be installed to ensure a discharge of wastewater to the sewerage system of fairly uniform composition and rate of flow.

Large fluctuations in composition and quantity of wastewater will deleteriously affect the operation of the sewage purification works.

(iv) Adjustment of the pH value to neutrality (pH 7,0) with lime before settlement and discharge into the sewerage system at this pH value.

In the case of a brewery which discharges its wastewater into a sewerage system reticulating sewage to a very large sewage purification works, major difficulties normally do not arise under normal working operations of the brewery and the sewage purification works.

Note: The wastewaters from a brewery arise from the cleaning of receptacles, process units, floors, bottles, casks, vats, fermenters, etc. A great deal of water is used for cleansing and alkalis and detergents are employed in the water. The pH value of the beer is c. 4,0 and stale beer has a lower pH value. Hence brewery wastewater as a whole is acidic.

II SORGHUM BEER

There is a legend among the Zulus concerning one Nomkubulwana, the Princess of Heaven, "who seems to be a kind of goddess of the corn, virtually a Zulu Ceres presiding over the growth of the grain and from her, it is said, the people learned how to make beer."[14]

Historical

This beverage which was originally the "home-brew" of the Blacks in Africa was initially termed by the Whites, "Kaffir Beer", then "Bantu Beer" and now "Sorghum" beer. The terms "Kaffir" and "Bantu" have been dropped for sensible reasons. However, the retention of the term beer is hardly appropriate when used in comparison with the normal image of beer.

Wilson[15] has stated that, "It is unfortunate that the word 'beer' should have been used in naming the Native product for it is utterly unlike the beers drunk by Europeans. Partly fermented Kaffir corn malt gruel is a fair description of the product", he considered.

Millet

According to Muller and Tobin[16] the most important of the millets is the giant millet called sorghum (*Sorghum vulgare* which is synonomous with durra, jowar, Guinea corn, kaffir corn, Indian millet, Egyptian corn). It probably originated in Africa where Egyptian tomb drawings show it in 2 200 BC and Assyrian ruins in 700 BC. Today sorghum has a wide distribution, growing in Africa, India, North China, Manchuria and the United States.

In the 1979 Annual Report of the Council for Scientific and Industrial Research (CSIR) it is stated that "The greater part of the sorghum grain used in South Africa is made into malt for the preparation of sorghum beer".

Apparently, the varieties that give prolific yields are not necessarily the best for sorghum beer manufacture and are not bird-proof. The National Food Research Institute has greatly improved the malt supply position by making it possible to use bird-proof sorghums (KF class sorghums), a class previously unsuited for beermaking.

The Variety of Indigenous Beverages: Fox[17] pointed out that apart from the Black national drinks made mainly from sorghum there is the non-intoxicating drink marewu (pronounced mahow), simply made from mealie meal (maize) and wheaten flour – a pleasantly acid, refreshing and nourishing beverage which is easy to prepare and is supplied fairly generally by employers to Black workers.

Fox[17] also indicated that a number of illicit brews have developed. Among these he mentions Isiquataviki ("Kill-me-quick") which is made of porridge, bread, syrup, brown sugar, yeast and bran; Sekonovani made of yeast, sugar and warm water better known as skokiaan (Zulu). The makers and purveyors of illegal brews (with a "kick" in them) received the descriptive appellation of "skokiaan queens" and some of these have resorted to the addition of many questionable adjuncts even going to the extent of adding portions of questionable flora and reptilia.

Fox[17] quotes further interesting drinks, viz. – Isishishimenyane (contracted to shimeya), an onomatapoeic expression for the swaying motion of an intoxicated man. This drink was concocted by sugar-cane workers. One brewer, it is stated, first cooked potatoes, then added black yeast, brown sugar, syrup and brandy! Another used hops, syrup, brown sugar, white sugar, strained imithombo, potatoes (mashed with skin and yeast to make shimeya). Another notable drink is Babaton which is made of yeast, imithombo, white sugar and stale bread.

All the above drinks illustrate the ingenuity of the Blacks and are given merely to enable a correct idea to be had of what, in fact, constitutes sorghum beer apart from the other beverages illicit and otherwise.

White[18] points out that there are numerous Native drinks in South Africa such as sorghum beer (Tshwala, Joala, Utywala), Leting, Marewu (mahow) all made from grain (as referred to by Fox).

He states that these drinks are both food and drink for the Natives. Fox, in his long lifetime a notable nutrition-biochemist employed at the South African Institute for Medical Research (SAIMR), has previously made the following statement, "We may agree with many experienced observers when they class kaffir beer as a food rather than merely an alcoholic beverage. It is a food not only because as usually consumed it approximates to a thin cereal gruel, but also because it contains small but quite appreciable quantities of certain vitamins which are apt to be lacking in the diet of the Native as it stands at present" (i.e. 1938).

Early Fermentation Processes

In a somewhat similar manner sorghum beer has been to the Black man of South Africa what beer is to the White man. In Part I beer has been dealt with and its origin can be traced to ancient times – originating in the valleys of the Euphrates and the Tigris rivers – but fermented foods were the concern of prehistoric people e.g. cheese (made from soured milk), mead (from honey), beer (from barley), wine (from grapes). Even breadmaking with yeast was known in early times.

Obviously, fermentation beverages were made for their alcoholic content. But, in as much as little was known in ancient times about micro-organisms, cases of poisoning and other unpleasant consequences must have arisen from indiscriminate imbibition of dubious concoctions since some organisms e.g. *Bacillus cereus* causes food poisoning and *Aspergillus flavus* can produce aflotoxin, a carcinogen.

The yeasts have been widely used in fermentation. In the case of beer we have noted that the yeasts used are *Saccharomyces cerevisiae* (top yeast) and *Saccharomyces carlsbergensis* (bottom yeast) as used respectively for the production from barley malt of ales and lager. In the case of wine and rough cider the organism used is *Saccharomyces ellipsoideus* which can withstand greater acidity than *S. cerevisiae*.

Saccharomyces cerevisiae is the fermentation organism used for making mead and bread but for making saké from rice, *Saccharomyces saké* is the organism used. Saké, the standard Japanese alcoholic beverage, is made by saccharifying rice starch by enzymes from *Aspergillus oryzae* and fermenting the sugary waste with the yeast.

The above-mentioned yeasts are all well-known and are pure strains of yeast but Wilson,[15] after examining a sample of sorghum beer under the microscope, observed a very assorted flora. Wild yeasts and all forms of non-motile bacteria were present whilst over the field of view he observed swimming motile bacteria of all the usual shapes. In other words wild yeasts, motile and non-motile bacteria abound. Therefore, we are not dealing with a pure culture such as *S. cerevisiae* or *S. carlsbergensis* as in a normal beer.

White[18] points out that the drinks mentioned by him (*vide ante*) which also included Marula beer (Ukanya) play an important part in tribal life. Beer drinks are held at the schools of initiation for boys and girls, at courtships, at weddings, at funerals, at the sewing and gathering of crops. In fact, he asserts that beer drinks are often held as a means of settling arguments.

Large-scale Manufacture of Sorghum Beer

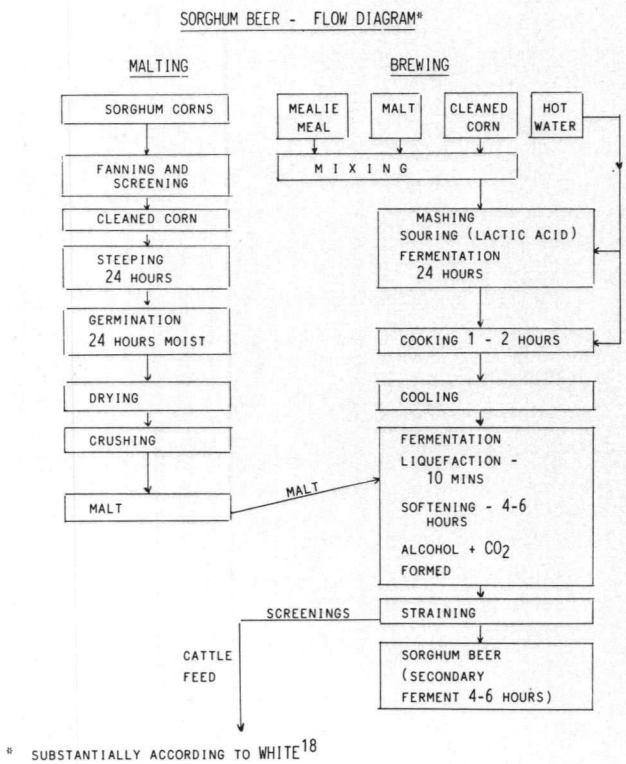


Figure 3

On January 1st, 1938, large-scale manufacture and sale of sorghum beer by local authorities was begun in South Africa. Durban Corporation had been in the field some years prior to this; this Borough Council actually began brewing in 1910!

This meant that the primitive domestic production of sorghum beer became a large-scale modern undertaking.

A study of sorghum beer manufacture was initiated at the Johannesburg Municipal Breweries and the city's biochemical laboratories only to be interrupted by World War II. However, work was continued by the National Chemical Research Laboratory of the CSIR from 1954 onwards and a great deal of useful work in this field has been done by Dr L Novelli.

Lazar[19] has given the procedure adopted at the Durban Municipal Brewery as reported to him in 1926, viz. –

"Germination proceeds between the temperatures of 70 – 90°F (c. 21 – 32°C), steeping occupies 15 to 40 hours, couching 2 days, withering 2 days, drying and curing 2 days. If the couch is turned or disturbed withering begins prematurely, and the corn is badly modified. 'We' work at relatively shallow depths and regulate temperatures by covering or uncovering with boards. With care 75 per cent of the grain germinates; if below this we adjust matters by using less new grain in the mash."

He gives the following results of analyses to illustrate the effect of malting on *sorghum vulgare* (Table IV).

Table IV

	Raw grain Per cent A	Grain after malting, drying and crushing Per cent B
Moisture	7,75	8,00
Acidity as lactic acid	0,058	0,076
Crude protein (N × 6,25)	9,34	9,45
Ether extract (fat)	5,49	2,88
Crude fibre	1,50	1,59
Reducing sugars	0,058	0,081
Non-reducing sugars. Sol. carbohydrates	2,66	5,02
Insoluble carbohydrates by difference	71,89	71,21
Mineral ash	1,30	1,25
NaCl	0,166	0,166
CaO	0,062	0,060
P_2O_5	0,676	0,701
Undetermined	0,40	0,32

Lazar[19] has also given results of malts from six sources from which he concludes, *inter alia*, that, –

(1) The moisture content of air-dried malts varies from 8 to 13 per cent. Artificial drying, he concludes, should reduce the moisture to 2 to 4 per cent.
(2) Titratable acidity is appreciably increased during malting.
(3) The sprouting process reduces the fat content.
(4) The increase of cellulosic material is accounted for by the development of long root fibres.
(5) The most important data are those on diastatic value.

The analyses show this to be absent from dried malts.

Additionally, Kamerman[20] has pointed out other important factors, viz. –

(1) Concentration of yeast – The velocity increase is proportional to the concentration till 6 per cent of yeast is present, after that the velocity is little affected;
(2) Concentration of sugar – In contrast to (1) the concentration of sugar has little effect on the velocity and provided the sugar concentration is maintained above 1 per cent no increased output can be attained by adding sugar.
(3) History of yeast culture – As is the case with all other living organisms the velocity of a metabolic reaction depends a great deal on the past history of the particular yeast organism. Old or ill-treated cultures show diminished activity. Such cultures become poisoned by their own waste products and this poisoning makes itself manifest in the so-called "tired" cultures. Fresh yeast, therefore, is better than old.
(4) Temperature – At 0°C fermentation proceeds slowly, but a rise in temperature brings about a progressively more rapid fermentation and at 20°C the velocity of fermentation is approximately twice that at 15°C. Most yeasts have their optimum temperature at about 25°C but a few thrive best at 35°C.
(5) The pH value of the fermenting liquid has a great influence on the end products. For ordinary alcoholic fermentation a pH value of from 5 to 6 is the best, but by judicious juggling with the acidity we can vary the end products considerably . . ."

Sorghum Beer – Food or Beverage

Novelli[21] considers that beverages are usually required to match up to the following requirements:

(i) Satisfy the thirst;
(ii) Delight the palate;
(iii) Provide stimulation.

He maintains that acid drinks generally slake one's thirst more satisfactorily than sweetish drinks. The lactic acid in sorghum beer is refreshing and thirst quenching.

One of the most important qualities of a good sorghum beer Novelli states is body, fullness, creaminess or smoothness largely due to gelatinized starch.

He points out, further, that sorghum beer has a high fusel oil content.

He gives the following information on fusel oil content:

Average sorghum beer	230 mg/ℓ
Average European beer	
(i) Brewed in South Africa	110 mg/ℓ
(ii) Brewed overseas	121 mg/ℓ

Illegally distilled concoctions he states have been found to contain 1 000 mg/ℓ of fusel oil – no doubt giving a good "hangover" to the imbiber!

Despite the high fusel oil content of sorghum beer it is not noted for "hangover"-producing properties – perhaps due to its high vitamin content.

Novelli states that sorghum beer is rich in B vitamins and gives the following relevant information (Table V):

Table V

Vitamin	Quantity in mg supplied by one Imperial quart (1,14 ℓ)		
	Sorghum Beer	European Beer	Milk
Thiamine	1,6	0,03 – 0,06	0,37
Riboflavin	1,0	0,39 – 0,64	1,95
Nicotinic acid	5,6	6,6 – 10,2	0,93

Other interesting characteristics referred to by Novelli for a typical sorghum beer include the following:

Total solids – 5 to 7 per cent (W/V), half of which is starch and 3 per cent alcohol.
Dextrins and sugars – small amounts.
Calorific value – 500 to 520 cal/quart i.e. equal to a half pound of bread or $^2/_3$ of a quart of milk.
Fat – Practically absent.
Protein content – 0,63 per cent.

As seen in Table V sorghum beer is rich in B vitamins which are derived from the sorghum, maize, malt and the yeast which is present substantially – unlike European beer the yeast is not filtered out.

Novelli concludes that sorghum beer is undoubtedly a beverage of great popularity which he says comes very close to being a food as well.

Perhaps he has overlooked the energy value of the alcohol present. (In dealing with alcohol Thorpe[22] states that alcohol has an energy value of 7 calories per gram i.e. greater than carbohydrate – thus alcohol must be admitted as a food although its use is somewhat restricted owing to its pharmacological action.) It has been stated that a double whisky has the same energy value as three eggs!

Fox has stated that in the Transkei "it appears that Native men can and do live for a considerable time solely on Kaffir beer, especially after a good harvest . . ."

The answer would appear to be yes – sorghum beer is both a beverage and a food.

Novelli stated[21] in 1963 that the brewing of sorghum beer was a municipal monopoly and a profit-making undertaking. However, the profits made (as at present) are ploughed-back for the welfare of the Blacks (clinics, etc.)

In order to improve the general quality of sorghum beer, research was started c. 1953 mainly due to the instigation of Mr I P Ferreira, at that time connected with the Non-European Affairs Department of the Vereeniging Municipality.

Initially, research was sponsored out of CSIR funds but in due course donations were received from local authorities and on May 11, 1955, the Institute of Administration of Non-European Affairs, clinched a research agreement and work was started on the malting of sorghum and brewing of sorghum beer. Further financial support was forthcoming from industry.

Subsequently on November 29, 1962 by Act No. 42 of 1962 arising from representations of the Department of Bantu Administration, the Minister of Bantu Affairs was empowered to establish a fund, to be known as the "Bantu Beer Research Fund".

One of the most pressing tasks was to undertake a survey of malts and malting yards. Special attention was paid to the development of diastatic power/activity.

In due course it was found that, unlike barley, high temperatures (25°C to 30°C) were needed for optimum malting.

Storage of Sorghum Beer

White[18] states that good beers can be stored for some days by refrigeration. However, it should be noted that (unlike European beer) the shelf-life of sorghum beer is short and poses problems from a sales point of view.

Corrosion of Vessels Holding Sorghum Beer

White[18] further states that ordinary iron vessels are rapidly corroded when used to hold the final brewery product. Aluminium, he states, is much better but the preferred material is undoubtedly stainless steel.

Waste from Sorghum Beer Manufacture

White[18] gives the following analysis of sorghum beer waste (screenings) after drying (Table VI):

Table VI

	Per cent by weight
Moisture	10
Ash	2
Protein (N × 6,25)	18
Fat	5
Crude fibre	5
Carbohydrate (by difference)	60
Calorific value: 4 to 5 calories per gram	
Analysis of Ash	
	Per cent by weight of ash
$Fe_2O_3 + Al_2O_3$	40
CaO	1
MgO	1
P_2O_5	14
K_2O	Trace
Cl	Trace

Gomes[23] classifies sorghum which may be used for making malt as follows:

(a) KR variety: This is considered the best and gives 20/25 bags per morgen (2 1/9 acre)
(b) KM variety: This sorghum gives twice the yield of KR variety but the diastatic activity of the malt produced is much less. However, treatment with formaldehyde effects improvement.
(c) Bird-Proof variety: This variety presented problems, due to the nature of the grain covering. However, this problem has been overcome (cf. Novelli).

Gomes[23] has given the details in Table VII concerning sorghum breweries he has visited.

Water Consumption

Hensen and Funcke,[24] in dealing with industrial water and effluent management in sorghum beer breweries, have quoted an average water consumption figure of water used to beer produced and sold of 4:1.

Sorghum Beer Losses

The same authors state that between 0 and 1,1 per cent of the total production of sorghum beer produced is lost.

Analyses of effluents taken at various breweries in the Pretoria – Witwatersrand area are given, *inter alia*, by Hensen and Funcke. (See Table VIII, p. 269.)

Disposal of Effluent

Most sorghum beer breweries are situated in "built-up" sewered areas of local authorities.

From information recorded the following desiderata would appear to be pertinent, viz. –

(1) Adjustment of the pH value of the effluent (e.g. by addition of lime) to a pH value just over 7,0.
(2) This to be followed by settlement in a suitable clarifier, further followed by a balancing tank of 6 to 8-h capacity (of the average daily flow).

Table VII

Brewery	Vol. of beer produced each month m³	Approx. water consumption per month m³	Vol. of effluent per month m³
1. Pretoria	8 000		55% of water consumption
2. Witbank	3 000	6 500	50% of water consumption
3. Rustenburg	2 000	1 198	
4. Potchefstroom	5 700	11 430	70% of water consumption
5. Ga-Rankuwa	1 000		
6. Ermelo	730	2 300	10% of water consumption
7. Nelspruit	1 500	5 800	17% of water consumption
8. Pietersburg	2 000	4 350	44% of water consumption
9. Randfontein	1 300	2 780	51,4% of water consumption
10. Standerton	2 000	6 125	
11. Nigel	unknown	215	2,2% of water consumption
12. Springs	unknown	4 800	27% of water consumption

Table VIII

(Sorghum Beer) Brewery	Effluent Composition (mg/ℓ except pH value)								
	1	2	3	4	5	6	7	8	9
pH Value	3,5 to 4,5	4,8	4,6	4,0 to 5,5	—	4,4	5,5 to 5,9	3,7 to 5,9	3,8
Oxygen Absorbed in 4 hours from acid N/80 $KMnO_4$ at 27°C	235 to 245	1 385	250 to 600	500 to 700	2 400	344	182 to 222	600 to 11 600	5 320
Free and saline ammonia as N	4,5 to 6,4	—	—	—	—	—	—	—	—
Suspended solids	1 470 to 1 700	—	—	—	—	870	—	—	530
Dissolved solids	1 485 to 2 135	—	—	—	—	704	2 930	—	—
Settleable solids	43 to 73	285	—	—	—	75	90 to 200	1,0 to 230	—
Chemical Oxygen Demand	4 580 to 6 670	—	—	—	—	—	—	—	10 570

Gomes[23] has indicated by diagram the effluent pretreatment plant at the Kwaggakop Brewery in Pretoria as follows (Figure 4):

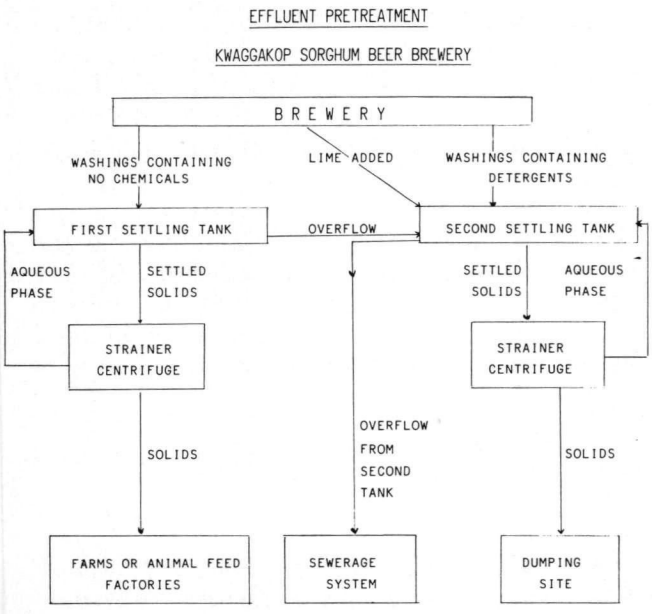


Figure 4

Although this does not indicate a balancing tank, the provision of two settlement tanks in series, depending on capacity probably serve this purpose.

The discharge of unsettled brewery waste can lead to chokage of sewers and such sewers, which are usually of concrete, can be severely corroded.

However, if the settleable solids are removed, the pH adjusted and the effluent discharged at a uniform rate into the sewerage system of a reasonable-size town such that dilution of the effluent with sewage is adequate, the mixture of the effluent and sewage can be adequately purified.

Administration Boards

Matters affecting the Black population of South Africa as they concern their specific interests are now administered by Administration Boards. These boards have been formed on a regional basis with a certain amount of self-autonomy which, *inter alia*, includes the control of the production and supply of sorghum beer, and the beerhalls in the Black townships.

REFERENCES

1. Anderson, A. (S.A. Breweries) Paper read to the Transvaal section of the S. Afr. Chem. Inst., *J. S. Afr. Industr. Chem.*, 1947, I (2) 29.
2. Anderson, A. Ibid. p. 26.
3. Anderson, A. Ibid. p. 26.
4. Rose, A.H. *"Industrial Microbiology"*, Butterworths, London, 1961, p. 160.
5. Richmond, I.A. *"Roman Britain"*, Penguin Books, Ltd., Harmoundsworth, Middlesex, England, 1963, p. 171.
6. Miller, B.M. and Litsky, W. *"Industrial Microbiology"*, McGraw-Hill Book Company, New York, London and Johannesburg, 1976, p. 168.
7. Thiel, P.G. and du Toit, P.J. *J. Inst. Brewing*, 1965, LXXI, pp. 509-514.
8. (a) Private Communication.
   (b) Wilson, Eva D., Fisher, Katherine H. and Fuqua, Mary E, *"Principles of Nutrition"*, 3rd Edn., John Wiley and Sons, New York et al., 1975, Appendix p. 550.
   (c) Bingham, Sheila. *"Dictionary of Nutrition"*, Barrie and Jenkins, London, 1977, p. 34.
9. Helmers, E.N., Frame, J.D., Greenberg, A.E. and Sawyer, C.N. *Sewage and Industr. Wastes*, 1951, **23**, 884.
10. Helmers, E.N., Frame, J.D., Greenberg, A.E. and Sawyer, C.N. Ibid, 1952.
11. Ruffer, H. Prof. Dr. Ing. *"Treatment of Highly Polluted Wastes in Germany"*, Paper presented to Workshop on New Aspects of Biological Treatment, Pretoria, 24 – 26 February, 1975.
12. Imhoff, K. Taskenbuch der Stadtentwässerung, 23 Aufl., München, 1972.
13. Miles, G.D. and Southgate, B.A. *"Modern Brewing Technology"*, Edited by Findlay, W.P.K., D.Sc., Beal, F.I., Macmillan Press, 1971, pp. 338-339.
14. Krige, E.J. *"Social System of the Zulus"*, Longmans, London, 1936.
15. Wilson, H. *J. S. Afr. Chem. Inst.*, 1938, XXI (2), 20.
16. Muller, G.H. and Tobin, G. *"Nutrition and Food Processing"*, Croom Helm, London, 1980, p. 136.
17. Fox, F.W. *"Preparation, Composition and Nutritional Value of Certain Kaffir Beers"*, *J. S. Afr. Chem. Inst.*, 1938, XXI (2), 29 et seq.
18. White, E.G. *"Kaffir Beer"*, Master of Science Thesis, University of the Witwatersrand, Johannesburg.
19. Lazar, O. *"Some Aspects of Malting Kaffir Corn"*, *J. S. Afr. Chem. Inst.*, 1938, XXI (2), 23 et seq.
20. Kamerman, P. *"Yeasts and their Functions"*, *J. S. Afr. Chem. Inst.*, 1938, XXI (2), 33 et seq.
21. Novelli, L. *"Bantu Beer – Food or Beverage?"* *"Food Industries of South Africa"*, 1963, (May) 16, p. 28.
22. Thorpe, W.V. *"Biochemistry for Medical Students"*, J. and A. Churchill Ltd., London, 1941, p. 405.
23. Gomes, A.A. *"Survey of the Sorghum Beer Brewing Industry"*, Internal Report, Department of Water Affairs, 1977.
24. Hensen, M.R. and Funke, J.W. *"Industrial Water and Effluent Management in Bantu-Beer Breweries"*, NIWR, Ref. No. W 3/24/1/2, June 1966.

15(7) WINE AND BRANDY PRODUCTION AND DISPOSAL OF THE ATTENDANT WASTES

Definition of Wine and Brandy

Wine can be produced from a number of fruits, dried fruits, vegetables and flowers by fermentation. In South Africa, apart from the wine of the grape which has the general designation "wine" there are a number of so-called "wines" (or "beers") also produced but to a much lesser extent (e.g. orange wine). These are generally named to indicate the fruit substrate used. Wine in the present connotation is the product of the grape only. The same applies to brandy as being the product from the distillation of wine. However, a well-known brandy peculiar to South Africa and distilled by certain farmers from fermented fruit, mainly peaches, is peach brandy or "mampoer", but this is not a marketed brandy.

According to the Wine, Spirits and Vinegar Act, 1913 (Act Number 15 of 1913) as amended by Section 3 of Act Number 37 of 1930, "wine" is defined as "the beverage produced solely by the alcoholic fermentation of the juice of fresh grapes . . .".

However, in terms of the Wine and Spirits Control Act, 1970 (Act Number 47 of 1970), "wine means wine or must of any description and includes grapes, grape juice, moskonfyt, raisins, sultanas and lees of wine".

Brandy as defined in Act Number 15 of 1913 "means the distillate resulting from the distillation of the produce of the vine . . .".

In terms of section 2 of Act Number 47 of 1970 no person shall

"(a) produce wine for distillation purposes, except under the authority of a permit issued by the vereniging" – which, in turn, means the Ko-operative Wijnbouwers Vereniging van Zuid-Afrika, Beperkt (commonly referred to as the K.W.V. – with headquarters in Paarl in the Cape Province).

Stills have to be registered but farmers, in some instances, have their own (sometimes "illicit") stills for distilling their brews for the delectation of themselves and others.

The production of ethyl alcohol is a separate industrial enterprise – properly controlled and is dealt with under fermentation industries – though it does bear relation to the wine industry by virtue of the fact that South African wines are fortified with added alcohol.

Viticulture in the Cape Province is a major agricultural activity of considerable proportions and a credit to the country by any standards. So, it is natural that some attention should be paid to wine and brandy ir so far as the production of these beverages on a large scale may give rise to wastes requiring attention.

WINE

Historical

Wine was made at the Cape from 1659 onwards. Wine was first made during van Riebeeck's governorship. Vine cuttings had been previously sent out from

Holland. The first wine estate was van Riebeeck's farm "Boschheuwel", now Bishopscourt.

Later with the arrival of Simon van der Stel as Governor of the Cape in 1679 the farm Groot Constantia was established. Van der Stel had a wide knowledge of viticulture and wine-making and was able to improve on the somewhat unskilled methods of van Riebeeck. He showed, *inter alia*, that it was necessary to wait until the grapes were fully ripe[1] before processing into wine.

Today the qualities of table grapes, wines and brandy owe a great deal to the efforts of Dr A J Perold and research carried out at the Oenological and Viticultural Research Institute at Stellenbosch and also to Dr C J G Niehaus and other scientists of the K.W.V. in Paarl.

Wine was made and imbibed by man from the earliest times. Harden[2] has stated, "The problem of alcoholic fermentation, of the origin and nature of that mysterious and apparently spontaneous change which converted the insipid juice of the grape into stimulating wine, seems to have exerted a fascination over the minds of natural philosophers from the earliest times . . .".

Mention of wine occurs in the Bible, viz. – Genesis IX, 20 et seq.

20. "And Noah began to be an husbandman, and he planted a vineyard"
21. "And he drank of the wine and was drunken . . .".

Bacon[3] states that at El-Jib (Gibeon – a city with biblical associations) an American expedition directed by Dr James B Pritchard in 1959 excavated the wine-making installations which appear to have been the basis of this ancient city's prosperity. Rock-cut storage vaults, plastered fermenting vats, wine presses and settling basins were discovered. He recorded, "the storage vaults were cut down into the soft limestone and were roughly bell-shaped, with a depth and diameter between 6 and 7 feet. The entrance, however, was only manhole-sized (about 29 inches in diameter) and was normally, it was assumed, sealed with a slab of rock. These vaults, being of porous rock, would not hold liquid and the wine was stored in vessels. The point of their use lies in their coolness. Even in the height of a Palestinian summer, the interior temperature stayed at about 65°F. Some vaults were however plastered and it is assumed that these were used as fermenting vats".

There seems little doubt that wine-making was practised some thousands of years ago both in countries of the Roman Empire and the Near East. The cultivation of vines has been placed as far back as 5 000 BC.[4]

Therefore, it is not without interest to relate one of the legends of how wine was first made.[5] It concerns a toothless Persian king who was fond of grapes but could no longer chew them so he expressed the juice of some grapes and stored the juice marking the container "poison" to prevent imbibation of the contents by uninvited persons.

After the container had been standing for some time a neglected member of his harem decided to end her life of misery and disenchantment by drinking a goodly portion of the designated "poison".

Having liberally partaken of the "poison" she, at first, felt euphoric and then "passed out" and was brought before the king who was greatly concerned at her apparently moribund condition. In due course, when she "surfaced" to a rejuvenated condition the king was overjoyed and partook of the "poison" himself. Thereafter, he always allowed his grape juice to ferment to what, in fact, was wine!

The South African Wine Industry

The South African wine industry is well-established after a number of vicissitudes of fortune from the time of van Riebeeck when the first wine was made in 1659 – a period of over 300 years.

Initially, the wine produced was not highly regarded but with the arrival in 1688 of the French Huguenots who were acquainted with wine-making the quality of the wines produced improved.

However, one of the problems which faced the expanding industry was the shortage of barrels, particularly for the export trade, as the local wood was unsuitable for cask manufacture and alternative materials were not available. Furthermore, the wines exported were found to be unsatisfactory on arrival at distant shores after a long sea journey.

With the take-over of the Cape by the British in 1795 there was a demand for Cape wines as the supply of French wines was cut off due to the French Revolutionary Wars (1792 – 1801) and the Napoleonic Wars (1805 – 1814). Thereat, Sir John Cradock, the Governor took steps to improve the quality of Cape wines to satisfy British purchasers who had been used to European wines.

Later – from 1861 onwards South African wines had to compete with European wines due to the abolition of heavy import duties previously placed on European wines.

Phylloxera ("dry-leaf"): *Phylloxera vastatrix*, a vine louse or aphid is yellowish brown in colour and less than one millimetre in length. It breeds at an enormous rate, resting in the winter in a wingless form on the roots of the vine. The females of the species crawl up the vines in springtime and lay eggs.

Phylloxera vastatrix was first discovered in California in 1880 being introduced with American vines from East of the Rocky Mountains. It is said to have appeared in North America and Southern Europe in 1863. Despite many attempts at eradication the infestation raged on and it was only possible to come to terms with the problem by using disease-resistant root stocks and so the practice of grafting of

vines on to resistant root stocks has continued to avoid future inroads of *Phylloxera*. Spraying the vines with carbon disulphide or petroleum emulsions is considered to have a remedial effect.

Grape Varieties: Two categories of wine grapes are in evidence, viz. – European cultivars (*Vitis vinifera*); and American cultivars (*Vitis labrusca*). There are some 8 000 known varieties of grapes which can be fermented but only about 50 varieties produce good wine. All these belong to the species *Vitis vinifera* cultivated since the time of the Romans in Europe and planted over 300 years ago at the Cape.

Red wines and rosé wines are produced from "black" grapes; their skins colour the fermenting juice or must.

White wines may be made from "black" or "white" grapes. Their extracted juices alone are fermented and in both cases such juices are "white".

Fermentation: When fully ripe, grapes contain an average of 18 per cent grape sugar. The sugar content of ripe grapes exceeds that of under-ripe specimens e.g. Muscat (very ripe) 25,53 per cent and Muscat (medium ripe) 21,52 per cent and variations occur from variety to variety e.g. Tokay (very ripe) 23,25 per cent and Malaga (very ripe) 22,70 per cent.

Apart from grape sugar ripe grapes contain potassium bitartrate, malic acid and to a lesser extent butyric acid, albuminoids, non-nitrogenous matter and ash.

The relative concentrations of these constituents vary with the type of grape, the nature of the soil and climate. The grape skin contains tannin ($C_{14}H_{10}O_9$), oils and (except in "white" grapes) colouring matter (oenocyanin). These all pass into the juices when the grapes are pressed.[6]

Alcohol Content of Wine: Natural wines have an alcohol content of the order of 10 to 15 per cent due to the die-off of fermentation in greater concentrations of alcohol.

In the case of fortified wines the alcohol content ranges from 15 to 22 per cent; alcohol, in many cases, being increased by the addition of brandy and in some instances by the addition of ethyl alcohol (C_2H_5OH) *per se*.*

In the production of sweet wines alcohol is added to stop the fermentation and at the same time retain some of the sugar still present in the fermentation mixture.

In fact, the high sugar and alcohol content of sweet table wines is achieved by various techniques:

(1) Musts with high sugar content are fermented and the fermentation checked before completion by cooling (Sauterne is produced this way).
(2) Sweet clarets are prepared by blending dry wine and grape juice.
(3) Port is made by the addition of brandy and sugar† to wine.

Sherry: Sherry is prepared by a double fermentation technique – first using normal wine yeast (*S. ellipsoideus*) followed by fermentation using the alcohol-resistant, film-forming yeast *Flor* (flower).

During fermentation the sugar in the grape is converted into ethyl alcohol mainly, traces of other alcohols, acids such as succinic, acetic, formic, butyric and propionic may be produced as well as some glycerin.[7]

The fermentable constituents of grapes are dextrose, laevulose and some inosite (inositol) and with these the adherent microflora which is essentially the yeast *Saccharomyces ellipsoideus*. This being so the production of wine as practised by man in ancient times was a simple process, but could lead to inconsistent results due to the presence of other organisms.

However, in modern wine-making, the use of sulphite to produce sulphur dioxide (SO_2) *in situ*, to which stray micro-organisms other than *S. ellipsoideus* are sensitive, ensures a straightforward fermentation by this yeast which is further insured by the addition of a pure culture of the yeast.

An outline of the wine-making process is shown by the flow diagram on page 273.

Variations of the procedures indicated are used to produce rosé wines instead of red wines. And, by the addition of chemicals, brandy, ethyl alcohol and herbs many different varieties of alcohol beverages may be prepared. In this respect reference could be made to vermouth which is a fortified wine to which an infusion of herbs has been added. In the case of liqueurs, alcohol, sugar or syrup, flavouring and perfume materials are used in various proportions.

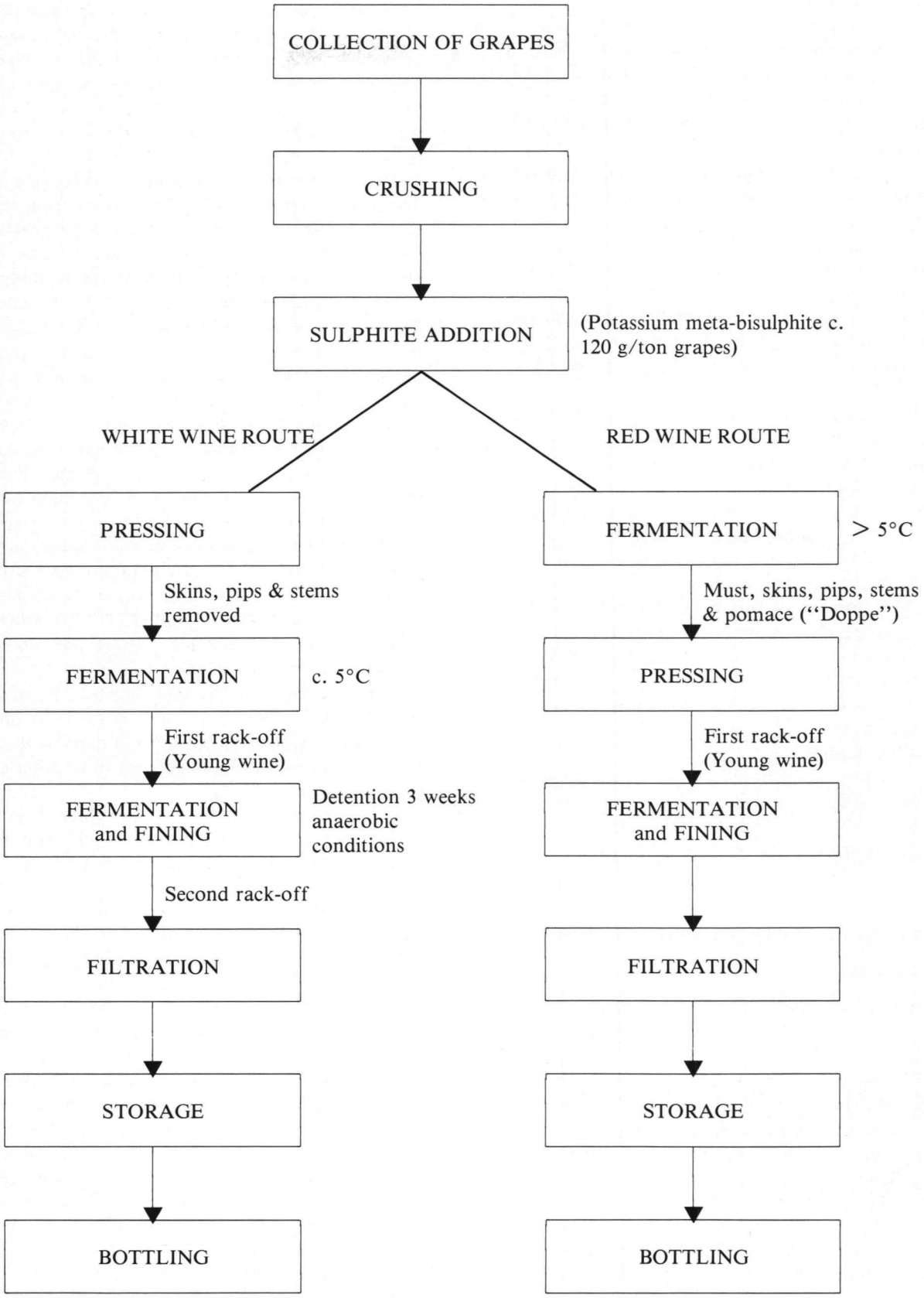
Wine Areas of South Africa: The well-established areas are confined to the Cape and include the following:

Olifantsrivier, Piquetberg, Swartland, Tulbach, Paarl, Constantia and Durbanville, Stellenbosch, Worcester, Robertson, Caledon, Swellendam and Klein Karroo. These have been demarcated for the production of "wines of origin". Tulbagh and Paarl (Boberg area) have been demarcated *inter alia* for the production of liqueur wines. However, other areas are involved.

The newer wine areas which have not been demarcated for the production of wines of origin include Vaalharts, Douglas, Barkly West, Upington and Kakamas. The wines from these areas contiguous to the Orange and Vaal Rivers are used for distilling and fortifying purposes.

*Alcohol distilled from wine.
†In South Africa no sugar addition is allowed – only sweet wines are used for port.

AN OUTLINE OF THE WINE-MAKING PROCESS



BRANDY

Brandy is made by distilling wine by methods which have been evolved over many years and have become traditional.

For example "cognac" has, by law, in France to be distilled according to the traditional way. This being so the great modern distilleries of Martell and Hennessy using gas-fired equipment differ little from a coal-fired still of a humble peasant both now and two centuries or more ago.

Patent stills i.e. Irish-type "Coffey" stills (due to Aeneas Coffey) are used for producing gin, grain whisky and vodka.

The difference between pot still distillation and patent still distillation is to be found in the fact that in the case of the latter stills the product is a "silent" spirit i.e. retaining little of the flavour characteristics of the original liquor. Hence, for example, in the case of gin the flavouring matter has to be added to the distillate.

Blended whisky, for instance, consists of a mixture of grain whisky produced by the patent still process and malt whisky produced by pot stills.

Distillation, using a pot still is a slow discontinuous process in contrast with patent still distillation which is continuous. In the case of "cognac", for instance, the product receives a double distillation thereby removing more of the earthy flavour which is present in once-distilled brandy. The distillation temperature is also an important factor.

Stills used are made of pure copper as this metal is least attacked by acids present during distillation. Cognac which is twice-distilled likely contains more copper in solution after distillation than other once-distilled brandies.

Components of brandy which are normally determined chemically, apart from copper, include aldehydes, esters, fusel oil, furfural, tannin and reducing sugar.

ATTENDANT WASTES AND THEIR DISPOSAL

Winery Wastes

Wastewater and residues from wineries include the following:

(1) Pomace (i.e. grape skins, pips and pulp);
(2) Lees (sludges remaining in the fermentation and ageing tanks: these contain potassium bitartrate);
(3) Argols (these crystallize out on the floors of fermentation vessels and consist of 70 to 90 per cent potassium bitartrate); and
(4) Wash water (Wash water does not usually present a significant pollution problem and can be discharged into a municipal sewer or can be irrigated on land).

The disposal of winery wastes does not present a problem of the same magnitude as the disposal of stillage/spent wine from brandy distilleries.

Where a winery is in a conveniently placed farming area it is possible to dispose of the winery effluent on land either by a system of broad irrigation and ploughing or by spray irrigation, in which event the effluent receives preliminary treatment by screening and settlement. In some cases evaporation ponds may be used as a method of disposal. The solid wastes require separate disposal but do not present a major problem.

The wine pressing season extends from late January to April each year. The operation is thus seasonal. Notwithstanding, during the off-season weaker effluent arisings of smaller volume occur from everyday activities such as bottle washing.

Where a winery gains access for its effluent into the sewerage system of a local authority, the acceptance into its sewers of the winery effluent requires to be carefully considered by such local authority to ensure that the winery discharge will not upset the sewage purification works. Suitable pretreatment of the effluent by screening and settlement and control of the discharge of the treated effluent into the municipal sewers by means of a balancing tank or other suitable means is required.

Pre-aeration with sewage at the sewage purification works, if such works employs the activated sludge method of treatment, may be required since the chemical oxygen demand (COD) of winery effluent can vary between 4 000 and 10 000 mg/ℓ – a common value being 6 000 mg/ℓ.

Where a winery has available to it a large daily supply of private water it becomes possible to suitably dilute the effluent with fresh water and use this mixture for spray irrigating the vineyards or other crops.

Co-operative Wineries: In the early days each farmer pressed his own grapes and made his own wine but now most farmers have joined co-operative wineries.

Co-operative wineries were established to unite a number of producers so that they could reap the benefits of collective negotiation and marketing, instead of each individual producer having to find his own outlet(s) for his wine. A "co-op" may have as few as 6 or as many as 200 "co-op" farmer members depending on the size of the farms concerned.

Each "co-op" appoints a professional wine maker to operate a winery for the members who deliver the grapes to him for pressing. Thus many wine farmers have become merely grape producers and the control of prices and sale of wines is all done through the K.W.V. (previously referred to). It has been stated that for the year 1982 to 1983 the K.W.V. had made a profit of R14-million.

There are a number of farmers who make, bottle and market their own wine as best they can. Their wines are known as "Estate Wines" and have been duly registered as such in terms of the relevant Wine

and Spirit Act.

There are some 46 wine estates in South Africa. Such estates being of sufficient size are able to handle the disposal of the winery wastes by the simple methods previously indicated without causing pollution of the water environment.

Wine Distillery Wastes

Wine distillery wastes, stillage or spent wine by whatever epithet you may call such effluent, is the residue from the distillation of wine to produce brandy or ethyl alcohol.

Stander[8,9] and co-workers of the National Institute for Water Research (NIWR) have tackled the problem of the treatment of wine distillery wastes by means of anaerobic digestion.

Stander[8] has stated, "The average strength (organic load) of distillery wastes is some 60 times as high as that of domestic sewage and consequently the effluent from a distillery may constitute as high a load as that from a town with a population of 75 000".

Wine distillation in South Africa is a seasonal operation starting in late February and lasting for about four months. In this respect it bears some resemblance to the sugar industry which is also a seasonal activity.

Spent wine centres include the following:

(1) Those with access to a municipal sewage purification works, viz. Paarl, Robertson,* Stellenbosch, Wellington* and Worcester,* and
(2) Those outside municipal areas without adequate sewage purification facilities, these include, – de Wet,† Goudini, Montagu, Vlottenburg,‡ Barrydale, Klawer, Ladismith, Villiersdorp and Vredendal.

Sustained research carried out by the NIWR during the period 1948 to 1968 has shown that spent wine can be digested anaerobically and the effluent from anaerobic treatment can be fed into the raw sewage influent of a sewage purification plant, at a controlled rate, for subsequent aerobic treatment in admixture with the sewage.

Successful large-scale experiments employing clarigesters have been carried out at the Stellenbosch and Paarl sewage purification works.

For successful operation a balancing tank has to be provided in order to by-pass and store the untreated spent wine surplus to that which can be fed to the clarigester at any time without upsetting its performance. Since distilling is seasonal, untreated waste which has been lagooned can be fed to the digester system at a later date during the off-season.

The digester is initially fed with raw sewage sludge and then distillery waste is added when the digestion of the sludge is "underway".

The optimum temperature for digestion was considered by Stander et al.[9] to be 30 to 35°C though it was not found possible to achieve this temperature range during the cold winter months without heating. The optimum detention period in the digestion compartment was considered to be 7,5 days.

It was found necessary to return the underflow of the clarifier section of the clarigester back to the digester section to maintain as high a concentration of anaerobic fermentation organisms as possible.

During normal operation a gas to feed-volume ratio of 14 – 15 to 1 was obtained. However, with lagooned waste the ratio was much less, viz. 2 – 6 to 1.

Furthermore, lagooned spent wine could be fed to the clarigester at a greater rate than fresh (non-lagooned) spent wine. In this connexion it should be noted that the COD values for fresh spent wines and lagooned spent wines were respectively 23 400 mg/ℓ and 12 600 mg/ℓ, clearly indicating that in the latter case substantial decomposition of organic constituents had taken place during lagooning.

A 12,192 m (40 ft) diameter (modified) clarigester was operated at Paarl with spent wine only, for five successive seasons from 1962 to 1966, whereupon it was taken over by the Municipality of Paarl and operated by Municipal personnel.

Likewise, at Stellenbosch a 15,24 m (50 ft) diameter clarigester provided with a separate sludge thickening tank and a sludge return to the digester has been in operation for some time.

Aerobic Treatment of Spent Wine Digester Effluent

As often happens with difficult treatable organic wastes (e.g. certain cannery wastes such as from oranges, grape fruit and pineapples), a preliminary anaerobic treatment renders such wastes more amenable to aerobic treatment thereafter and so it is with spent wine wastes.

The average composition of spent wine distillery waste as used at Paarl and Stellenbosch is given by Stander et al.[9] (See Table on page 276).

Although over 97 per cent reduction in COD content (mg/ℓ) can be achieved by anaerobic digestion the effluent discharged from a clarigester unit still contains about 1,8 per cent of biologically intractable material. Furthermore, the effluent produced is unfit for discharge into a water course. However, with further aerobic treatment in a sewage purification works, a further 40 per cent of the intractable material is converted and also with the dilution afforded by the combined treatment e.g. 1 in 50, the final effluent from the combined treatment will con-

*The spent wine in these cases, however, is disposed of to land and by evaporation.
†This distillery has moved to Wadeville (Germiston).
‡Vlottenburg distillery discharges its effluent to the Stellenbosch sewage purification works.

form with the quality requirements of the General Standard and be suitable for discharge into a water course in terms of the Water Act (Act Number 54 of 1956).

The work of the NIWR investigators indicates that spent wine digester effluent can be fed in with sewage to a conventional sewage purification works for final aerobic stabilization. This is easy of application in cases where a spent wine digestion plant is situated in juxtaposition to a sewage purification plant. However, in the case of an isolated distillery, separate aerobic treatment of digester effluent is necessary. In this latter case the ideal operating temperature of the digester will be more readily achieved due to the receipt by the digester of warmer spent wine supplied direct from the distillery next to it.

The average composition of spent wine distillery waste as used at Paarl and Stellenbosch

pH Value	Total Solids g/ℓ	Loss on Ignition 600°C g/ℓ	Suspended Solids g/ℓ	COD g/ℓ	BOD_5 g/ℓ	Organic Nitrogen g/ℓ	Ammon N mg/ℓ	Total Phosphorus as PO_4 mg/ℓ	Copper mg/ℓ	Total Alkalinity mg/ℓ $CaCO_3$
4,6	15,5	12,5	1,5	23,5	23	350	10	300	3,0	Nil

REFERENCES

1. De Jongh, F. *"Encyclopaedia of South African Wine"*, 2nd Edition, Butterworth and Company (S.A.) Pty., Limited, Durban, 1981.
2. Harden, A. *"Alcoholic Fermentation"*, Longmans Green and Company, London, New York, Toronto, 1932, p. 1.
3. Bacon, E. *"Archaeology – Discoveries in the 1960's"*, Praeger Publishers, New York, Washington, 1971, pp. 165, 166.
4. Parma, C. *"The Wine Estates of South Africa"*, Purnell, Cape Town, Johannesburg, London, 1979, p. VI.
5. Somewhat as related in *"A Guide to South African Wines"*, by Graham Etherington, Don Nelson, Cape Town, 1979, p. 57.
6. Thorp, F.H. and Lewis, W.K. *"Outlines of Industrial Chemistry"*, 3rd Edition, The Macmillan Company, London, 1945, p. 440.
7. Creuss, W.V., Joslyn, M.A. and Saymill, L.G. *"Laboratory Examination of Wines and other Fermented Fruit Products"*, The AVI Publishing Company, Inc. New York, 1934, p. 12.
8. Stander, G.J. *"Treatment of Wine Distillery Wastes by Anaerobic Digestion"*, CSIR Report Number 340.
9. Stander, G.J., Baillie, R.D. and Ross, W.R. CSIR Report Number 270, September, 1968.

15(8) PROGRESS IN THE CONTROL OF POLLUTION IN THE SUGAR INDUSTRY IN SOUTH AFRICA

INTRODUCTION

Historical

Cane sugar (sucrose), $C_{12}H_{22}O_{11}$, is found in the roots, tubers and in the stems and flowers of plants as well as in the sap of certain trees. It is produced mainly from sugar-beet and sugar-cane.

Apart from beet and sugar-cane, sugar is obtained to a lesser extent from the sugar maple, maize, sorghum and a species of palm.

In some areas of the world the coco palm, the aloe, the maples and the sorghums, as well as other plants have served as minor, but locally important sources of sweetish foods or sugar. In prehistorical and classical periods some fruits and honey were the major sweet foods.

In South Africa sugar is produced commercially from sugar-cane which is grown in Natal and the Eastern Transvaal.

The country of origin of sugar-cane is unknown

though it is generally believed to have originated in Northern India* and Arabia – the earliest mention of it being in some legends concerning Buddha about the fourth century BC. It is stated to have been introduced into Southern Europe by the Moors and later transplanted to the West Indies and other tropical countries. The Chinese who first acquired an interest in sugar-cane from India at about 100 BC brought sugar-cane to Java and the Philippines.

Christopher Columbus introduced sugar-cane into Santo Domingo in 1494 from where it was taken to Cuba from whence, in due course, it was introduced into the West Indian, Central American and South American States (e.g. Louisiana).

The sugar-cane is a giant perennial grass producing clumps of solid, prominently jointed stalks. Diverse varieties of sugar-cane are grown in the widely separated sugar-cane regions of the world. While some sugar-cane plants produce seeds, cane growers plant and re-plant their fields with pieces of stalks. Under favourable conditions the eyes of these pieces or cuttings propagate new cane.

Sugar-cane grows best on a rich, moist soil under sunny skies in a tropical climate† and the appropriate sugar-cane areas of the Republic have been chosen accordingly. For best growth a uniformly high temperature, strong sunlight and adequate showers or overhead irrigation are necessary during the growing season.

Sugar is contained in the juice which is well distributed in the sugar-cane stems to the extent of as much as twenty (20) per cent although in Cuba it is of the order of 17 per cent and in Louisiana it is only 12 per cent.

The earliest evidence of sugar in the solid state appears to date from about 500 AD in Persia (now Iran). The original Persian name for white sugar was "kandi-sefid" from which the word "candy" is derived. The Indian word "Shekar" or "Shakar" for sugar points to the origin of the word "sugar".

Carbohydrates

The sugars, together with many related compounds such as starch, cellulose, the gums, etc. which are the products of plant life are conveniently grouped together as carbohydrates.

The name carbohydrate was originally given to a group of compounds composed of carbon, hydrogen and oxygen and the term indicates that these compounds contain, in addition to carbon (C) in the molecule hydrogen (H) and oxygen (O) in the proportion in which they appear in water (H_2O) e.g. sugar (sucrose) $C_{12}H_{22}O_{11}$ could be expressed as $C_{12}(H_2O)_{11}$ and starch $C_6H_{10}O_5$ as $C_6(H_2O)_5$.

However, it must be emphasized that the atoms of H and O are not present as water (H_2O).

The observable properties of many carbohydrates differ substantially, e.g. some dissolve readily, some are sweet tasting (sucrose, glucose), some are paste-forming (starches) and yet again some are completely insoluble (cellulose). However, chemically they are related – the starches and cellulose being capable of breakdown to glucose.

Carbohydrates may be conveniently classified as follows:

(1) Monosaccharides, or simple sugars (e.g. glucose, fructose).
(2) Sugar-like polysaccharides. These are built up of monosaccharides and resemble them in solubility, taste and chemical properties e.g. cane-sugar (sucrose), malt-sugar (maltose) and milk-sugar (lactose), etc.
(3) Polysaccharides which are unlike sugars. These are condensation products of simple sugars but are not soluble in water but can form colloidal solutions (e.g. starches, glycogen, cellulose).

It will be seen from the above classification that sugar-cane (sucrose) is a polysaccharide – in fact, it is a disaccharide. If a solution of cane-sugar is boiled with a little dilute acid hydrolysis occurs and the sugar is split up into two isomeric sugars, viz. – glucose and fructose as shown by the following:

$$\underset{\text{cane-sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O} = \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{fructose}}{C_6H_{12}O_6}$$

The product is called "invert sugar".

When a cane-sugar solution is fermented by the agency of yeast the hydrolysis proceeds further to form ethyl alcohol (ethanol) and carbon dioxide as shown as follows:

$$\underset{\text{glucose + fructose}}{C_6H_{12}O_6} = \underset{\text{ethyl alcohol}}{2\,C_2H_5OH} + \underset{\text{carbon dioxide (gas)}}{2\,CO_2}$$

The linear representation of the two monosaccharides is as follows:

Glucose – $CH_2OH(CHOH)_4CHO$
Fructose – $CH_2OHCO(CHOH)_3CH_2OH$

Though each contains 6 carbon, 12 hydrogen and 6 oxygen atoms the spatial arrangements in the molecule are different.

Sucrose is in fact a compound formed by hydrolysis with enzymes from d-glucose and d-fructose.

*Aykroyd[1] states "No wild ancestor of the cane is known with certainty today. The plant from which it sprang was probably a native of South-east Asia, or conceivably of some island in the Pacific. Its *recorded history* began in India, when Nearchus, a member of Alexander's invading army, wrote of sugar, and hence of sugar-cane in the Punjab in 325 BC".

†Jenkins[2] states "The highest latitudes in which sugar-cane is grown are approximately 30°S in Natal, Argentina, and at the southern extreme of the Australian industry, and at 34°N in the north-west frontier provinces of West Pakistan, with a small industry in southern Spain at nearly 37°N. These last two areas are at the extreme limit of climate suitable for cane . . ."

The South African Scene

Sugar was first produced in Natal in 1851 by Edmund Morewood[3,4,5,6,7,8] using cane grown on a 2 hectare plot at Umhloti.* Since then the South African sugar industry has grown to the stage where the annual production exceeds 2 million tons thereby ranking it as the 8th largest amongst world sugar producers.

In South Africa sugar-cane is grown in three areas, viz. – Natal Coastal Belt; Natal Midlands; Eastern Transvaal.

Durban is the main centre for the refining and export of sugar. A large sugar terminal exists at the Durban docks through which about $^{2}/_{3}$ of the Republic's annual production passes for export overseas.

Sugar-cane grows repetitively after being cut. Fresh cane cuttings are planted every eight years and crops are harvested every 9 to 12 months. The harvesting period is normally about 9 months from May to January. The industry therefore, is a seasonal one.

The industry's research station at Mount Edgecombe sponsored by the South African Sugar Association provides scientific and agronomical advice and assistance to cane growers. The Sugar Milling Research Institute in Durban also operates to the benefit of the industry as a whole.

The South African Sugar Association acts as a medium for communication and improvement within the industry and supports the *"Sugar Journal"* which is a publication of importance. There is, also, the South African Sugar Technologists Association – certain members of which have applied themselves assiduously to pollution control problems at mills.

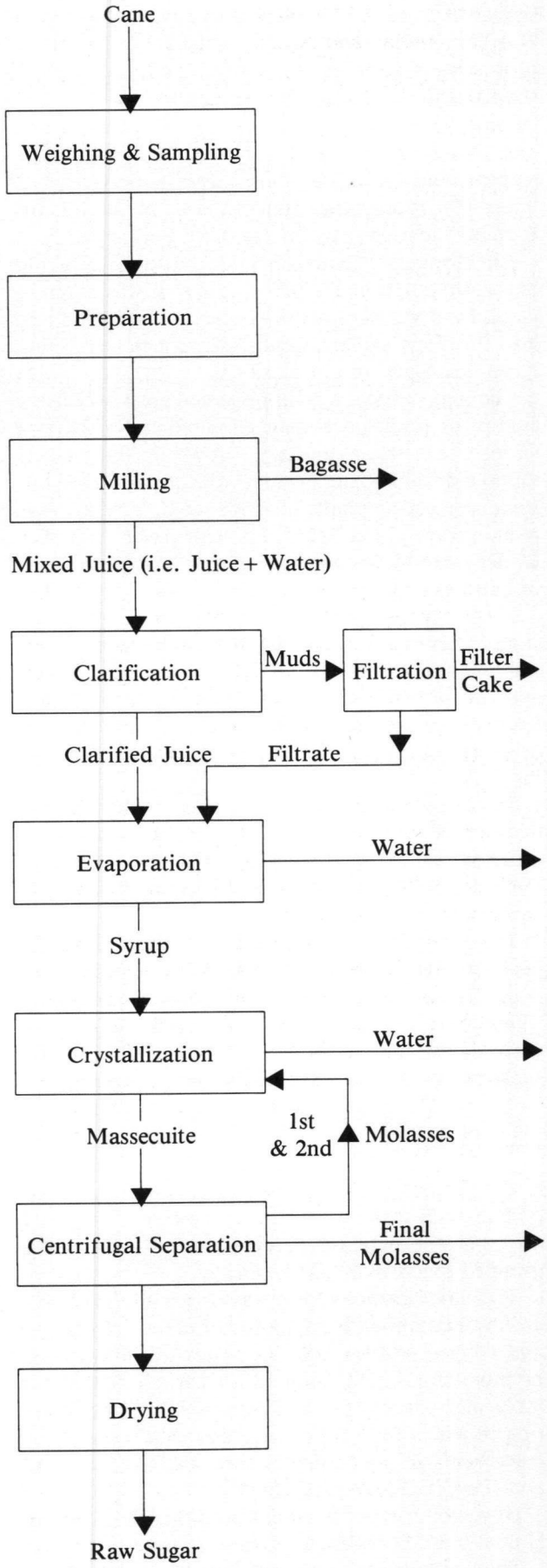
MANUFACTURE OF CANE SUGAR

The manufacturing process involved in the production of raw sugar from surgar-cane is as follows (cf. Flow Diagram):

Extraction of Juice

On arrival at the mill for processing the cane is first knifed and then further disintegrated in a hammer mill to a state conducive to the extraction of sugar from it. The extraction is carried out by diffusion whereby the sugar is washed out of the fragmented cane by repeated rinsing with hot condensate water. The extract is a water solution of sugar containing dissolved solids impurities of the order of some 12 per cent. The dissolved solids consist, *inter alia*, of inorganic salts, organic acids and albuminoid substances.

*In recognition of Morewood's pioneering efforts, the site of his mill at Compensation has been turned into a Garden of Remembrance and declared a National Historical Monument.



Flow Diagram of Raw Sugar Process

Clarification of Mixed Juice

This solution is generally defecated by liming and heating. The acidity of the juice is neutralized by milk of lime and the temperature raised to boiling point. After settlement in clarifiers the remaining suspended solids are removed by means of rotary vacuum filters – the fine fraction of bagasse in the mixture serving as a filter-aid. The filter cake is disposed of on land as a soil-building supplement.

The bulk of the bagasse (i.e. cane fibre from which sugar has been extracted) is then dried to approximately 50 per cent moisture and is used as boiler fuel and any excess just burned. In two notable instances excess bagasse from a sugar mill is supplied to an adjacent pulp and paper mill, one producing kraft paper and the other fine paper.

Defecating Processes[9]

(a) The most commonly used (and least expensive) process used is as follows:
Just enough lime is applied to the juice to neutralize its natural acidity. This process is universally, but not exclusively used by sugar manufacturers.

(b) *Sulphitation Process*

In this process an excess of lime is added to the juice and this excess is afterwards or simultaneously neutralized by blowing SO_2 gas through the juice or by contacting the juice with the gas in a sulphur tower.

Up to 1954 all factories but one in South Africa used the sulphitation process for manufacturing raw sugar, or for turning-out simultaneously about half of their product as mill-white and the other half as raw sugar. Subsequent to 1954 the sulphitation defecation process was phased-out in favour of the simple liming procedure (as in (a)).

(c) *Carbonatation Process*

This process involves the use of a considerable quantity of lime to clarify the mixed juice. Excess lime is precipitated as $CaCO_3$ by blowing CO_2 gas through the juice and filtering off the precipitate. This process is universally used in the beet-sugar industry for the production of both raw and white sugar.

In the cane-sugar industry mixed juice carbonatation factories are gradually disappearing for economic reasons although the assiduous use of the process results in the production of a very good quality mill white sugar. At one time the Natal Estates company used this process and sold the sugar so produced as refined sugar.

In the carbonatation process gassing with CO_2 may be carried out in one stage (single carbonatation) or two sequential gassing stages followed sequentially by filtration – this is referred to as double carbonatation.

Production of Sugar Crystals from Clarified Juice

The clarified juice is evaporated in multiple effect evaporators to a syrup of roughly 70 per cent solids content and then in a single effect evaporation to a mixture of sugar crystals and mother liquor (massecuite). The sugar crystals are then separated from the mother liquor by centrifuging. The resultant molasses fraction which is low in sugar content is sold as a stock feed or used as a feedstock (substrate) for industrial fermentation processes, e.g. production of ethyl alcohol (ethanol) and carbon dioxide – the latter being transformed into "dry ice".

A portion of the sugar produced at this stage may be sold locally and the bulk refined. A number of mills have their own refineries; others transport the raw sugar to a central refinery in Durban.

Refining of Raw Sugar: At refineries the raw sugar received is initially transferred to a mixer where much of the adhering molasses is removed from the sugar crystals by washing with syrup. The surplus syrup is centrifuged off, water added to the sugar and the melt treated with a small amount of lime and carbon dioxide gas bubbled through to precipitate the impurities which are removed by filter press – the filtrate being decolorized thereafter by the agency of bone char, activated carbon or ion exchange resins. The filter press solids ("milo") may be suitably disposed of on land.

The syrup is then concentrated in a vacuum pan to crystallize to a suitable crystal size after which the adhering syrup is removed by centrifugation – leaving a pure white sugar.

Chemicals Used in Sugar Processing: Many substances and combinations of substances have been proposed or used for the clarification and decolorization of sugar products. Amongst these may be mentioned lime (in various forms and conditions); sulphurous acid; sodium carbonate ("soda ash"); phosphoric acid.

In the production of white sugar – in addition to lime, sulphur dioxide (SO_2) is used in the sulphitation process and carbon dioxide (CO_2) in the carbonatation process.

For the final decolorization of sugar activated carbon or bone char may be used. All of these substances may report to a greater or less extent in the effluent together with particles coagulated from solution or flocculated from suspension.

Effluents Arising from Operations at Sugar Mills and Sugar Refineries: From what has been stated so far it will be readily appreciated that arising from

normal operating practices, accidents, cleaning operations, etc., the effluents encountered in the sugar industry are likely to contain pollutants from spillages of juice during milling or diffusion processes, overflowing of surge tanks, entrainment in evaporators and vacuum pans as well as leaks from pipes, valves and pump glands.

Potential pollutants include spilled rotary vacuum filter cake, filter press solids (milo), massecuite or molasses, bagasse, fly ash (smuts), boiler blow down, etc.

During periods of cleaning or shutdown pollution can result from the cleaning and washing down of process units such as heaters, evaporators, clarifiers, etc.

The Complete Effluent Scenario at a Mill

From a pollution control point of view we are concerned with all the effluents (wastewater) emanating from a sugar mill and its associated residences, compounds and other living quarters. Sugar mills are established in rural areas amid cane fields. This being so accommodation has to be provided for employees. Ablution and sanitary facilities have to be provided for employees at the mill and in the mill-townships' residences. This means that, apart from mill effluents, domestic sewage has to be dealt with.

The burning of bagasse results in atmospheric pollution due to the discharge of black particles up the main factory chimney stack. Most mills have been forced, in terms of the anti air pollution requirements of the Department of Health and Population Development to prevent such discharges. As a result mills have installed wet scrubbers which give rise to so-called "smuts water" (fly ash) which ceases to pollute the atmosphere but, instead, transfers its pollution to the water environment!

The normal effluents, therefore, which have to be dealt with are the following:

(1) Mill effluent consisting of dunder (daily wash water), cooling water, effluent arising from condensers which contains entrained juice;
(2) Smuts water;
(3) Domestic sewage.

The fact that the operations are seasonal, of course, introduces a new dimension into the problems of treatment of the wastewaters.

Mill effluents will vary in composition from mill to mill, more particularly depending on whether a refinery is operated or not and the nature and condition of the process units used. Mill effluents are normally devoid of toxic substances. The Chemical Oxygen Demand (COD) of mill effluent is considerable and may vary from as low as 500 mg/ℓ to values over 3 000 mg/ℓ. Under abnormal conditions even this latter value can be far exceeded.

The effluents are difficult to degrade biologically since they are deficient in nitrogen and phosphorus which elements are necessary to effect satisfactory degradation of the inherent organic material present – mainly carbohydrates.

In order to treat the variable effluent discharge from a mill recourse requires to be had to some form of balancing or surge facilities either in the form of properly engineered tanks or a system of ponds.

Thirteen years or so ago, on the advice of the South African Bureau of Standards, a directive was given by the Department to the South African Sugar Millers Association to the effect that certain mills be required to dispose of mill effluent on land for irrigation (e.g. of cane and/or trees) – no effluent being allowed to discharge into a river. This directive applied to mills which re-circulated condenser water. Other mills using water on the "once-through" basis were required to purify their effluents for discharge into a river. In this case certain quality requirements of the General Standard were waved, viz. – colour, odour, taste, dissolved oxygen, typical (faecal) coli, temperature, Oxygen Absorbed in 4 hours, suspended solids and a relaxation of the COD requirement to 120 mg/ℓ above that of the intake water was granted. The soap, oil and grease requirement of the General Standard was relaxed to 5 mg/ℓ.

The solids in smuts water can be settled out in ponds or dams and the dried solids disposed of by landfill or when mixed with filter cake or filter press solids may be broadcast on cane fields.

Domestic sewage is treated by septic tank-French drain combinations, pond systems or in properly designed and engineered sewage purification works using biological filtration or activated sludge plants. In the last case effluents of General Standard quality may be produced.

From an analysis of recorded information available it can be said that progress has been made but it is considered that where effluent is discharged into a river the mills concerned should be encouraged to aim at General Standard quality.

Progress

In assessing progress sight must not be lost of the fact that the sugar industry has had its "ups and downs" due to market conditions and water shortages, and also, the fact that it is a seasonal industry. The industry has experienced buoyant periods but due to the lack of rain on occasions it has become necessary to curtail operations at some of the mills. However, the industry can well cope with necessary expenditure on pollution control.

Amongst the problems calling for attention the following may be listed:

(1) Production of effluent of General Standard quality for all mills discharging effluent into a river;
(2) Improving the irrigation methods to prevent run-

off and seepage to rivers – and lagoons;
(3) Prevention of secondary pollution by exercising more care in the handling and broadcasting over cane fields of mud/filter cake, milo, etc;
(4) Adequate removal and disposal of smuts from smuts water from water scrubbers;
(5) Treatment of effluent from a waterborne system of sanitation in a sewage purification works to produce effluent of General Standard quality for discharge into a river.

In certain parts of the world where sugar is grown and sugar mills operate and where disposal methods are not restrictive it has been customary to store effluents for discharge into a river when it is in spate. Such a practice would be regarded in South Africa as an unpardonable dodge or expedient lacking in management responsibility, moral justification and also in conflict with sections 21 and 23 of the Water Act (Act 54 of 1956).

Production of Effluent of General Standard Quality

In a joint paper by D E Simpson and J Hemens of the National Institute for Water Research and S M H Cox of the Sugar Milling Research Institute[10] the authors concluded that the activated sludge process was suitable for the purification of mill effluents provided additional nitrogen and phosphorus-containing substances are added. In laboratory studies the substances added included urea and potassium-hydrogen-phosphate and in the pilot plant investigations septic tank effluent, urea and superphosphate were added to the dunder water being treated.

Later Simpson and Hemens reported[11] their conclusions on sugar mill effluent treatment with nutrient addition.

Their results show that when treating mill effluents with a mean COD value of 2 987 mg/ℓ it was possible to obtain an effluent, after settlement, with a COD value of 103 mg/ℓ and, after filtration a COD value of 79 mg/ℓ. (General Standard limit 75 mg/ℓ.)

They have concluded that, –

(1) Efficient activated sludge treatment of sugar mill effluent is possible if supplementary nitrogen and phosphorus are provided;
(2) Addition of these nutrients can approximately double the rate of COD removal and is essential for the production of settleable sludge and a low turbidity effluent;
(3) A minimum satisfactory supplementary COD:N:P ratio in the input was found to be 100:2:0,4;
(4) The optimum load factor was determined to be 0,6 g COD/day per gram MLSS (Mixed Liquor Suspended Solids) with an average SVI (Sludge Volume Index) of 53 mℓ/g;
(5) A well-stabilized effluent was produced, with average settled COD and BOD of 97 and 13 mg/ℓ respectively;
(6) Dewatering of excess sludge to form a manageable solid can be achieved on a conventional drying bed without any form of pretreatment.

At a number of mills Pasveer ditch-type activated sludge plants have been used for treating mill effluent. At one plant an effluent with an Oxygen Absorbed in 4-h value of 14 mg/ℓ and a COD value of 101 mg/ℓ respectively has been reported: at another an Oxygen Absorbed value for the final effluent was found to range between 5,8 and 7,4 mg/ℓ.

At some mills it has been found satisfactory to allow a certain amount of anaerobic action to take place in a pond system before further purifying the composite of effluents aerobically.

However, anaerobiosis in pond systems can give rise to malodours though it is possible to use masking agents to reduce the unpleasant olfactory assault caused by the dissemination of unpleasant smells.

Addition of well-nitrified effluent from a sewage purification works can assist in this connexion. Anaerobic pretreatment is certainly of value in that it causes a diminution in the concentration of reducing sugars and increases the pH value and alkalinity to render the pond contents more suitable for aerobic treatment (e.g. activated sludge or biofiltration).

In order to effect satisfactory aerobic purification as the 'end of the line' treatment it has been suggested that nitrogen and phosphorus in the form of urea and superphosphate be accurately and regularly (at least once per day) dosed to the influent to the plant and the following ratios of constituent parameters observed:

	COD	N	P
Biofilters	100	4	0,8
Activated sludge plant	100	2	0,4

(Parameters in mg/ℓ)

For anaerobic pond systems the suggested ratios are COD, 100; N, 4; P, 0,8.

POLLUTION CONTROL

Sugar mill and sugar refinery effluents are variable in composition and amount, throughout the processing season, but, subject to good housekeeping methods followed at the mills and refineries and on the farm lands, pollution occurs only in the sense that the water and land environments are subjected to finite concentrations of soluble carbohydrates which provide a substrate for rapid biological growth and in the case of discharge of effluent into a waterbody may cause depletion of the dissolved oxygen and, in certain circumstances, the possibility of anaerobic action exists.

Good housekeeping methods include: Bunding of molasses storage areas; removal of solids from water scrubber effluent (smuts water) – satisfactory disposal of the solids removed and return of the

clarified effluent water for re-use; disposal of mud, filter cake, milo etc. on land; ensuring that cultivation of cane is restricted to areas, the borders of which do not approach within 20 m of a river bank and, likewise, ensuring that dumping of milo, etc. is kept at a safe distance (exceeding 20 m) from a river bank; ensuring by cut-off canals and contour walls that runoff from irrigated cane fields to a river or estuary does not take place during storms; provision of a satisfactory system of drains and bund walls to prevent runoff and accidental discharges from the mill area gaining access to a river during storms.

If these matters are satisfactorily attended to by mill managements and, fortunately, with a number of exceptions they are, then dangers from adventitious discharges are eliminated and the main regular effluent streams can be confined and adequately purified thereby preventing pollution of rivers and river estuaries.

WASTEWATER TREATMENT PROCEDURES

Difficulties at once arise in using biological methods for treating mill effluents on a continuous flow basis. The fact that the industry operates on a weekly cycle of six days with one day in each week set aside for mill and refinery maintenance and cleansing calls for certain variations of treatment processes. The fact that mills close down each year for a period of about three months introduces a major problem to be overcome.

A purification plant employing the activated sludge process or biofiltration should be fed, ideally, at a constant rate and continuously. For best results the organic load of the influent should be reasonably constant and uniform.

Sewage Purification: As far as the operation of a mill's sewage works is concerned this can be run continuously throughout each year though the flow treated during the shut-down period may be considerably reduced. To stop a sewage purification works for a lengthy period and re-start it again has a completely upsetting effect on the quality of the effluent, the plant efficiency suffering considerably during the dormant and re-start-up periods. Therefore, it is advisable to ensure that the sewage purification works operates continuously throughout each year.

Mill Effluent Purification: When treating mill effluent (with addition of nitrogen and phosphorus compounds and/or sewage) a satisfactory *modus operandi* of the sewage purification works and the mill effluent purification plant has to be worked out. One mill has solved this problem by continuously operating the sewage purification plant during the shut-down period though at a considerably lower feedrate and discharging the effluent from this to an activated sludge plant fed with effluent from an anaerobic pond containing mill effluent discharge. This maintains the viability of the activated sludge plant for the oncoming season.

The clarified effluent is then discharged into a large dam which overflows to the river.

The purpose of this type of processing is to maintain both the sewage purification plant and the mill effluent purification plant in a viable condition and at a lower operating cost during the shut-down period.

Another mill deals with the problem by discharging mill effluent into an anaerobic pond and then treating the effluent from this in a high-rate biofiltration plant with recirculation. The sewage is treated separately in an activated sludge plant.

The general procedure adopted by the industry is to discharge either mill effluent and sewage, or mill effluent and purified sewage effluent into an anaerobic pond or set of ponds. The effluent from this "reservoir" is either used for irrigation or treated in an activated sludge or biofiltration plant and the final effluent discharged into a river.

There is little doubt that by accumulating all effluents in a pond system initially avoids surges and makes it possible to supply a purification plant continuously and evenly throughout the year and so ensures maximum operational capability at all times provided sufficient nitrogen and phosphorus are present in the mixture fed to such purification plant.

Danger Signals: With the progress that has been made in the last decade and the technology on hand, effluents from the sugar industry can be satisfactorily treated. The production of effluent of General Standard quality is now possible and within the capability of the companies operating sugar mills.

However, with the world oil situation in the present state of flux and the general energy requirements of the Republic a matter of great import attention is being given to the production of ethyl alcohol (ethanol) as a fuel in its own right or as a fuel volume extender.

Ethanol, as has been indicated previously, can be produced from molasses by fermentation. However, the molasses slop remaining after fermentation is likely to present a considerable disposal problem but it can be overcome.

ENTERPRISE

Syrup: A number of mills produce syrup.

Furfural: One sugar mill has shown enterprise in producing furfural from bagasse. The plant and process employed is somewhat unique in the Republic and is operated on lines similar to a plant in Hungary. No effluent problems of real magnitude have been encountered due to this operation.

Furfural (furfuraldehyde) is also known as fural, pyromucic aldehyde, Artificial Oil of Ants can be

produced from sugar, bran, oathulls and corn cobs. It is used as a solvent and in the manufacture of varnishes and artificial resins. One local use is to remove waxes from lubricating oils. From furfural, *furfuryl alcohol* is prepared by reduction or by means of the Cannizzaro reaction.

Diacetyl: A product produced at the same mill is diacetyl which can be used as a carrier of aroma of butter, vinegar, coffee and other foods.

Products from Molasses:

(1) *Ethyl Alcohol (Ethanol):* The fermentation of molasses by the agency of yeast follows the following route:
Inversion of the sucrose present in the molasses by the action of the enzyme invertase secreted by the yeast to invert sugar and the conversion by the yeast of the invert sugar to ethyl alcohol (ethanol) and carbon dioxide. From ethyl alcohol a large number of compounds can be produced chemically (e.g. acetone).

(2) *Butyl Alcohol and Acetone:* Butyl alcohol and acetone can be prepared from molasses by fermentation with *Clostridium acetobutylicum* and related anaerobes. Butyl alcohol is used as a solvent for nitrocellulose lacquers; acetone is a valuable solvent in the cosmetic and explosives industries.

(3) *Glycerol:* Glycerol has been prepared in South Africa by fermentation of molasses. However, the product did not gain acceptance by the explosives industry in competition with glycerol produced by the hydrolysis of fats.

(4) *Citric Acid:* Some years ago the National Chemical Research Laboratory of the Council for Scientific and Industrial Research (CSIR) carried out laboratory studies on the production of citric acid by fermentation of molasses. Feasibility studies on large-scale production at a sugar mill were undertaken but the project was dropped mainly due to economic considerations of the production by this method in comparison with other available methods of production not using molasses.

An inhibiting factor to enthusiasm for the molasses fermentation route, at the time, was the necessity to operate large-scale production by means of a controlling pilot plant due to the variability of the substrate material from the mill influencing fermentation.

In all fermentations where molasses is used as a substrate the spent liquor remains a disposal problem which has to be dealt with in a number of ways, notably by evaporation. Disposal on ploughed land has been practised but to treat such spent liquors by biological methods such as by biofiltration or activated sludge treatment appears too costly to contemplate. However, two companies operate in Durban manufacturing ethanol from molasses obtained from the sugar industry and are able to dispose of the effluents from their fermentation processes by way of one of the marine pipelines of the Durban Corporation.

Yeast: Yeast is also manufactured. Yeast effluent is highly polluting but, fortunately, discharge via deep-sea pipeline has been used as a means of disposal.

Acetic Acid: The recovery of acetic acid from effluent from a furfural plant associated with a sugar mill is being contemplated. At present, the effluent from this factory discharges to sea.

Building Board: It was indicated (cf.) that bagasse was used in the manufacture of kraft paper. It has also been used in the production of hard-board which, at the time, looked promising but production was discontinued due to certain drawbacks to its use, found later. However, a factory operating in juxtaposition to a sugar mill in the Eastern Transvaal produces fibre-board from the bagasse supplied to it by the mill.

There is little doubt that thought and attention has been given, in the last ten years, to better control of wastewater from sugar mills and also to the production of materials from waste materials from the industry. If, in the process of producing these by-products, the overall pollution burden is reduced they are to be welcomed. Failing this the industry will require to solve any new pollution problems resulting from any such contemplated developments.

SUGAR MILLS: BRIEF DETAILS, WATER USAGE AND DISPOSAL OF EFFLUENT

Amatikulu Sugar Mill

Source of water: Amatikulu River.

The mill's effluent is collected in an anaerobic dam and pumped to irrigation.

Darnall Sugar Mill

Source of Water: Nonoti River.

Mill effluent together with purified domestic effluent is pumped to an anaerobic dam and from there to an irrigation dam situated in the canefields and irrigated.

Empangeni Sugar Mill

This mill will be closed after the first phase of the new Felixton II Mill is operational (planned for January 1984).
Source of Water: 14 boreholes plus a fresh water dam.

Somewhat over 50 per cent of the effluent is used for the scrubbers and the rest is pumped to an irrigation dam.

Entumeni Sugar Mill

Source of water: Ntumeni River.

The Mill's effluent is collected in a sump and after filtration (D.S.M. screen) pumped to irrigation.

Felixton Sugar Mill

This mill will be closed in 1985 when the second phase of the new Felixton II Mill is operational.
Source of water: Umhlatuzi River.

Effluent to two anaerobic ponds; treated domestic sewage is also discharged to the ponds. From the second pond the effluent is pumped to two biofilters and after settling discharged to the river (quality is good).

Gledhow Sugar Mill, Stanger

Source of water: Umvoti River.

Effluent is pumped to the effluent purification installation of the Sappi Fine Paper Mill and mixed and treated with the paper mill effluent.

Glendale Sugar Mill

Source of water: Umvoti River.

The mill effluent is mixed with river water and pumped to irrigation.

The overflow from the scrubbers and ash-plant is discharged into a settling dam.

Huletts Sugar Limited – Maidstone Mill

Source of water: Tongaat and Mona Rivers.

Effluent discharged to irrigation.

Cooling water overflow returned to river. Quality does not always comply with the General Standard.

The factory washwater and the return flow from the scrubbers pass through a primary sedimenter before being pumped to a large clarifier.

The overflow from the clarifier is partly returned to the scrubbers and partly pumped to irrigation. The underflow of the clarifier is dewatered in a multi-roll filter and mixed with the factory's filter cake (milo) and disposed of on land.

Illovo Sugar Mill

Source of water: Illovo River.

The mill's effluent is pumped to an irrigation dam and irrigated on canefields.

The Natal Estates Limited, Mount Edgcombe Sugar Mill

Source of water: the Umdloti, Umhlanga and Piesang Rivers.

The mill effluent is collected in dams and pumped to irrigation.

A weir has been installed in the local stream running through the irrigated fields to catch the runoff and pipe it to another irrigation dam.

Noodsberg Sugar Mill, Dalton

Source of water: Boreholes.

Effluent treated in an anaerobic dam followed by a Pasveer ditch and discharged into a large dam.

Pongola Sugar Milling Co., Ltd.

Source of water: Pongola River.

Dunder Water: Treated in a Pasveer ditch together with sewage effluent and irrigated.

There are plans to reuse some of this treated effluent.

Cooling Water Overflow: Discharged to Pongola River. The quality of this effluent was very poor at one stage but has improved considerably. The present COD is c. 100 mg/ℓ.

Sezela Sugar Mill

Source of water: Sezela and Ifafa Rivers.

The effluent is purified in an extended aeration activated sludge treatment plant. At present part of the purified effluent is discharged to the Sezela lagoon but after completion of the installation of all the new equipment the total flow of the final effluent will be returned to the mill and used in the process.

Transvaal Suikerkorporasie Beperk, Malalane

Source of water: Crocodile River.

Effluent (dunder water and ash water from cleaning of stack gases) is irrigated.

Cooling water overflow is returned to the Crocodile River. Domestic sewage effluent is purified in Wright-Anderson plant and mixed with the cooling water overflow. The return to the Crocodile River conforms consistently with the General Standard.

This mill operates its own refinery.

Umfolosi Sugar Mill

Source of water: Umfolosi River.

The effluent is discharged to an anaerobic dam, then treated in a Pasveer ditch followed by anaerobic dam and discharged to the river, complying most of the time with the requirements of the General Standard.

Umzimkulu Sugar Mill

Source of water: Umzimkulu River.

The mill effluent is collected in an anaerobic dam

and from there pumped to irrigation.

As the irrigation system has not worked successfully the Company has been requested to install a Pasveer ditch to treat the effluent from the anaerobic dam.

Union Co-operative Bark and Sugar Company: Dalton

Source of water: Ekamanzi River.

The effluent is collected in a system of four ponds and pumped to an aeration treatment plant.

The final effluent is returned to the mill. In case there is a surplus of effluent, spray pipes and an evaporation dam are installed to deal with this surplus.

Huletts Refinery: Durban

Cooling water and ash-water overflow to a cooling pond and then discharge into Umhlatuzana River.

Sugar contamination and temperature of effluent call for better control.

Dunder water discharged to Durban municipal sewerage system. Saline effluent from resin plant is transferred by road to the outfall of the Durban Corporation's Southern Sewage Treatment Works.

REFERENCES

1. Aykroyd, W.R. *"Sweet Malefactor"*, *"Sugar, Slavery and Human Society"*, Heinemann, London, 1967, p. 10 et seq.
2. Jenkins, G.A. *"Introduction to Cane Sugar Technology"*, Elsevier Publishing Company, Amsterdam, London, New York, 1966, p. 2.
3. Buchanan, Barbara, I. *"Natal Memoirs"*, Shuter and Shooter, Pietermaritzburg, 1941, p. 224 et seq.
4. Hattersley, A.F. (a) *"Portrait of a Colony"* – *"The story of Natal"* – Cambridge University Press, 1940, p. 67.
   (b) *"More Annals of Natal"* with Historical Introduction by A.F. Hattersley, Shuter and Shooter, Pietermaritzburg, 1936, p. 38.
5. Shuter, C.F. *"Englishman's Inn"*, Sugar in Natal, Howard Timmins, Cape Town, 1963, p. 74 et seq.
6. Beater, B.E. *"Natal Regional Survey – Report No. 5"*, Soils of the Sugar Belt, Oxford University Press, Cape Town, 1962, Part 3, Zululand.
7. Buchanan, W.K. *"Natal Regional Survey, Volume 13 – Agriculture in Natal"* – *"The Sugar Industry"*, Oxford University Press, London, New York, 1957, p. 43 et seq.
8. Brookes, E.A. and Webb, C. de B. *"A History of Natal"*, University of Natal Press, Pietermaritzburg, 3rd Impression, 1979, p. 80.
9. Peck, G.M. *"The Manufacture of Sugar from Sugar-Cane"*, Edited by Douwes-Dekker, K. Sugar Milling Research Institute, University of Natal (Printed by Hayne and Gibson, Durban), 1973, p. 3.
10. Simpson, D.E., Hemens, J. and Cox, S.M.H. S. Afr. Sugar Technol. Assoc., June, 1972.
11. Simpson, D.E. and Hemens, J. *J. Water Poll. Control Fed.*, 1973, 45(10), 2194.

Chapter 16 DISPOSAL OF SOLID, TOXIC AND HAZARDOUS WASTES

"What's not destroy'd by Time's devouring hand"
Revd. James Bramston
1729

I DISPOSAL OF SOLID WASTES

Solid wastes constitute the normally solid wastes arising from human and animal activities. Apart from garbage such solids include the vast heterogeneous conglomeration of household and commercial rubbish together with the more uniform acervations of agricultural, industrial and mineral wastes.

Types of Wastes

(1) *Food Wastes (or Garbage):* These wastes represent the animal, vegetable and fruit discards from the preparation, cooking and eating of foods. These wastes are highly putrescible and give rise to offensive odours during decomposition. Apart from household garbage considerable amounts of food wastes are generated by restaurants, hospitals, hostels, prisons, stores, markets, etc.

(2) *Rubbish:* Rubbish consists of combustible and non-combustible solid wastes. Included in an array of combustibles are such materials as paper, cardboard, plastics, textiles, rubber, leather, wood, furniture and garden cuttings and non-combustibles include glass, crockery, metal cans, aluminium ware, iron and non-ferrous metal appliances, implements, culinary utensils together with dirt.

(3) *Ashes and Residues:* In this category we have the materials remaining after the combustion of wood, coal, coke and other combustible wastes in homes and in a variety of facilities and establishments where heating and cooking take place. Ashes and residues are composed of fine powdery materials, cinders and clinker as well as small amounts of burned and partially burned materials. Glass, crockery and a number of metals are found in large municipal incinerator residues.

(4) *Builders' Rubble:* These wastes consist of demolition wastes from razed buildings and construction wastes arising from the construction of new buildings and alterations and additions to old ones. These wastes include dirt together with variable quantities of waste building materials such as bricks, concrete, plaster, stones, timber, tiles, broken or damaged metal and earthenware piping and appurtenances, electrical conduit and metal reinforcing rods, etc.

(5) *Urban Litter and Diffuse Source Wastes:* These include street sweepings, roadside litter, the contents of municipal and other litter waste receptacles, dead animals and abandoned vehicles.

(6) *Water and Wastewater Treatment Sludges:* These wastes are disposed of by the water and sewage authorities as separate waste entities although screenings from sewage purification works may be included in municipal waste collection routines and sewage sludge may be used together with agricultural wastes in composting.

(7) *Agricultural Wastes:* These include wastes from the planting and harvesting of crops, operation of dairies and feedlots.

(8) *Hazardous Wastes:* These inlcude chemical, biological, flammable, explosive, radioactive and toxic wastes which present an immediate or delayed danger to human beings, animal and plant life. (These wastes are dealt with separately in Sections II and III of this chapter.)

Urban Refuse

(i) *United States*

Tshobanoglous, Thiesen and Eliassen[1] have given the following information concerning the physical composition of municipal solid wastes in the USA:

Component	Per Cent by Weight		
	Range	Typical	Davis California
Food wastes	6-12	15	4,5
Paper	25-45	40	43,1
Cardboard	3-15	4	6,5
Plastics	2- 8	3	1,8
Textiles	0- 4	2	0,2
Rubber	0- 2	0,5	0,8
Leather	0- 2	0,5	0,7
Garden trimmings	0-20	12	14,3
Wood	1- 4	2	3,5
Glass	4-16	8	7,5
Tin cans	2- 8	6	5,2
Non-ferrous metals	0- 1	1	1,5
Ferrous metals	0- 4	2	4,3
Dirt, ashes, bricks, etc.	0-10	4	1,1

The same authors[1] have quoted the following information on unit quantities of solid wastes generated in the United States as obtained from a "National Survey of Community Solid Waste Practices" carried out by the US Department of Health, Education and Welfare in 1968:

Per Capita Solid Wastes Collected in the United States, 1968

Source or Composition	Population Reporting (000)	Kg/capita/day
Combined household and commercial	48 970	1,84
Industrial	29 330	0,84
Institutional	20 533	0,11
Demolition and construction	23 697	0,30
Street and alley cleanings	35 340	0,11
Tree and landscaping	25 890	0,08
Park and beach	17 230	0,07
Catch basin	22 010	0,02
Sewage treatment plant solids	20 504	0,21
	Total	3,58

(ii) *Britain*

On the other hand the following information (also for 1968) has been published[2] for average representative samples of house refuse from towns in Britain (mainly in England):

Type of Refuse	Per Cent	Average Weight Household per Week (kg)
Fine dust and small cinder - 1,27 cm	17,44	2,3
Cinder + 1,27 cm - 1,45 cm	4,45	0,6
Vegetable and putrescible	17,61	2,3
Paper	36,91	4,9
Metal (ferrous and non-ferrous)	8,87	1,2
Rag (including bagging and all textiles)	2,35	0,3
Glassware (bottles, jars and cullet)	9,11	1,2
Unclassified debris (combustible and incombustible)	2,14	0,3
Plastics	1,12	0,1
Total	100,000	13,2*

Density of refuse as collected ... 157 kg/m^3

Salvage of Materials: An investigation of the materials salvaged by local authorities in Britain (either at source or subsequently in disposal processes) from a population of c. 33 million revealed the following:

For the Year	Waste Paper (tonnes)	Scrap Metal (tonnes)	Other Salvage (tonnes)	Total (tonnes)
1963/1964	256 500	65 950	92 550	415 000
1964/1965	225 440	58 340	68 520	352 300
1965/1966	256 800	60 130	72 970	389 900
1966/1967	227 960	57 110	32 530	317 600

(iii) *South Africa*

Verrier[3] has established the following information for solid wastes generated and collected in Cape Town and Johannesburg, viz:

City	Domestic Refuse Generation Rate (kg/capita/day)
Cape Town	0,8
Johannesburg	1,4†

*The projected National average for 1980 is given as 14,5 and for the Greater London area, the projected 1980 total is given as 14,0. The National average for the 365 day year 1968/69 for house and trade refuse collected per person per day is given as 0,80 kg.

†Bolitho[4] has given the daily per capita rate for Johannesburg as:
c. 2,0 kg for White areas (estimated);
c. 1,1 kg for all areas.

The composition of domestic refuse in Johannesburg is given by Verrier[3] as follows:

Category	Equivalent Dry Mass as Per Cent of Total Dry Mass Johannesburg
Putrescibles	17,0
Kraft	9,8
Newsprint	13,9
Common paper	14,0
Plastics	8,5
Glass	14,1
Ferrous metals	8,9
Aluminium	1,1
Other metals	0,1
Rags, rubber, leather	2,1
Unclassified	8,8
Fines (or ash)	1,7

Changes in Composition and Density: Bolitho[4] (1973), has drawn attention to the marked changes which have taken place in the composition and density of refuse since 1936.
Changes of note have been:

(1) Reduction in density to one-half of the 1936 figure, accompanied by a great increase in volume per "generator";
(2) Vast increase in paper content (× 2,5 to 1969);
(3) Increases in plastic content;
(4) Great decrease in ash and cinder content;
(5) Growth in paper, metal and glass content due to the increase in frozen and canned foods and beverages.

Barnard[5] has given the following analysis of a survey of municipal waste disposal practices in South Africa carried out in 1975 by the Department of Health and Welfare:

Practice	Province				To-tal	Per Cent
	Cape	Natal	OFS	Tvl.		
Uncontrolled disposal	121	27	46	31	225	27,6
Landfilling	126	53	40	120	339	41,6
Incineration	116	7	12	35	170	20,8
Composting	21	2	0	8	31	3,8
Recovery (partial)	0	4	7	14	25	3,1
No service	7	3	3	12	25	3,1
Total	391					
Grand Total					815	

Solid Waste Management

Urban solid waste management encompasses the following six component functional activities, viz:

(1) Generation;
(2) On-site storage;
(3) Collection;
(4) Transfer and transport;
(5) Processing and recovery;
(6) Disposal.

(1) *Waste Generation:* More consideration is now being given by householders and others to the separation of such items as newspapers and cardboard, metal cans, bottles, etc. from garbage stored for collection. However, the habits of individuals are not easily controllable in the matter of discarding wrappings, cardboard containers, etc. which are dropped shamelessly anywhere except in receptacles provided for the purpose thereby littering pavements, pathways and streets.

(2) *On-site Storage:* The provision of storage for solid wastes is a commitment for all householders, flat/apartment, commercial and industrial building owners or renters. On-site storage is necessary for aesthetic as well as practical reasons. Due to the biological decompositon of the wastes they require to be collected regularly and within a period of less than eight days.

Metal or high-density plastic containers – retained by the ratepayer – or disposable plastic bags are commonly used means for on-site storage. The use of removable plastic bags stored in metal or high-density plastic bins provided with lids represent fairly common present-day practice.

(3) *Collection:* This involves the collection and transport of wastes from the collection points of houses and buildings to either:

(a) the disposal site (usually within a distance not exceeding c. 16 km), or,
(b) a transfer station, processing station or landfill site.

Collection costs represent the major cost item of urban solid waste disposal. Unlike sewage disposal which requires a sewerage system for conveyance of the sewage to the purification works, transport of solid wastes requires the use of special transport vehicles to carry the wastes for disposal.

Note: Krige[6] has suggested that more use should be made of the sewer as a transport medium for certain wastes normally transported by surface vehicle (cf. Chapter 6). However, the

remaining wastes which would require surface transport would still be considerable.

(4) *Transfer and Transport:* This involves the transfer, usually at a transfer station, of wastes from the smaller collection vehicles to larger ones for subsequent long-distance transport to the disposal site.

(5) *Processing and Recovery:* This involves the use of plant for the recovery of usable materials. Plant used can include comminutors such as hammer mills or drum pulverizers, electromagnetic separators for the retrieval of iron, eddy-current separators for aluminium, screens for glass separation.

(6) *Disposal:* Solid wastes are ultimately transported to a landfill site. A modern landfill is a method of disposing of solid wastes on land without creating a nuisance or constituting a health hazard due to rodent and insect breeding and the pollution of surface and groundwater.

Refuse Disposal Methods in England

Refuse disposed of by local authorities in England in 1966/67 (excluding demolition waste) has been reported (''Refuse Disposal'', H M Stationery Office, 1975, p.8) as having been dealt with as follows:

	Per cent
(a) Direct tipping on land	90,4
Pretreatment by:	
(b) Separation/Incineration	7,6
(c) Direct incineration	0,7
(d) Pulverization	1,0
(e) Composting	0,3

Processed refuse and residue are mainly disposed of by tipping.

Methods of Disposal of Urban Refuse

There are only two methods of disposal of urban solid wastes, viz. –
Disposal on land or,
Disposal in the sea.

The latter method is practised, in certain instances for the disposal of sewage and sewage sludges but the practice of ocean dumping of solid wastes was prohibited by US Supreme Court decision in the United States in 1933 and Britain discontinued the practice in the early 1950's. The control of dumping of substances or articles in the sea is subject, in the UK, to the provisions of the ''Dumping at Sea Act, 1974''.

The use of land for the disposal of solid wastes, therefore, would appear to be the only logical solution to the problem of urban solid waste disposal. The crux of the problem, naturally, is to decide on the best practical method of land disposal.

The uncontrolled dumping of solid wastes at disposal sites (i.e. uncontrolled tipping) can give rise to many unfavourable consequences such as –

(1) The dissemination of unpleasant odours;
(2) The breeding of insects such as the common house fly *(Musca domestica)**;
(3) Infestation by rodents;
(4) The inroads of human and animal scavengers;†
(5) Pollution of the groundwater and of surface water.

The five drawbacks cited can be overcome by controlled sanitary landfill procedures.

Sanitary Landfill

Sanitary landfilling is considered to be the most economical and acceptable method of solid waste disposal. This method of disposal consists of an overall operation in which the wastes for disposal are compacted and covered with a layer of soil at the end of each day's operation. When the disposal site has reached its capacity limit and all disposal operations have been completed a final top layer of at least 0,6 m of soil or other suitable inert material is applied.

The Department of the Environment in Britain recommends the following precaution for ''Controlled Tipping'' (Sanitary Landfill):

(1) The deposit to be made in layers.
(2) No layer to exceed 1,83 m in depth.
(3) Each layer to be covered, on all surfaces exposed to the air, with at least 23 cm of earth or other suitable substance; provided that during the formation of any layer not more than 1,67 m^2 for every 3 m^3 of refuse deposited daily may be left uncovered at one time.
(4) No refuse to be left uncovered for more than 24 h from the time of deposit.
(5) Sufficient screens or other suitable apparatus to be provided, where necessary, to prevent paper and other debris from being blown by the wind away from the place of the deposit.
(6) No refuse to be deposited in water.
(7) All reasonable precautions to be taken to prevent the outbreak of fires and the breeding of

*In 1910 Copeman, Howlett and Merriman[7] carried out investigations at Postwick (a small village about five miles (c. 8 km) East of Norwich), where inhabitants suffered from a plague of flies resulting from the breeding facilities afforded by a large refuse tip about 0,8 km away. Using marked flies the investigators found that many of the marked flies were able to travel between 732 – 914 m and, in fact, one fly travelled 1 554 m in 48 h.

†A depositing site should be adequately fenced and provided with lockable gates to prevent the ingress of large and small animals, scavengers and illegal depositors of wastes. A record of refuse deliveries should be kept by the gate attendant.

flies and vermin in the deposit. Hollow receptacles likely to provide breeding places for vermin to be flattened or filled before being covered with refuse.

(8) Deposits consisting entirely or mainly of fish, animal or other organic refuse to be covered forthwith with earth or other equally suitable substance to a depth of at least 0,6 m.

(9) Deposits to be maintained in a tidy condition; tins, hollow vessels and other loose debris not to be left lying on or about the place of deposit.

(10) Sufficient and competent labour to be provided in connexion with the deposit to enable the necessary measures to be taken for the prevention of a nuisance.

(11) So far as practicable each layer which has been laid and covered with soil to be allowed to settle before the next layer is added.

(12) Whenever practicable the person making the deposit should avoid raising the surface of the tip above the general level of the adjoining land.

(13) All refuse to be disposed of with such despatch and be so protected during transport as to avoid the risk of nuisance.

Transformations within a Solid Waste Deposit

Both aerobic and anaerobic organisms are present in refuse upon discharge at the depositing site. Initially aerobic decomposition of biodegradable organic matter will take place due to the presence of entrapped air. However, this interstitial air is readily exhausted and anaerobic digestion becomes established.

A significant source of micro-organisms – both aerobic and anaerobic – is the soil which is used as daily cover to the deposited layers of solid wastes. Moisture being present, proteins, carbohydrates and fats are biodegraded (as in sewage sludge digestion), cellulose not so rapidly and plastics still considerably less.

Gases resulting include mainly methane and carbon dioxide plus smaller quantities of hydrogen sulphide and hydrogen, and – intermediately – volatile organic acids are formed. For the on-going biodegradation it is necessary to ensure that moisture is present in the deposit.

Under normal conditions the rate of decomposition reaches a peak within 2 years and then reduces gradually over a period of as much as 25 years or longer. However, if the wastes in a well-compacted landfill are not kept moist by the addition timeously of adequate amounts of water (e.g. by spraying) decomposition of many materials does not take place.

Gases Present in Landfills: Gases found in landfills include ammonia, carbon dioxide, hydrogen, hydrogen sulphide, methane, nitrogen and oxygen. Of these carbon dioxide and methane are the most abundant and arise from the anaerobic decomposition of the organic wastes. Of the two constituents carbon dioxide (CO_2) has a density of 1,9768 g/ℓ and methane (CH_4) 0,7167 g/ℓ, both at 0°C and 1 atmosphere pressure. This being so the amount of methane would increase with time whereas the carban dioxide would descend with the leachate in the deposit. The solubility of CO_2 in water at 0°C and 1 atm. is 0,3346 g/100 g water whereas the solubility of CH_4 is only 0,003959 g/100 g water also at 0°C and 1 atm.

Leachate: The liquid which percolates through solid wastes constitutes leachate. Leachate contains extracted soluble and suspended matter arising from the decomposing wastes. Such leachate being highly polluting is unfit for discharge into a watercourse and should not be allowed to gain access to the groundwater regime.

Barnard[5] has shown that leachate is much more highly polluting than raw sewage. He has done this by reference to chemical analyses for parameters such as COD, C, N, Cd, Cr, Cu and Fe.

On the other hand Tshobanoglous, Thiesen and Eliassen[8] have given the following data (derived from various sources) on the composition of leachate from landfills:

Constituent	Value mg/ℓ (except pH)	
	Range	Typical
BOD_5 (Biochemical Oxygen Demand – 5 days)	2 000 – 3 000	10 000
TOC (Total Organic Carbon)	1 500 – 20 000	6 000
COD (Chemical Oxygen Demand)	3 000 – 45 000	18 000
Total Suspended Solids	200 – 1 000	500
Organic Nitrogen	10 – 600	200
Ammoniacal Nitrogen	10 – 800	200
Nitrate	5 – 40	25
Total Phosphorus	1 – 70	30
Ortho Phosphorus	1 – 50	20
Alkalinity as $CaCO_3$	1 000 – 10 000	3 000
pH Value	5,3 – 8,5	6
Total Hardness as $CaCO_3$	300 – 10 000	3 500
Calcium	200 – 3 000	1 000
Magnesium	50 – 1 500	250
Potassium	200 – 2 000	300
Sodium	200 – 2 000	500
Chloride	100 – 3 000	500
Sulphate	100 – 1 500	300
Total Iron	50 – 600	60

Treatment of Leachate: In some cases, and where convenient, leachate has been collected and disposed

of by discharge into a sewerage system conveying sewage to a sewage purification works, or, alternatively, by discharge into a sea outfall. However, in most cases such methods of overcoming the problem are not possible and on-site methods of treatment of leachate are necessary. Methods of on-site treatment which have been proposed have included –

(1) Settlement, chemical treatment and filtration;
(2) Treatment by extended aeration activated sludge method;
(3) Recirculation of leachate through the deposit (by spraying).

Robinson and Maris[9] have investigated the treatment of leachates from domestic wastes in landfill sites. They have investigated the effects of recirculating leachate through the "Seamer Carr Landfill" in Yorkshire, England.

The part of the landfill site used for the research investigation was 2,5 ha in area and lined with a 3-mm thick high-density polyethylene membrane. Four lines of porous tile drains across the lined area made it possible for leachate which collected in the base of the site to drain to a sump from where it was pumped into a storage lagoon with a capacity of 1 500 m^3, from where it could be recirculated. Suitably high (3 m) bund walls were constructed from clay soil around the edge of the lined area to prevent runoff or drifting of sprayed leachate. Leachate was sprayed on to the area under investigation by pumping from the storage lagoon using 100-mm diameter flexible tubing to a number of perforated distribution tubes set flat on the surface of the refuse in such fixed positions to effect vertical jetting of the recycled leachate at 5 m intervals and to a height of 4 m.

Results obtained for the leachate draining from the control area and the recycle area of the Seamer Carr Landfill during July 1980 were as follows:

Parameter	Whole Site	Control Area	Recycle Area
pH Value	5,75	5,97	5,77
COD	60 400	62 400	43 981
BOD_5	35 800	38 000	21 780
TOC	17 600	19 800	11 000
Volatile acids (as C)	13 578	14 609	10 056
Ammoniacal N	900	990	729
Chloride	2 160	2 760	2 059
Sodium	1 900	2 400	1 850
Magnesium	370	420	324
Potassium	1 060	2 050	1 194
Calcium	3 750	4 100	2 725
Chromium	0,65	1,0	0,66
Manganese	200	250	133
Iron	1 300	2 050	1 225
Nickel	1,3	1,65	0,83
Copper	0,05	0,05	0,05
Zinc	145	130	99
Cadmium	0,004	0,003	0,003
Lead	0,5	0,64	0,04

Robinson and Maris concluded that although some organic materials can be removed from leachate during recirculation, concentrations of ammonia, chloride and COD may remain high. This, they state, will make it difficult for discharge of lower strength leachates to surface waters unless considerable dilution is available.

They conclude, further, that recirculation of leachate can offer benefits in reducing the volume* and strength of leachate, but cannot be considered to be a complete answer to surface leachate discharges. At many sites a combination of recirculation and aerobic biological treatment may be the most effective option.

The authors noted that good removal of BOD (more than 98 per cent) from settled effluents and COD (more than 92 per cent) results from aerobic biological treatment of leachate from a waste landfill at low temperatures.

Cost of Landfill Operations vs. other Disposal Methods

The following is a guide of costs per ton, including the disposal, where appropriate, on adjacent sites reported for England:[2]

Disposal Method	Cost per ton, 1969 prices, including loan charges and land costs
Controlled tipping	50p to £ 1
Pulverization	£ 1,25 to £ 2
Composting (fully mechanized)	£ 2,5 to £ 3,5
Incineration	£ 2,5 to £ 3,5

Note: Although the costs are not recent, nevertheless, they serve to show that controlled tipping/sanitary landfill is the cheapest method for the disposal of urban solid wastes.

In New York the complete cost of disposal of wastes by landfill has been reported† (in 1949) as being 7,5 US cents per cubic yard as against 30,5 US cents per cubic yard for incineration.

*Due to evaporation arising from spraying.
†McCord C P and Witheridge W N *"Odors – Physiology and Control"*, McGraw Hill Book Company Inc., New York, 1949, p 139.[10]

Therefore, it would appear that sanitary landfilling is the least costly of the methods practised for the disposal of solid wastes. However, additional costs must necessarily arise, in certain instances, for the treatment of leachate to improve its quality for discharge into a sewer, watercourse, river, or for agricultural use by irrigation.

Some of the advantages and disadvantages of sanitary landfills are as follows:

Advantages:

(1) Where suitable land is available within reasonable transportable distance for urban refuse sanitary landfilling is usually the most economical method of solid waste disiposal.
(2) The initial investment is low compared with other disposal methods.
(3) Wasteland may be reclaimed for subsequent use for sportsfields, golf courses, airports, etc.
(4) Only crawler tractor scrapers, steel wheel compactors and other readily available equipment are needed for on-site operations.

Disadvantages:

(1) In highly populated areas, suitable land may not be available within economical transporting distance.
(2) Proper sanitary landfilling standards must be daily adhered to – otherwise the operation will become an uncontrolled refuse deposit.
(3) Sanitary landfills located in residential areas can give rise to extreme public resentment.
(4) A completed landfill will require periodic maintenance due to settlement.

Solid Wastes Disposal in South Africa

During the 1973 session of Parliament steps were taken to bring about co-ordinated action in regard to environmental conservation and the combating of pollution. A Cabinet Committee and a South African Committee on Environmental Conservation (later called the Council for the Environment) were established.

Investigation and studies led to the drafting of legislation on the abatement of noise, the disposal of solid wastes and the combating of littering. The Hoon Commission of Inquiry which examined the solid wastes and littering aspects recommended:

- The co-ordination of the activities of all organizations concerned with solid waste and littering control and stimulation of anti-littering and anti-pollution campaigns;
- The adoption of methods and application of incentives to promote re-use, recycling and reclamation of packaging materials, prevention of raw material depletion and combating pollution;
- The application of means to regulate production, decrease, utilization and disposal of solid waste;
- The creation of procedures for profitable use or re-use of urban solid waste, including generation of energy;
- The establishment of means for the recovery, recycling and re-use of urban solid wastes;
- The development of methods and measures to effect and enforce sorting of urban solid wastes at source;
- The development of guidelines for the evaluation of packaging materials and containers.

These recommendations amongst others were incorporated in the White Paper on a national policy regarding environmental conservation in 1980, which eventually resulted in the promulgation of the Environment Conservation Act (No. 100 of 1982).

The Environment Conservation Act, 1982

The Environment Conservation Act (No. 100 of 1982) incorporated the recommendations of the Hoon Commission.

In dealing with the Environment Conservation Act and the proposed regulations Barnard[11] concludes by stating, "South Africa had to lean heavily on the experience abroad for the development of pollution control legislation, but in view of the uneven distribution of water resources in particular, measures had to be stricter here than for many other countries. The recent promulgation of the Environment Conservation Act with the provision to regulate solid waste handling and littering has however put South Africa in a strong position to take the lead in international spheres once more.

But legislation alone is not enough. The regulations must be backed up by a well-planned educational and training campaign, assisted by both the public and the private sector, and aimed at all levels of society".

South African Legislation Controlling Solid Wastes Disposal

South African legislation enacted to control the disposal of waste material includes the Dumping at Sea Control Act No. 73 of 1980; the Water Act No. 54 of 1956; the Water Amendment Act No. 96 of 1984; the Environment Conservation Act No. 100 of 1982 and Regulations proposed in terms of Section 12(2)(a) of the Act in terms of Government Notice 1549 of 12 July 1985 and radioactive active wastes controlled by regulations in terms of the Nuclear Energy Act No. 92 of 1982.

Water pollution which may arise from solid waste disposal sites is controlled by the Water Act No. 54 of 1956 and the Water Amendment Act No. 96 of 1984. Other water pollution control measures include

Sections 36 to 38 of the Health Act No. 63 of 1977; the Sea Shore Act No. 21 of 1935; the Sea Fisheries Act No. 58 of 1973; the Prevention and Combating of Pollution of the Sea by Oil Act No. 67 of 1971 and the Dumping at Sea Act No. 73 of 1980.

Regulations in Terms of Section 12(2)(a) of the Environment Conservation Act, 1982, Relating to the Control of the Disposal of Solid Waste

In these regulations "solid waste" is defined as "any solid refuse or waste originating from any residential, commercial or industrial area and includes any semi-solid, liquid or gaseous substance contained therein". Significant regulations are Nos. 2(a) and (b); 3; 4(a) and (b); 5; 6; 8; and 9. These are as follows:

2(a) Any person managing a waste disposal site or waste treatment plant at the date of commencement of these regulations shall, within 90 days of the said date, notify the Director-General by registered post of the existence of such site or plant and within six months from the said date, furnish the particulars referred to in regulation 5 in respect thereof.

2(b) Any person intending to acquire, prepare, construct or alter a waste disposal site or waste treatment plant or who at the date of commencement of these regulations is engaged in the acquisition, preparation, construction or alteration of such site or plant shall, before acquiring such site or plant or commencing such preparation, construction or alteration or, as the case may be, before continuing with such acquisition, preparation, construction or alteration, notify the Director-General by registered post of such intention or engagement and furnish the particulars referred to in regulation 5 in respect of the site or plant concerned.

3. The Director-General shall classify and keep a register of every waste disposal site of which he is notified in terms of regulation 2, and in respect of which a licence is issued in terms of regulation 6, according to the geo-hydrological characteristics thereof and the types of solid waste disposed of or to be disposed of thereon.

4(a) As from a date to be published by the Minister in the *Gazette* no person shall –

(i) except under the authority of a valid licence granted in terms of regulation 6 and in accordance with any conditions attached to such licence, acquire, operate, prepare, construct or alter any waste disposal site or waste treatment plant; or,

(ii) dispose of solid waste otherwise than on a waste disposal site or by means of waste treatment plant contemplated in subparagraph (i).

(b) The provisions of paragraph (a) (ii) shall not apply in respect of solid waste deposited in a container for the purpose of the disposal thereof by a local authority, body or person having authority to undertake the treatment or disposal of solid waste.

5. Any person applying for a licence in respect of any waste disposal site or waste treatment plant shall, unless the Director-General approves otherwise, submit to the Director-General the information and documents referred to in the Schedule to these regulations.

6. The Director-General may grant a licence in respect of any waste disposal site or waste treatment plant as applied for or with such modifications or subject to such general conditions as he may from time to time determine in respect of the various types of waste disposal sites as classified under regulation 3 or such special conditions as he may impose in respect of the waste disposal site concerned, or he may refuse to grant a licence and he may, after a licence has been granted, at any time amend the conditions to which it is subject.

8. Any person disposing of solid waste shall –

(a) operate and maintain any waste disposal site or waste treatment plant used for the purpose in such manner so as to restrict any public nuisance, health hazard or any damage to the environment caused thereby, to a minimum;

(b) fence in any waste disposal site used for the purpose as deemed necessary by the Director-General in respect of each particular site and stipulated in the licence issued in respect of such site;

(c) erect a weather-proof and clearly legible notice board made of durable material in both official languages and an indigenous language spoken in the surrounding area on all gates in the fence, prohibiting un-authorised entry to the waste disposal site and indicating the hours of operation and the name, address and telephone number of the licence holder and the person in charge of the site;

(d) drill such boreholes to such depth and at such intervals and equip each borehole as the Director-General may specify in respect of each particular waste disposal site;

(e) have samples of water occurring in the said boreholes so analysed and retain a record of such analyses for such a period as may be specified by the Director-General in respect of each particular waste disposal site and submit a summary of such analyses to the Director-General before 15 January and 15 July every year;

(f) by means of properly designed, constructed and maintained works –

(i) divert from the waste disposal site all stormwater arising from the maximum

flood with an average frequency of once in 50 years;

(ii) retain on the waste disposal site all runoff arising on the site from the expected maximum rainfall during a period of 24 hours with an average frequency of once in 50 years and make provision for a dry freeboard of not less than 0,5 metres at all times; and

(iii) retain on the waste disposal site all seepage and eroded material arising on the site;

(g) treat such waste prior and subsequent to disposal thereof as may be specified in the licence of the waste disposal site or waste treatment plant concerned;

(h) keep a record of the types and quantities of such waste disposed of daily for such period as may be specified by the Director-General in respect of each particular waste disposal site or type of waste and submit a summary of such record to the Director-General before 15 January and 15 July every year;

(i) place any type of solid waste specified by the Director-General in a container prescribed in such specification and which shall be clearly marked in both official languages and an indigenous language spoken in the surrounding area to indicate the contents of the container, and dispose of the said waste in the manner prescribed in such specification;

(j) at the end of each working day cover all layers of waste with material approved by the Director-General so arranged as to ensure that rainwater penetration is restricted to a minimum and the free drainage of surface water to the works referred to in regulation 8 (f) (ii) and (iii);

(k) notify the Director-General by registered post at least one year in advance of the proposed closure of any waste disposal site;

(l) immediately after abandoning disposal operations at any waste disposal site, cover the entire area of the site with a layer of material approved by the Director-General, not less than one metre in depth after compaction and so graded and rounded off that –

(i) no ponding of precipitation occurs;

(ii) free drainage of rainfall is ensured without causing erosion; and

(iii) the area is kept free of objects and materials likely to interfere with the final restoration of the site including the vegetation thereof if so required by the Director-General;

(m) if interrupting disposal operations at any waste disposal site, for any reason, for a period in excess of three months, immediately notify the Director-General by registered post of such interruption.

9. Any person disposing of solid waste shall not –

(a) use a waste disposal site with an aeration zone between the waste and the ground water of less than 2 metres above the wet season high elevation of the water table unless suitable engineering is approved by the Director-General;

(b) use a waste disposal site situated below the maximum level likely to be reached with an average frequency of once in 50 years by flood-water in any watercourse;

(c) without the prior consent in writing of the Director-General use, sell, let or alienate temporarily or permanently for purposes other than the disposal of solid waste, any waste disposal site used by him; and

(d) employ any contractor to undertake such disposal unless an agreement approved by the Director-General has been concluded with such contractor, which agreement shall, unless otherwise authorised by the Director-General, provide for the following;

(i) Compliance by the contractor, where applicable, with these regulations;

(ii) the source, quantity and chemical nature of the waste to be disposed of;

(iii) any precautions to be taken by the contractor in handling the waste;

(iv) the method of disposal;

(v) a certificate to be signed by the said person and the contractor in respect of each load of waste removed reflecting a serial number, the date of removal, the quantity and type of waste removed and the destination of the waste;

and the said person shall keep such certificates for a period of not less than five years and make them available for inspection by the Director-General upon request.

Classification of Waste Disposal Sites

In terms of regulation 6 of the regulations promulgated in terms of section 12(2)(a) of the Environment Conservation Act No. 100 of 1982 (q.v.):

"the Director-General may grant a licence in respect of any waste disposal site . . ." ". . . under such special conditions as he may impose in respect of the waste disposal site concerned . . ."

When an application is made for permission to dispose of wastes it is necessary to specify the following:

(1) Particulars of the types of waste to be disposed of;

(2) Topographical details of the locality and geohydrological information concerning the proposed depositing site.

Three classes of site have been designated, as follows:

Class of Site	Function of Site
No. 1	Containment
No. 2	Sanitary Landfill
No. 3	Unsuitable for any waste disposal

Waste Acceptance Criteria

(1) *General Requirements:* These apply to all wastes for disposal irrespective of class of site –
   (i) The pH value of waste *per se* or a 1 : 1 w/w extract with distilled water shall be within the range pH 7 – 12.
   (ii) Free cyanide shall not exceed 0,4 mg CN/ℓ.
   (iii) Free sulphide shall not exceed 10 mg S/ℓ.
   (iv) The flashpoint of the waste as measured by the Standard Closed Cup Method must be below 60°C.
   (v) Reaction of the waste with air or water within the range pH 7 – 12 shall not take place to produce inflammable, explosive or toxic gases.
   (vi) No highly reactive oxidizing or reducing compounds shall be present in the waste.

(2) *Class 1 Site:* This is a site considered safe for the disposal of toxic and poisonous industrial wastes. In many cases pretreatment and in some cases encapsulation will be necessary before disposal in the depositing site. Being a containment site no discharge or seepage to the water environment should take place.

The following wastes may be accepted to a Class 1 site subject to certain chemical constraints and preliminary treatment:

Pharmaceutical wastes
Polychlorinated biphenyls (PCB's)
Organochlorine compounds
Pesticides
Organolead sludges
Water-soluble inks and dyes
Water-soluble salt sludge and salt solutions.

Special Provisions in Respect of Wastes for Disposal in a Class 1 Site:

(a) PCB's, non-biodegradable organochlorine pesticides and arsenic compounds must be enclosed in steel containers. Such containers must be encapsulated in 33 MPa concrete. The concrete is required to be at least 15 cm thick around each container and steel reinforcing shall be used to prevent the concrete from fracturing. The concrete shall be vibrated down in a trench as a safeguard against earthquakes.
(b) Pesticides (other than non-biodegradable organochlorine compounds) shall be disposed of as specified in the SABS Code of Practice for Pesticide Disposal (1979) to landfill sites.
(c) Organolead sludges shall be oxidized by weathering in a special demarcated clay-bunded area in the site; the weathering process shall be considered complete when the lead (Pb) content of the air above the sludge falls below 0,01 mg/ℓ.

Permeability: A Class 1 site should have an attenuation zone permeability not exceeding 10^{-6} cm/s and an aeration zone of at least 2 m.

(3) *Class 2 Site:* This is a site for the disposal of urban refuse and certain insoluble industrial wastes. Wastes include the following:

Heavy metal sulphides
Heavy metal hydroxides
Calcium sulphates
Barium sulphates
Calcium phosphates
Heavy metal phosphates
Calcium fluorides
Heavy metal oxides
Cellulosic wastes
Adhesives
Rubber wastes
Interceptor sludges
Food wastes
Fats, waxes and greases
Industrial effluent treatment sludges
PVA and oil paint sludges
Bituminous wastes
Vegetable oil wastes
Hydrocarbon solvents
Organic resins
Phenolic sludges
Asbestos wastes

Permeability: A Class 2 site should have a permeability not exceeding 10^{-3} cm/s and an aeration zone of at least 2 m.

(4) *Class 3 Site:* This type of proposed site is one which is in direct hydraulic continuity with the ground water table and so is quite unsuitable for the disposal of urban and industrial wastes.

Comment

Many landfill sites have been located near watercourses or in hydraulic continuity with the ground water and control of sites has been somewhat inadequate. Conformance with the new regulations will lead to improved conditions and less pollution of the water environment.

II TOXIC WASTES

The word toxic is derived from the Greek, "Toxi-

kon" – poison for arrows (from "toxon", a bow). Toxicity may be defined as the ability of a chemical molecule or substance to produce injury once it reaches a susceptible site in or on an organism.

Many of the toxic materials encountered today are xenobiotic compounds* synthesized by the chemical industry to assist in the control of various forms of life which threaten human activities. Among these chemical controlling agents we have pesticides (e.g. herbicides, rodenticides, insecticides, miticides, fungicides).

Slater[12] has postulated that: "By suitable manipulations within artificially constructed laboratory communities it may eventually be possible to evolve a single organism able to work in our normal surroundings and do the job for us. Perhaps we may one day be able to spray genetically-constructed organisms where they are needed, just as we now apply dangerous xenobiotic compounds".

There is little doubt that many micro-organisms have been able to adapt to the metabolization or commutation of compounds and substances of a toxic nature.† None the less, for the present, reliance for the disposal or destruction of toxic wastes has to be sought by other practicable means.

The following table gives a list of "toxic and dangerous" wastes defined by the 1978 Directive of the EEC:

List of "Toxic and Dangerous" Wastes Defined by 1978 EEC Directive

Arsenic and its compounds
Cadmium and its compounds
Beryllium and its compounds
Lead and its compounds
Phenols and phenolic compounds
Isocyanates
Chlorinated solvents
Biocides and phytopharmaceutical compounds
Pharmaceutical compounds
Ethers
Asbestos dust and fibres
Tellurium and its compounds
Carcinogenic polycyclic aromatic hydrocarbons
Metal carbonyls
Acid and/or basic materials used in the surface treatment and finishing of metals
Mercury and its compounds
Thallium and its compounds
Hexavalent chromium compounds
Antimony and its compounds
Organic and inorganic cyanides (excluding inert polymeric materials)
Organic solvents
Tarry materials from refining and tar residues from distilling
Peroxides, chlorates, perchlorates and azides
Chemical laboratory materials not identifiable and/or new, whose effect on the environment is not known
Selenium and its compounds
Soluble copper compounds

Finnecy[13] in dealing with aspects of control of hazardous waste disposal in the European Economic Community (EEC) states that, in outline, the EEC policy states that goverments should act to:

(1) Encourage the maximum beneficial utilization of resources and to minimize waste by : encouraging use of processes producing the lowest quantity of waste or those that minimize hazard potential of waste; encourging the maximum recovery of value from unavoidable wastes produced;
(2) Introduce control mechanisms to ensure that the wastes which cannot be recycled are disposed of by methods that ensure adequate pretection of public health and the environment;
(3) Ensure that costs of waste disposal are as low as possible while satisfying environmental protection requirements and public health preservation.

He states that few countries disagree on point (2) but different emphasis may be placed on points (1) and (3) and, more particularly, the interpretation of point (3). However, he seemed to think that the British approach of "best practical means" was gaining increased acceptance.

A summary of the main provisions of the 1978 Directive of the EEC (78/319/EEC, Official Journal L84, 31 March 1978) is as follows:

- Member states shall encourage minimum production of toxic and dangerous wastes by encouraging maximum reclamation of value from wastes.
- Toxic and dangerous waste is to be disposed of without endangering human health or the environment, and in particular : without risk to water, air, soil, plants or animals; without causing a nuisance through noise or odours; and without adversely affecting the countryside or places of special interest.
- Competent authorities shall be established, responsible for planning, organization, authorization and supervision of operations for the disposal of toxic and dangerous wastes.
- Where necessary, toxic and dangerous wastes should be kept separate from other materials and wastes when being collected, transported, stored or deposited.
- Toxic and dangerous waste should be packaged and labelled appropriately to indicate its nature, composition and amount.
- Presence of toxic and dangerous wastes should be

*Xenobiotic compounds are compounds which have either not been present in any part of the biosphere in large amounts or have never before appeared in it.

†Recent research at Michigan State University has revealed that a white rot fungus, can degrade DDT into carbon dioxide.

noted and recorded at each site where it has been deposited.

- Installations for storage, treatment and/or disposal of toxic and dangerous waste must have a permit or authorization from the competent authorities. No other plans may be used for these purposes.
- Transport of toxic and dangerous wastes should be controlled by the competent authorities.
- Permits for any installation for treatment, storage or disposal of toxic and dangerous wastes can stipulate : the type and quantity of waste; the technical requirements; precautions to be taken; the disposal site(s); and the methods of disposal. Permits may also include conditions and obligations.
- In accordance with the "polluter pays" principle, costs of disposal of toxic and dangerous waste shall be borne by the holder or previous holder of the waste. If any levies are charged by member states to defray these costs, the yield may be used to finance control measures relating to toxic and dangerous wastes or research pertaining to the elimination of these wastes.
- The competent authorities shall draw up and maintain plans for the disposal of toxic and dangerous wastes. The plans should cover, *inter alia* the quantity of such waste, disposal methods, specialized treatment centre (where necessary) and suitable disposal sites. These plans should be public and copies sent to the Commission who will, together with the member states, review the plans to ensure that implementation of the Directive is effectively co-ordinated.
- Member states may depart from the Directive in cases of emergency. The Commission shall be informed of such departures.
- Full records shall be kept by all authorized installations.
- The competent authorities have rights to inspect authorized installations to ensure compliance with the Directive.
- Member states shall furnish the Commission with a situation report on the disposal of toxic and dangerous waste every three years. These reports will be circulated among the other member states.

Some Interesting Legal Requirements of a Number of EEC Countries

It is interesting to note that Danish law for the control of hazardous wastes is based on the existence of the central hazardous waste treatment plant at Kommunekemi at Nyborg and a nationwide collection and transportation system which is associated with this plant operation. Kommunekemi is run as a joint venture by a consortium which includes Danish industry, the Association of Local Government and the Danish Ministry of the Environment.

France has extensive laws dealing with the treatment, disposal and reclamation of value from hazardous wastes. French law on hazardous wastes incorporates the EEC Directive.

Significantly, French law incorporates the concept of "classified installations" and lays down certain procedures to be followed in factories that have an impact on the local environment.

A point of interest in the Belgian law on toxic wastes is that every industrial enterprise must appoint an appropriate member of staff to be responsible for protecting the environment. This person has the right to exercise control as he considers fit and has an obligation to report to the authorities if he suspects that toxic waste generated by his company is not being properly handled.

As far as the UK is concerned the law involves no special requirements for the treatment or disposal of hazardous wastes as such, beyond the requirement that all disposal sites are licensed as being suitable for the wastes received, whether hazardous or not. However, reserved statutory powers do exist and could result in certain wastes being directed to specific treatment or disposal sites.

Hazardous Waste Arisings in Western Europe

Mills[14] has given the following information on hazardous waste arisings. This information has been obtained from a number of reliable sources:

Country	Annual "Hazardous" Waste Arising(t)		
	For in-house disposal	For external disposal	Total
Austria		350 000	
Belgium	671 000	429 000	1 100 000
Denmark			100 000
West Germany	15 000 000	3 000 000	18 000 000
France	1 500 000	500 000	200 000
Ireland			100 000
Italy			4 900 000
Luxembourg			
Netherlands	260 000	240 000	500 000
Norway	61 000	66 000	127 000
Portugal			2 800 000
Spain			
Sweden	241 000	279 000	520 000
Switzerland		114 000	
UK			4 800 000
(England)	1 500 000	2 200 000	3 700 000

Some significant European hazardous waste disposal routes have been given by Mills[15] as follows:

Country	Domestic Disposal (t/a)					Disposal outside country of origin				Unknown (t/a)
	Landfill	Incineration	Treatment	Recovery	Other	Dumping at sea (1980)	Incineration at sea (1980)	Herfa-Neurode	Other	
Austria	150 000?	200 000				nil	318	yes	yes	
Belgium	500 000?					533 000	12 951	yes	yes	
Denmark	1 200	28 000	22 000			9 000	nil	950	2 000	
West Germany	2 425 000	540 000				2 180 000	90 000	35 000	39 000	
France	150 000	246 000	84 000	146 000	20 000	3 257 000	11 000	5 370	yes	
Ireland	66 600	11 200		7 000	1 600	751 000	nil	no	yes	13 000
Italy	4 600 000?						42		yes	
Luxembourg								yes		
Netherlands	250 000?	60 000	24 000	42 000	2 400	15 000	6 000	8 200	60 000	
Norway	100 000?				8 000	10	nil	yes	yes	
Portugal						nil	nil			
Spain						304 000	nil			
Sweden	500 000?					nil	5 900	400	14 300	
Switzerland	65 000	4 000	20 000	10 000		nil	1 873	2 800	10 000	
UK (England)	1 350 000	60 000	350 000			441 000	nil	1 080	no	

Note: According to Mills[15] in 1983 West Germany had established : 22 large landfill sites; 23 treatment installations; 17 incinerator plants and one underground storage facility (in the potash mine at Herfa-Neurode).

Pesticides

Prior to the discovery of the insecticidal properties of DDT in the Swiss laboratories of the Geigy Company in 1939 the insecticides used were mainly naturally occurring products and inorganic chemicals. However, the next 25 years saw the production of a large number of insecticides and other pesticides as is shown in the following tabulation:

Organic Pesticides in General Use, 1965[16]

Classification	Approximate No. in Use
Insecticides	95
Miticides	17
Nematocides	12
Rodenticides	9
Fungicides	68
Miscellaneous	86
(Repellants, fish toxicants, etc.)	8

Chemical insecticides serve a vital role in efficient agricultural production. However, with their increased use and their consequent spread to situations far removed from the points of initial application, widespread concern was expressed over the likely risks to the environment and the effects of their use on man and his food supply. This concern has been justified since many modern pesticides persist under a variety of environmental conditions. Consequently, the control of the nature and use of pesticides became necessary as well as the allowable quantities in foods and feeds.

Note: In this regard an "International Symposium on the Chemical Control of the Human Environment" was held under the auspices of the International Union of Pure and Applied Chemistry (IUPAC) at the University of the Witwatersrand, Johannesburg, from 14 – 18 July, 1969. At this symposium many of the papers presented dealt with pesticides. There are two general classes of chemical insecticides, viz. –

(1) Chlorinated hydrocarbon insecticides;
(2) Organophosphorus insecticides.

(1) Chlorinated Hydrocarbon Insecticides

There are three classes of chlorinated hydrocarbons, viz:

Class I : Oxygenated Compounds

Chlorobenzilate
Dicofol
Dieldrin
Endosulfan
Endrin
Kepone
Methyloxychlor
Nestran
Ovex
Sulfenone
Tetrachlor

Class II : Benzenoid, Non-oxygenated Compounds

BHC
Chlorbenside
DDT
Lindane
Perthane
TDE
Zectran

Class III : Non-oxygenated, Non-benzenoid Compounds

Aldrin
Chlordane
Heptachlor
Mirex
Strobane
Toxaphene

Available information indicates that in the presence of water volatilization of chlorinated hydrocarbon insecticides takes place followed by degradation by ultraviolet light when exposed to the atmosphere.[17]

Aldrin and dieldrin tend to move upward into the top 5 cm soil layer. They are degraded microbiologically, chemically and by ultraviolet light and are volatilized.

Chlorinated hydrocarbons accumulate in the fatty tissue of the animal body. In the case of rats and birds fed on a diet containing dieldrin at a given level they accumulate the insecticide in their fatty tissue up to an equilibrium amount and adapt to the toxicant and gradually metabolize the chemical at a faster rate than the intake rate.

Buescher, Dougherty and Skrinde[18] found that aldrin and dieldrin are removed from water by aeration under laboratory conditions. However, lindane gave no measurable effects under similar aerating conditions.

(2) Organophosphorus Insecticides

A chemical classification of the most widely used compounds of this type is as follows:

Aliphatic Derivatives

Butonate
Demeton
Dichlorvos
Dimefox
Dimethoate
Dithiodimeton
Ethion
Malathion
Methyl dimeton
Mevinphos
Mipafox
Naled
Phorate
Phosphamidon
Shradan
Sulfotep
TEPP
Trichlorofon

Aromatic (cyclic) Derivatives

Azinphosmethyl
Carbophenothion
Diazinon
Dicapthon
Endothion
EPN
Fenthion
Methyl parathion
Parathion
Ronnel

All organophosphorus insecticides undergo similar reactions. All are inhibitors of the enzyme cholinesterase and their potency depends not only upon their intrinsic affinity but also on anti-cholinesterase properties acquired through *in vivo* metabolism. The number of toxic organophosphorus compounds which can be synthesized seems to be considerable but of all these parathion, methyl parathion and malathion are the most commonly known and used.

These insecticides (cf. following water solubility table) range from totally water-soluble compounds to virtually insoluble ones. Some water-soluble compounds lose their toxicity and no longer display their systemic properties in a water environment.

The organophosphorus compounds tend to hydrolyse and break down into relatively non-toxic and innocuous end products after short periods of time.[18]

On the other hand, the chlorinated hydrocarbon compounds are resistant to biological and natural chemical degradation in the water environment.

Water Solubilities of some Organophosphorus Compounds

Compound	mg/ℓ	Compound	mg/ℓ
Carbophenothion	2	Phorate	15
Parathion	24	Malathion	145
Azinphosmethyl	33	Dichlorvos	1 000
Diazinon	40	Dimethoate	7 000
Methyl parathion	50	Mevinphos	Infinite

Herbicides

There are two classes of herbicides: Selective and non-selective. However, many selective herbicides when used in higher dosages become non-selective.

Chemical Classification of Herbicides

Substituted phenols
Chlorophenoxy compounds
Substituted acetic and propionic acids
Amides and thioamides
Substituted ureas
Carbamates and dithiocarbamates
Symmetrical triazines
Benzoic acid derivatives
Miscellaneous herbicides

Bipyridilium compounds include the non-selective herbicides paraquat and diquat. The phenoxyacetates (MCPA; 2,4-D; 2,4,5-T) are widely used for selective weed control. The triazine chemical series includes the following herbicides:
Simazine, atrazine, prometryne, desmetryne.

The herbicidal triazines are not very soluble in water and are virtually non-volatile.

Pesticide Poisoning

The Department of Health and Social Security in Britain has specified the following chemicals in the Health and Safety (Agriculture) (Poisonous Substances) Regulations, 1975, viz:

(1) ***Dinitro Compounds***
Dinoseb (DNBP) and its salts
Dinoterb and its salts
DNOC (DNC) and its salts

(2) ***Organochlorine Compounds***
Endosulfan
Endrin

(3) ***Organophosphorus Compounds***
Amiton and its salts
Azinphos-ethyl
Azinphos-methyl
Chlorfenvinphos
Dimephion
Demeton
Demeton-methyl
Demeton-S-methyl
Demeton-S-methyl sulphone
Dialifos
Dichlorvos
Dimefox
Dioxathion
Disulfoton
Ethion
Fonofos
Mazidox
Mecarbam
Mephosfolan
Methidathion
Mevinphos
Mipafox
Omethoate
Oxydemeton-methyl
Parathion
Phenkapton
Phorate
Phosphamidon
Primiphos-ethyl
Schradan
Sulfotep
TEPP
Thiometon
Thionazin
Triazophos
Vamidothion

(4) ***Fluoracetic Acid Derivatives***
Fluoracetamide

(5) ***Organomercury Compounds***
Not specified – However, methyl mercury is very poisonous (cf. the Minamata episode, Chapter 17).

(6) ***Arsenic Compounds***
Sodium arsenite
Potassium arsenite

(7) ***Organotin Compounds***
Fentin acetate
Fentin hydroxide

(8) ***Carbamates***
Aldicarb
Carabofuran
Methomyl
Oxamyl

(9) ***Soil Fumigants***
Chloropicrin

(10) ***Miscellaneous Organic Compounds***
Cycloheximide
Drazoxolon
Endothal and its salts
Fenaminosulf
Fenazaflor
Formetanate
Nicotine and its salts

III HAZARDOUS WASTES

Broadly considered there are five categories of hazardous wastes, viz:

(1) Chemical
(2) Biological
(3) Flammable
(4) Explosive
(5) Radioactive

Certain chemical wastes have been discussed under Section II – ("Toxic Wastes") of this chapter where the impact of pesticides on the water environment has been considered. However, chemical wastes may be classified as follows:

(1) Synthetic organic chemicals
(2) Inorganic metals, salts, acids and bases
(3) Flammables
(4) Explosives

A sample list of hazardous chemicals is given in the following collection of non-radioactive hazardous wastes [presented in EPA report to US Congress, 1974 (Publication SW. 115)], viz:

Miscellaneous Inorganics

Ammonium chromate
Ammonium dichromate
Antimony pentafluoride
Antimony trifluoride
Arsenic trichloride
Arsenic trioxide
Cadmium (alloys)
Cadmium chloride
Cadmium cyanide
Cadmium nitrate
Cadmium oxide
Cadmium phosphate
Cadmium potassium cyanide
Cadmium (powdered)
Cadmium sulfate
Calcium arsenate
Calcium arsenite
Calcium cyanides
Chromic acid
Copper arsenate
Copper cyanides
Cyanide (ion)
Decaborane
Diborane
Hexaborane
Hydrazine
Hydrazine azide
Lead arsenate
Lead arsenite
Lead azide
Lead cyanide
Mercuric chloride
Mercuric cyanide
Mercuric diammonium chloride
Mercuric nitrate
Mercuric sulfate
Mercury
Nickel carbonyl
Nickel cyanide
Pentaborane-9
Pentaborane-11
Perchloric acid (72%)
Phosgene (carbonyl chloride)
Potassium arsenite
Potassium chromate
Potassium cyanide
Potassium dichromate
Selenium
Silver azide
Silver cyanide
Sodium arsenate
Sodium arsenite
Sodium bichromate
Sodium chromate
Sodium cyanide
Sodium monofluoroacetate
Tetraborane
Thallium compounds
Zinc arsenate

Miscellaneous Inorganics (Continued)

Magnesium arsenite	Zinc arsenite
Manganese arsenate	Zinc cyanide

Halogens and Interhalogens

Bromine pentafluoride	Chlorine trifluoride
Chlorine	Fluorine
Chlorine pentafluoride	Perchloryl fluoride

Miscellaneous Organics

Acrolein	Lewisite (2-chloroethenyl dichloroarsine)
Alkyl leads	Mannitol hexanitrate
Carcinogens (in general)	Nitroaniline
Chloropicrin	Nitrocellulose
Copper acetylide	Nitrogen mustards (2,2′, 2″ trichloro-triethylamine)
Copper chlorotetrazole	Nitroglycerin
Cyanuric triazide	Organic mercury compounds
Diazodinitrophenol (DDNP)	Pentachlorophenol
Dimethyl sulfate	Picric acid
Dinitrobenzene	Potassium dinitrobenz-furoxan (KDNBF)
Dinitro cresols	Silver acetylide
Dinitrophenol	Silver tetrazene
Dinitrotoluene	Tear gas (CN) (Chloroacetophenone)
Dipenterythritol hexanitrate (DPEHN)	Tear gas (CS) (2-chlorobenzylidene malononitrile
GB (propoxy (2)-methylphosphoryl fluoride)	Tetrazene
Gelatinized nitrocellulose (PNC)	VX (ethoxy-methyl phosphoryl N,N dipropoxy-(2,2)-thiocholine)
Glycol dinitrate	
Gold fulminate	
Lead 2,4-dinitroresorcinate	
Lead styphnate	

Organic Halogen Compounds

Aldrin	Ethylene bromide
Chlorinated aromatics	Fluorides (organic)
Chlordane	Guthion
Copper acetoarsenite	Heptachlor
2,4-D (2,4-dichlorophen-oxyacetic acid)	Lindane
	Methyl bromide
DDD	Methyl chloride
DDT	Methyl parathion
Demeton	Parathion
Dieldrin	Polychlorinated biphenyls
Endrin	

Hazardous biological wastes include discards from hospitals and nursing homes, medical procedures and surgical operations; and wastes from biochemical engineering plants and certain pharmaceutical industries.

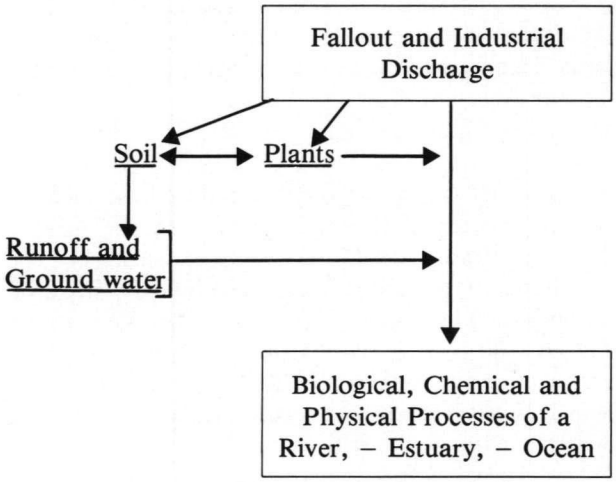
Flammable hazardous wastes are also classified as chemical wastes. They include organic solvents, oils, plasticizers and organic sludges.

Explosives require careful storage and should be dealt with by accredited explosives factory employees, ordinance, military and lawful mining and blasting personnel. No explosives are allowed to be discarded for collection as solid waste or refuse.

Radioactive Wastes

Radioactive substances emit ionizing radiation which is of concern as such radiation may persist for long periods of time.

The probable paths followed by most radionuclides upon introduction to the environment are shown in the following diagram:



Radioactivity can enter the air, water and land environments directly. Radionuclides which enter the atmosphere are likely to return to the earth due to the settlement of dust particles and rainfall and so enter the land and water environments to be accumulated by the soil, vegetation, scattered wastes and a variety of animal life on or in the soil and in the water (including algae).

Radionuclides in the aquatic environment will tend to settle with suspended particles and join the mud sediments. The bottom muds will also gain radioactivity from the water by physico-chemical processes such as adsorption and ion-exchange.

Radionuclides entering the aquatic environment may pass up the food chain – first to green plants, then to herbivorous animals which eat the green plants, and then on to the devourers of herbivorous animal flesh – and so on. Many organisms can accumulate radionuclides directly from the environment. However, where the level of radioactivity is low food chain uptake of radionuclides is important.

Disposal of Radioactive Wastes in South Africa

The disposal of radionuclides in South Africa is controlled by conditions issued in terms of the Nuclear Energy Act (Act No. 92 of 1982) and, prior to the promulgation of this Act, in terms of the

Atomic Energy Act (Act No. 90 of 1967). Act No. 92 of 1982 vests authority for the control, regulation and disposal of radioactive wastes in the Atomic Energy Corporation of South Africa Limited.

Nuclear licences or authorities are granted by the Corporation. The holder of an authority may not dispose of radioactive material or radioactive waste without permission having been obtained from the Corporation. Also, the recipient of such radioactive material or radioactive waste must be duly authorized by the Corporation. The holder of an authority is required to exercise meticulous care to ensure that radioactive waste is discarded in a manner approved by the Corporation.

The policy of the Atomic Energy Corporation of South Africa Limited (AEC) in regard to the "Discarding of Radioactive Waste by Isotope Users" has been framed in terms of section 50(1) of the Nuclear Energy Act (No. 92 of 1982) and, *inter alia,* includes the following directives:

Authority to use radioactive material for medical or non-medical purposes is granted by the Atomic Energy Corporation (AEC) in accordance with the conditions concerning the use of radioactive material as published in Notice AEB. 1/80 in the Government Gazette No. 7315, 28 November 1980, in which radioactive material is defined as ". . . any substance which consists of, or contains any radioactive nuclide whether natural or artificial, and whose specific activity exceeds 0,0002 microcurie per gram (74 bequerel per gram) of chemical element and which has a total activity greater than 0,1 microcurie (3,7 kilobequerel);"

In conformity with the AEC's conditions relating to the use of radioactive material, all users must keep a register with details of every sealed source in their possession in which, eventually, the method of discarding is indicated. Furthermore, all medical users with general unrestricted authority must submit an annual report with details of the discarding of the radioactive waste.

"The holder of the authority shall not discard any radioactive material or cause it to be discarded without the written permission of the Corporation. When a sealed source is discarded, the particulars of the discarding shall be entered in the source register. The holder of the authority, shall take meticulous care in the discarding of radioactive waste, and such discarding shall be effected only in a manner approved by the Corporation from time to time either generally or in any particular case".

Discarding of Radioactive Waste: Policy directives of the Atomic Energy Corporation of South Africa Limited (AEC) have been enunciated as follows:

(1) No authorization for the use of radioactive material is granted, without thorough examination of the proposed method of radioactive waste discarding. Such discarding is subject to the usual inspections as well as special surveys of environmental activity, if necessary.
(2) All authorizations concerning waste are submitted to the National Committee for Nuclear Technology for comment and information. Difficult cases are first submitted to the Committee before authorization is granted.
(3) In cases where the local authority possesses the necessary technical knowledge and apparatus enabling them to have sufficient control over radioactive waste discarding to the satisfaction of the national control committee; the local authority may be given the necessary authority to accept responsibility for the application of control measures in cooperation with the controlling body. (The Government Mining Engineer is already responsible for the waste control at uranium and thorium mines; the Department of Environment bears responsibility in regard to public streams.)
(4) Owing to the widely divergent circumstances and relatively limited range of the problem, no further conditions are being considered. Where necessary, for example for medical users, the AEC may formulate suitable codes of practice.
(5) The recommendations of the International Committee on Radiation Protection (ICRP) are used as the basis in the consideration of every case. This also applies to tracer experiments where the radioactive material is liberated as part of the investigation.
(6) Users must keep a record of all waste discarded of and the method of discarding, this is compulsory by condition for all sealed sources as well as in the annual reports of the hospitals.
(7) Until such time as the dumping of radioactive material into the sea has been more closely studied, it is not considered a suitable or approved method of discarding.

Principles of Disposal

(1) *Solid Materials*
   (i) The only permissible method for the discarding of solid radioactive material is its storage in a manner approved by the controlling body. Solid materials may not, however, be discarded of on public land, municipal refuse dumps, etc.;
   (ii) The compression or incineration of radioactively contaminated solid materials is permissible in order to concentrate it, provided that the resulting radioactive gases, aerosols and dust may under no circumstances exceed the maximum ICRP concentrations regarding exposure and intake.
(2) *Liquids*
   (i) Treatment of radioactive liquids to concentrate them, e.g. by evaporation or chemical

treatment, is permissible and recommended where applicable.

(ii) The discarding of liquid radioactive waste into sewerage systems is permissible, subject to the conditions applicable in each individual case, and subject to the condition that the concentration in the sewer after mixing may not exceed the maximum permissible ICRP concentrations regarding exposure and intake.*

(iii) Radioactive liquids complying with ICRP recommendations may be discharged into public streams provided that the approval of the Department of Environment is obtained.

(iv) The discharge of radioactive liquids onto the ground will not be accepted as a means of discarding.

(3) *Gases*

(i) The liberation of any radioactive gases must occur in such a manner that the recommendations of the ICRP* for radiation workers and for the public are at all times complied with.

(ii) The liberation of any solid or liquid materials in gases, i.e. aerosols, must at all times be limited to the maximum permissible concentration.

National Nuclear Research Centre – Pelindaba

The National Nuclear Research Centre is established at Pelindaba some 30 km west of Pretoria. In 1961 steps were taken to provide facilities for treating waste, waste storage and waste disposal. These facilities have been used for radioactive wastes arising throughout the Republic. The wastes dealt with inlcude waste from the Safari-I Reactor at Pelindaba, research establishments, hospitals, industry, agriculture, etc.

National Radioactive Waste Repository – Vaalputs

With the establishment of a nuclear power station at Koeberg near Cape Town it became necessary to establish a safe site for the disposal of spent fuel elements from Koeberg. After extensive multidisciplinary investigations a site was chosen at Vaalputs. This has become known as the Vaalputs Radioactive Waste Repository. The Vaalputs site is intended to be used for high-level radioactive wastes. However, so far, its use has been confined to low and intermediate level radioactive wastes. Koeberg wastes have yet to be dispatched to Vaalputs and this is not likely to occur for some time yet. In the interim, surface storage of spent fuel elements from Koeberg is being investigated. However, its must be emphasized that South Africa adheres to the regulations of the International Atomic Energy Agency as far as the safehandling of radioactive wastes is concerned.

**Recommendations of the International Commission on Radiological Protection (ICRP) Publication 2. Report of Committee 11 on Permissible Dose for Internal Radiation (1959).*

Legislation

The various aspects of ionizing radiation are covered by the following acts:

(1) Nuclear Energy Act (Act No. 92 of 1982).
(2) Hazardous Substances Act (Act No. 15 of 1973).
(3) Mining Rights Act (Act No. 20 of 1967) – to a limited extent.

A number of former acts dealing with the original Atomic Energy Board have been repealed and replaced by Act No. 92 of 1982 – the Nuclear Energy Act and in terms of this Act the Atomic Energy Board has been re-established as the Nuclear Development Corporation of South Africa (Proprietary) Limited (NUCOR); it no longer exercises control of ionizing radiation which is now the concern of the Atomic Energy Corporation of South Africa Limited (AEC). Both NUCOR and UCOR (the Uranium Enrichment Corporation of South Africa (Proprietary) Limited) are subsidiary companies of the AEC. The Atomic Energy Corporation (AEC) acts on the advice of the independent Council for Nuclear Safety as does the Minister of Mineral and Energy Affairs who appoints the members to this advisory committee. But the final control is vested in the Minister.

REFERENCES

1. Tshobanoglous, G., Thiesen, H. and Eliassen, R. *"Solid Wastes – Engineering Principles and Management Issues"*, McGraw Hill Kogakusha Ltd., 1977, p.55.
2. *"Refuse Disposal"*, Report of the Working Committee on Refuse Disposal, Department of the Environment, London, H M Stationery Office, 1971, (Fourth Impression, 1975), p. 23.
3. Verrier, S.J. *"The Choice of Appropriate Technologies in Southern Africa"*, *The Solid Waste Bulletin* No. 11, Supplement to *Municipal Engineer*, May/June 1983, pp. 19-21.
4. Bolitho, V. *"Urban Solid Waste Engineering"*, a Paper given to the South African Institution of Civil Engineers, 24 July, 1973.
5. Barnard, J.J. *"Voorgestelde Wetgewing in Verband met Beheer oor Afvullingsterreine"*, Private Communication, Department of Water Affairs.
6. Krige, P.R. *Public Health*, 1957, 20(3), 35; Loc.cit. 1957, 20(4), 13; *J. and Proc. Inst. S P*, 1957, (1), 74.
7. Copeman, S.M., Howlett, F.M. and Merriman, G. *"An Experimental Investigation on the Range of Flight of Flies"*, Reports to the Local Government Board on Public Health and Medical Subjects, 1911, New Series No. 53, 1-10.
8. Tshobanoglous, G., Thiesen, H. and Eliassen, R. Ibid, p. 332.
9. Robinson, H.D. and Maris, P.J. *J. Water Poll. Control Fed*, 1985, 57(1), 30.
10. *Amer. J. Pub. Health*, 1940, 30, 1391.
11. Barnard, J.J. *"Licencing in Terms of the Act"*, Solid Waste Bulletin, Published by the Institute of Solid Waste Management (South Africa).
12. Slater, J.H. *"New Microbes Tackle Toxic Compounds"*, *S Afr. J. Sci*, 1982, 78, 101.
13. Finnecy, E.E. *Chemistry and Industry*, London, 6 June 1983, p. 416.
14. Mills, D.A. *Chemistry and Industry*, London, 6 June 1983, p. 421.
15. Mills, D.A. Ibid, p. 422.
16. Advances in Chemistry Series 60, ACS, Washington DC, 1966.
17. Roburn, J. *Chemistry and Industry*, London, 1963, 1555.
18. Buescher, C.A., Dougherty, J.H. and Skrinde, R.T. *J. Water Poll. Control Fed.*, 1964, 36(8), 1005.

Chapter 17 MARINE PIPELINES FOR DISPOSAL OF SEWAGE AND INTRACTABLE INDUSTRIAL WASTES

"Of Neptune's empire let us sing,
At whose command the waves obey;
To whom the rivers tribute pay,
Down the high mountains sliding;
To whom the scaly nation yields
Homage for the crystal fields
Wherein they dwell . . ." T. Campion

The picture of the world ocean* conjured up in the minds of people and the uses it serves are numerous and diverse.

However, the pristine image has been sullied, somewhat, in the last few decades by such occurrences as:

(1) The Minamata episode[1] when poisoning by methyl mercury of many individuals and domestic animals took place from imbibation of sea foods taken from the Minamata Bay sea area in Japan;
(2) The considerable pollution, resulting from industrial discharges, in the upper Adriatic Sea which have affected this sea's ecosystem.[2]

The world ocean* is stated by Strahler and Strahler[3] to cover 71 per cent of the globe; with an average depth of c. 3 800 m, when shallow seas are included with the deep main ocean basins. For major portions of the Atlantic, Pacific and Indian oceans the average depth is about 4 000 m. The total volume of the world ocean is considered to be about $1{,}4 \times 10^9$ km^3.

Therefore, it is hardly surprising that use has been made of this vast body of water as a suitable repository for sewage and industrial wastes and, in any case, it has been pointed out that rivers and run-off from land after rains – for aeons of time, have added pollution to this vast water body.

None the less what is consonant for deep-sea situations may be absonant for inshore situations, bays, estuaries and enclosed seas.

Thus it is necessary to give consideration to many aspects of the problem of marine disposal taking into account the nature and volume of a particular discharge and the prevailing sea conditions at the point or points of discharge.

Water Movements Around the South African Coast

Water movements around the South African coast can be divided into definite oceanographic regions, viz:

– The East coast region and the
– West coast region.

Cape Point can be regarded as the region of mixing of the Agulhas current which follows the coastline in a south-westerly direction and the northward flowing Benguela current which flows along the west coast.

The Agulhas Current: Shannon[4] has described the Agulhas current as a narrow, fast moving body of tropical origin with a surface temperature of 21 to 25°C and a salinity of 35,2 to 35,5 per cent (i.e. Tropical Surface Water category).

He concluded, from available data, that the main body of the Agulhas Current varies in width from c. 32 km to c. 160 km. He indicated that the Agulhas Current follows the general direction of the continental shelf fairly closely with current strengths as low as 60 cm/s on low tide. However, by ship's drift observations velocities between 1 and 2 m/s have been observed.

Shannon has concluded that the Agulhus Current is not merely a surface phenomenon, but extends to considerable depths showing uniform current direction over the entire water column.

In dealing with the evolution of the Agulhas Current Martin[5] has illustrated the circulation patterns in the South West Indian Ocean as shown in Figure 1. It will be seen that the surface/near surface Agulhas Current moves in a south-westerly direction following the shoreline from the north coast of Natal towards Port Elizabeth in the Cape.

Schumann, Perrins and Hunter[6] have shown by thermal infrared image taken by the Tiros N satellite that upwelling takes place off Cape Recife, Cape St Francis and Cape Seal.

Lutjeharms[7] has dealt with certain features of the

*The term "world ocean" refers to the combined ocean bodies and seas of the globe.

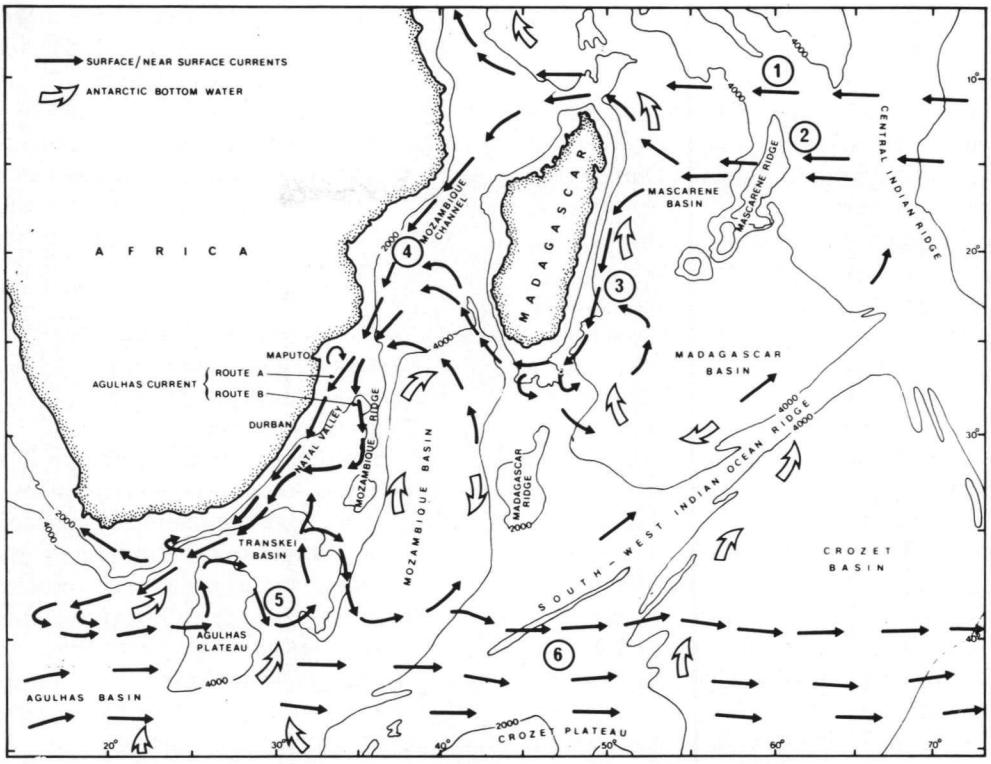


Fig. 1. Circulation patterns in the South-West Indian Ocean. Surface/near-surface currents = black arrows. (1) North Equatorial Current (part of the North Indian Ocean subtropical gyre). (2) South Equatorial Current. (3) East Madagascar Current. (4) Mozambique Current. (5) Agulhas Return Current. (6) West Wind drift at subtropical convergence (all sub-units of the South Indian Ocean subtropical gyre). Note the two flow-paths, Route A and Route B, of the Agulhas Current, as well as the recycling of Agulhas Return Current water in the Transkei and Mozambique Basins and west of the South-West Indian Ocean Ridge. Open arrows indicate cold under-currents of Antarctic Bottom Water in abyssal areas. 2000 m and 4000 m isobaths outline the main bathymetric features.

Agulhas Current from information received from satellite remote sensing which has helped create a conceptual image of the Southern Agulhas Current. This accords with that of Martin[5].

The Benguela Current: The Benguela Current is regarded by Shannon as the cool upwelled water found between 15°S and 34°S and within a distance of 185,24 km (100 nautical miles) from the west coast. Warmer water to the west of the Benguela Currrent is the South-East Trade Wind Drift which forms part of the anticyclonic circulation in the South Atlantic Ocean.

The temperature of the Benguela Current during a period of maximum upwelling may be as low as 9°C and the salinity as low as 34,6 per cent.

Shannon states that the Benguela Current flows northwards roughly following the isobaths between latitudes 34°S and 23°S. North of 23°S it tends to veer away from the coast. The observed rate of flow of the Benguela Current varies between 25 cm/s and 50 cm/s. Furthermore, this current is not a surface phenomenon. A close inshore counter-current moves in a southerly direction, the frequency being highest during the winter period.

Inshore Mixing of the Agulhas and Benguela Currents: Shannon considered that the inshore area of mixing of the two currents can be demarcated by the region between the 21°E meridian and a line running in a west-south-westerly direction from the Cape of Good Hope.

Longshore Currents: Longshore currents are caused by the deflection of water impelled towards the shoreland. When the sea's waves approach the shore diagonally the movement is stopped by the land and water is deflected along the shore. If waves approach from the left, the deflected motion (or longshore current) is usually to the right and for a right approach the so-called longshore current will be to the left.

Where the wave approach is normal to the beach line rip currents are set up in an opposite direction to the wave approach.

Continental Shelf: In 1955 the International Committee on the Nomenclature of Ocean Bottom Features defined a shelf as the "zone around the continents, extending from low-water line to the depth at which there is a marked increase of slope to greater depth". The outer slope is referred to as the continental slope. However, in cases where there are more than one increase in declination legal difficulties are apparent. Consequently, UNESCO suggested that where two or more large changes in the downward slope of the shelf occurred the point at which the most marked change occurred should be taken as the edge of the continental shelf provided that it lies at depths of less than 600 m.

It will be realized, of course, that though the term

"shelf" is used it does not have the aspect of a shelf and "flat" and uneven varieties can occur.

Shelf Circulation of Water: Malan and Schumann[8], by means of Landsat imagery confirmed Natal shelf circulation from St. Lucia to Umkomaas. This had been previously reported on by Pearce, Schumann and Lundie[9] who stated that the Agulhus Current can be considered to be the outer boundary of the shelf circulation; in most cases they pointed out that it is marked in the surface waters by a region of intense cyclonic shear, with which is associated a relatively strong thermal front. They aver that over a distance of a few kilometres the current speed can increase from relatively low coastal values to greater than 1 m/s in the current with a corresponding temperature rise of 1° to 2°C.

Harris[10] has dealt with the water movements in the region between the Natal Coast and the Agulhas Current. He has shown and illustrated the frequency of near surface current speed and direction parallel to the Natal Coast c. 1,6 km offshore and has indicated that in the section between Port Durnford and Umkomaas the current direction alternates between north-going and south-going. This, he stated, is especially marked in the regions Durban to Green Point and Umhlanga to the mouth of the Umvoti River.

Marine Pollution

Definition of Pollution: According to Johnston[11] the usually accepted definition of "pollution" is that evolved by the SCOR Working Group of the United Nations, viz:

"The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities."

Disposal of Wastewater into the Coastal Fluid-Solid Interface: It is necessary to give some thought to this important interfacial region since the need for marine pipelines for the discharge of wastewater has arisen, in part, due to the abuse by discharges of sewage and effluents into this important area of the environment which includes the following:

(1) Sand dunes;
(2) Beach area;
(3) Neritic* region;
(4) Estuaries and lagoons.

Ecological Divisions of the Sea: Ecologically the divisions of the ocean are related to depth of water, distance from the land and the degree of light penetration. We have the overlying water (pelagic) and bottom water (benthic). The pelagic division is constituted by the "neritic"* or nearshore and the oceanic – the open sea sections.

Plancton (floating) and nektonic (swimming) organisms are found in the pelagic regions and crawling or creeping organisms in the benthic region – some of the benthic organisms live within the sediment and others on the surface of the sediment or attached to rocks.

(1) *Sand Dunes:* The South African coastline is marked by extensive sandy beaches and a variety of sand dunes. In fact, many of the edifices in Durban have been built on sand.

Sand dunes present problems in the Cape and attempts to contain the movement of dunes due to wind have been made by vegetating the dunes with suitable trees, shrubs and grasses. Consequently, there have been cases where communities have been allowed to dispose of purified sewage effluent into sand dunes as the effluent discharged into these sandy areas helps the growth of vegetation and so consolidates the sand dunes.

(2) *Beach Area*

(i) *Septic Tank Effluent:* Pollution of this area is caused by the discharges from septic tanks associated with seaside establishments (hotels, holiday camps, etc.). This has arisen from the fallacious conclusion that the septic tanks, as normally installed, produce effluents of a quality satisfactory for discharge into a beach area, lagoon or estuary.

Unfortunately, the retention period of sewage in a septic tank is subject to the vagaries of the number of contributors which fluctuate considerably from "off-season" to "in-season" periods.

Unless septic tank effluent receives further satisfactory treatment its discharge into the beach area should be prohibited. Attemps have been made to treat septic tank effluent using bio-disc filters. This has met with a measure of success.

(ii) Well-point Systems: In a number of cases – due to the situation of a "seaside" sewage purification works – it has been necessary to discharge purified sewage effluent into the beach sand by a well-point system.

This has proved satisfactory provided the effluent is of General Standard quality at all times and the well-point system is properly supervised and maintained.

*This is the nearshore (shallow) region and includes the littoral or inter-tidal and surf zones. The term "neritic" is derived from "Nereus" – the Greek God of shallow water.

(3) *Neritic Region:* Any discharges into this region should be of General Standard quality and should be discharged at a point at least one (1) metre below LWOST (Low Water Ordinary Spring Tides).

In the past, there have been some disposal systems where wastewater has been held back and stored during the incoming tidal period and then allowed to discharge on the outgoing tide. This is an unsatisfactory method of disposal and gives rise to odour. This method is no longer an approved practice in South Africa.

(4) *Estuaries and Lagoons:* There are approximately 73 estuaries along the Natal Coast. G Begg was appointed by the Natal Town and Regional Planning Commission as a Research Fellow to evaluate the condition of Natal's estuaries. The work was conducted under the auspices of the Oceanographic Research Institute, Durban.

In dealing with the Sipingo Lagoon (at Isipingo) Begg[12] has recorded *inter alia*, . . . "it is one of the most severely degraded of estuarine systems in Natal. This situation has arisen chiefly as a result of mouth closure, once the inflowing rivers which previously fed into the estuary, were diverted elsewhere. With insufficient tidal exchange, industrial and sewage wastes accumulated and plants such as *Eichornia* (the water hyacinth) and animals such as bilharzia snails flourished . . ."

There are a number of estuaries along the Natal coast which become barred by sand during certain periods and have to be opened-up to allow the interchange of waters to take place. Naturally, without free access of lagoon contents to the sea the condition of lagoons deteriorate and present a sea-pollution threat when opened up to act as an estuary.

Disposal of Wastewater in the Ocean

From all the foregoing it will be realized that for discharges which present a threat to the beach and neritic areas as far as pollution of the sea is concerned, disposal should take place at a point or points such that the beach and other nearshore zones remain inviolate within the context of the definition of pollution given (*vide ante*).

This would naturally bear reference to chemical and bacteriological norms in addition to the other deleterious effects cited in the definition. More specifically, as applying to South Africa this should be read in conjunction with Section 23 of the Water Amendment Act, 1984 (Act No. 96 of 1984) wherein it is stated, as follows:

"23(1)(a) Any person who wilfully or negligently does any act which could pollute public or private water, including underground water, or sea water in such a way as to render it less fit –

(i) for the purpose for which it is or could be ordinarily used by other persons (including the Government, the South African Transport Services and/any provincial administration);
(ii) for the propogation of fish or other aquatic life; or
(iii) for recreational or other ligitimate purposes, shall be guilty of an offence.

(b) If in any prosecution under paragraph (a) it is proved that the accused committed any act which could pollute water referred to in that paragraph in any manner mentioned therein, it shall be presumed, until the contrary is proved, that the accused committed such act wilfully or negligently.

(2) The provisions of subsection (1) shall not apply in respect of any act performed in accordance with section 21 or 22."

Marine Pipelines

In designing a marine pipeline system an important consideration is that of ensuring quick and adequate dispersion of the wastewater in the sea without giving rise to unsightly plumes and any adverse side effects. The point(s) of discharge should be so located in the sea in such a situation as to ensure that return of pollution to the shore does not occur. This is particularly important to prevent pollution of bathing beaches.

In this context it might be appropriate to quote the remarks of Professor J K Mallory of the University of Cape Town in opening the discussion on a paper by Oliff, Livingstone and Stone[13] on *"Factors Determining Dilution in the Marine Environment"*, viz:

. . . "The sea was a fickle mistress, changing her mind at the slightest whim. Man could not control these changes because the causes of change, such as wind, were themselves beyond his control . . ."

Stander, Oliff and Linvingstone[14] in dealing with *"Problems in Using the Sea as Part of a Waste Disposal System"* have concluded, *inter alia*,

"Once all the information has been obtained on the use made of the disposal area, then it becomes possible to design a waste outfall to attain acceptable standards in the area.

Predictions of the probable dilutions at the shore for various lengths of submarine pipeline are made on the basis of Brooks[15] which is reasonable for conditions in Natal, and the relative risks at the shore are determined. A suitable position and length of pipeline can then be determined, if it is possible to use one at all. If this length of pipeline is an uneconomical proposition, then pretreatment of effluent is required to attain the degree of dilution possible with the selected economic length of pipeline . . ."

The Problem of Dilution at Ocean Outfalls

The dilution method of sewage disposal presup-

poses that provided the ambient water is sufficient to enable the normal aerobic biological processes to proceed unhindered purification of the sewage will result. Therefore, the importance of dilution cannot be gainsayed.

Furthermore, with certain highly coloured and concentrated industrial effluents, prior dilution, before discharge, would serve to assuage the adverse ecological impact.

Some attention has been paid to predilution and premixing but Sharp[16] has drawn attention to the limitations of diluting devices.

Agg and White[17] have pointed out that for sewage the most efficient outfall, in terms of maximum dilution at the water surface, operates at a densimetric Froude number of unity. They investigated six possible designs for devices to achieve predilution of sewage.

Stagnant Conditions

For outfalls operating in still water the following relationship is given, viz:

$$\frac{Co}{Cm} = \phi\left(\frac{y}{D} \cdot Fr\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, Co is the initial concentration of the effluent/sewage,
Cm the concentration at height y above the outfall,
ϕ signifies function,
y is the height above the outfall,
Fr the densimetric Froude number,
D the diameter of the outfall.

The densimetric Froude number is defined as follows:

$$Fr = \frac{uj}{\left\{g.\frac{(\rho_a - \rho_o)}{\rho_o}.D\right\}^{1/2}} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where, uj is the velolcity of the jet at the outfall,
g the acceleration due to gravity,
ρ_a the density of the receiving water,
ρ_o the density of the effluent,
D the diameter of the outfall.

Mobile Conditions

For conditions where the water is moving equation (1) may be modified as follows:

$$\frac{Co}{Cm} = \phi\left(\frac{y}{D} \cdot Fr \cdot \frac{uj}{ua}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where, ua is the velocity of the receiving water, and,
$\frac{uj}{ua}$ the velocity ratio of the jet at the outfall and that of the receiving water.

Of the methods examined by Agg and White for inducing mixing and dilution, they state that the most promising appeared to be that based on the principle of horizontal tangential discharge into a device of circular plan.

The average overall dilution of sewage obtained at the water surface could be doubled by fitting the device to a horizontal pipe discharging into shallow coastal water.

Sharp[16] points out that one of the earliest and simplest attempts to draw receiving water into an outfall before discharge employed the venturi principle. This involved restricting the diameter of the discharge pipe at a section near the outfall. This enabled suction of the ambient water through a port in the pipe wall. By this method it was considered possible to reduce the concentration of the effluent by c. 50 per cent before discharge.

Other devices which have been employed include the use of jet pumps or mixing tubes; the use of baffles and other devices to obstruct or otherwise alter the flow pattern; splitting the flow into two components.

Another method involves discharging the effluent adjacent to a horizontal wall or sloping boundary. The proximity of the boundary causes the jet to cling to such boundary surface for some distance before rising and causes eddies which further assist dilution.

Predilution devices are considered to be more effective in shallow water than in deep water.

South African Practice

In South African ocean discharge systems it is usual to fit a fairly long diffuser section as part of the discharge pipeline system. The diffuser section is provided with a large number of smaller diameter outlet pipes arranged regularly and systematically along the diffuser section.

This ensures discharge of the sewage or industrial effluent over a large area and satisfactory velocity of discharge from the separate discharge ports than would be the case with an open-ended discharge pipeline. It ensures better mixing and dilution with the ambient sea water.

It is necessary for the discharge to take place under pressure from the land either from a "high-level" tank or by pumping.

Operating pipeline systems along the coast in deep water in the sea include situations such as Durban (sewage and sewage sludge – two marine pipelines); Umbogintwini (wastes from TiO_2 manufacture); Umkomaas (wastes mainly black liquor from a pulp factory). Due to continental shelf configuration and currents at Richards Bay a dual pipeline system with simple diffuser design has been installed for marine disposal of screened comminuted sewage, black liquor from a pulp factory and waste gypsum from a fertilizer factory.

Note: The above are major systems in Natal.

However, all pipeline and other discharges to sea are dealt with later in this chapter under a "List of Officially Recognized Marine Discharges along the South African Coast".

It should be pointed out that regular underwater inspections of pipelines are necessary and obligatory since experience has shown that at points between the diffuser section and the shore leaks can take place – particularly with ageing pipelines. This leads to stressed conditions for the animal life in the surrounding sea water and on the sea-bed, as well as for bathing and boating enthusiasts operating in such areas.

Pollution Surveys Around the South-Western Coast

Eagle, Greenwood, Hennig and Orren[18] concluded from their preliminary survey of pollution in the Mossel Bay area that the beaches and rivers around Mossel Bay are largely unpolluted. However, point sources of pollution do occur, notably, from the factory discharge at Voorbaai.

Orren, Fricke, Eagle, Greenwood and Gledhill[19] have shown that a stressed condition was present at Green Point (Cape Town) sewage outfall. This was illustrated by animal distribution, high 4-hours Oxygen Absorbed values, high trace-metal content of sediments and low oxygen concentration in the water.

Fricke, Eagle, Gledhill, Greenwood and Orren[20] have concluded, from a limited survey, that there is a certain degree of organic enrichment in the beach at Hout Bay which has led to almost anoxic conditions within the sediments, accompanied by extremely small numbers of interstitial animals.

Atkins[21] made a study of the False Bay Area from the point of view of the disposal of sewage and industrial wastes. He stated that from his investigations none of the areas investigated was suitable for the discharge of large quantities of sewage or industrial waste with the possible exception of Simons Bay.

He pointed out, *inter alia,* that current movement is slow and generally in a clockwise direction. Due to the shallowness of the water, dilution coefficients are low.

From the foregoing it will be realized that consent for the discharge of sewage, sewage sludge or industrial effluents into the sea should only be allowed under prescribed conditions which should safeguard the established aquatic environment.

At this stage there is no reason for disquiet in regard to pollution along the South African coast but certain sections and situations require to be systematically monitored and effluent discharges strictly controlled at factories.

In this connexion, regular surveillance of a number of maritime sections and situations should take place – if not on a regular basis at least from time to time. These include the following:

The Richards Bay area;
The section from Port Durnford to Umkomaas;
East London – particularly at Hood Point at the outfall of the Cyril Lord pipeline : since the proximity of a factory manufacturing atracine (a herbicide) is considered a pollutional threat;
Port Elizabeth;
Mossel Bay;
False Bay – Somerset West/Strand and Simonstown;
Cape Town – Camps Bay and Mouille Point outfalls areas;
Hout Bay harbour area;
Milnerton;
Saldanha Bay;
St Helena Bay.

List of Officially Recognized Discharges along the South African Coast

There are some 67 or more officially recognized discharges to the sea around the coast of South Africa. These vary in daily volume of sewage or sewage effluent discharge of 40 m^3 of septic tank effluent at Shelly Beach (Natal, South Coast) to as much as 2 800 m^3 per day of screened "macerated"/comminuted sewage at Camps Bay (Cape Town); and for industrial effluents from as little as 13 000 m^3/day from Marine Products, Laaiplek, to an average of combined effluent (mainly "black liquor") and arisings of 75 000 m^3/day from the Mondi Paper Company Limited at Richards Bay – (allowable daily peak of 95 000 m^3).

The following is a list of discharges taken clockwise around the coast from Richards Bay on the North Coast of Natal to Lamberts Bay on the Cape's West Coast:

(1) Richards Bay : Effluent from:
(i) Mondi Paper Company Limited;
(ii) Triomf Fertilizer Limited;
(iii) Alusaf; and
(iv) Screened comminuted sewage from the Municipality of Richards Bay.

Effluent discharged 5 km out to sea by Mlatuze Water Board's dual pipeline system.

(2) Port Durnford : Ngoye Paper Mills (Pty) Ltd.:
Partially treated effluent discharged near shoreline on isolated beach area.

(3) Sheffield Beach (Flats):
Purified effluent of General Standard quality discharged to the surf zone.

(4) Ballitoville:
Purified sewage effluent of General Standard quality discharged via stormwater drain to surf zone via beach.

(5) Tongaat:

(i) Shalimar Flats : Purified effluent of General Standard quality discharged to the surf zone.

(ii) David Whitehead Limited : Textile effluent discharged to the surf zone.

(6) Umdloti Beach:

Purified sewage effluent of General Standard quality discharged to the surf zone.

(7) Durban:

(i) Northern Wastewater Treatment Works – Effluent of General Standard quality discharged via Blue Lagoon to the surf zone.

(ii) Central Wastewater Treatment Works – sewage and raw sewage sludge (with floatables removed) disposed of by deep sea marine pipeline 3,2 km out to sea.

(iii) Southern Wastewater Treatment Works – sewage and intractable industrial effluents disposed of by deep sea marine pipeline 4,2 km from the shore.

(8) Umbogintwini:

African Explosives and Chemical Industries:

(i) Effluent arisings from a number of processes discharged to the surf zone.

(ii) Condensate from amines plant discharged to the surf zone.

(iii) S A Tioxide (Pty) Ltd.: Effluent containing ferrous sulphate and sulphuric acid discharged c. 1,8 km out to the sea at a depth of not less than 30 m. Volume of daily discharge does not exceed 1 763 m^3.

(9) Umkomaas:

(i) South African Industrial Cellulose Corporation (SAICCOR) Ltd. 80 000 m^3 per day effluent ("black liquor" plus other arisings) disposed of by submarine pipeline out to sea 2,5 km from shoreline: (effluent – which is warm is pumped).

(ii) Municipal sewage is purified to General Standard quality and discharged into surf zone.

(10) Scottburgh:

Municipal sewage is purified to General Standard quality and discharged into surf zone.

(11) Port Shepstone:

Purified sewage effluent discharged to the surf zone.

(12) Shelly Beach:

Septic tank effluent discharged to the surf zone.

(13) Uvongo:

Septic tank effluents discharged into lagoon and surf zone.

(14) Margate:

Municipal sewage effluent of General Standard quality discharged into surf zone via lagoon.

(15) Ramsgate:

Effluent from domestic sewage treatment plant is discharged to the surf zone.

(16) S A Police Holiday Resort, Port Edward:

Purified sewage effluent (septic tank plus biodisc filter) discharged to the surf zone.

(17) East London:

(i) Nahoon outfall : Domestic sewage discharged to the surf zone.

(ii) Bats Cave outfall : Domestic sewage plus industrial effluent is discharged to the surf zone.

(iii) Hood Point outfall : Domestic sewage plus industrial effluent is discharged to the surf zone.

(iv) "Cyril Lord" outfall at Hood Point : Textile wastes discharged to sea. (Pipeline installed by the Department of Water Affairs.)

(18) Port Elizabeth:

(i) Fishwater Flats : Purified domestic sewage discharged to sea 1 m below LWOST.

(ii) Fishwater Flats : Treated industrial effluent discharged to sea at 1 m below LWOST.

(iii) Cape Recife : Purified sewage effluent discharged to sea at 1 m below LWOST.

(19) Knysna:

(i) Municipality discharges treated sewage effluent via an open channel to the Knysna Lagoon.

(ii) Thesens and Co. : Sea water used for cooling is returned to the sea at an increase in temperature of 13°C.

(20) Mossel Bay:

(i) Municipality : Raw sewage is discharged to sea via two pipelines.

(ii) Langeberg Korporasie Beperk : Food processing effluent disposed of to sea.

(21) Hermanus:

(i) Municipal sewage effluent discharged to sea at 1 m below LWOST.

(ii) Sea Plant Products : Saline effluent discharged on to rocks c. 100 m from the shore.

(iii) Walker Bay Canners : Saline effluent discharged on to rocks c. 100 m from the shore.

(22) Gordons's Bay:

Purified sewage effluent of General Standard quality discharged to the surf zone.

(23) Strand and Somerset West:

(i) Purified sewage effluent of General Standard quality from Macassar Sewage Purification Works discharged to lagoon at the

mouth of the Eerste River, 100 m from the sea.

(ii) Somchem (Somerset West) : Chemical effluent discharged to sea below LWOST.

(iii) Gants Foods : Fruit and vegetable processing effluents (suspended matter removed) discharged to sea at 1 m below LWOST.

(iv) African Explosives and Chemical Industries Limited:

(a) Effluent from nitroglycerine plant discharged to sea below LWOST.

(b) Purified sewage effluent of General Standard quality and effluent from the nitrocotton plant, chemical plant plus acid process effluents discharged to sea at high water mark.

(24) Fish Hoek, Noordhoek, Kommetjie:

Wildevoëlvlei Sewage Purification Works : Sewage from Fish Hoek, Ocean View, Sun Valley, Noordhoek and Kommetjie is purified to General Standard quality and discharged to sea via a lagoon.

(25) Simonstown:

(i) Municipality : Purified sewage effluent of General Standard quality is discharged to the surf zone.

(ii) Marine Oil Refiners Limited : Effluent arisings from oil refining, soap and margarine manufacturing etc., discharged to sea at 1 m below LWOST.

(26) Hout Bay:

Domestic sewage and industrial effluent is discharged to the harbour.

(27) Llandudno:

Purified domestic sewage effluent is discharged to the surf zone.

(28) Cape Town and Purlieus:

(i) Camps Bay outfall : Screened comminuted sewage is discharged 1 370 m from the shore at a depth of 25 m below LWOST.

(ii) Mouille Point outfall : Sewage is discharged 1 550 m from sea wall. Depth of outlet diffuser section 28 m below LWOST.

(iii) Cape Flats Sewage Purification Works : Purified sewage effluent flows over beach area to the sea – (portion "lost" to seepage).

(29) Milnerton:

(i) Caltex Oil (S A) (Pty) Ltd. : Effluent is discharged to deep sea 554 m from the shore.

(ii) Fedmis : Effluent discharged to sea 380 m from the shore.

In addition, and classified separately, there are the following Western Cape fish processing industries which give rise to polluting effluents (Under the sponsorship of the Water Research Commission a great deal of progress has been made in improving the quality of these effluents):

(30) Western Cape Fish Processing Industries:

(i) Gansbaai : Gansbaai Marine Products.

(ii) Hout Bay:

(a) Dromedaris Visserye Beperk.

(b) Da Gama Fishing Industry, Hout Bay.

(iii) Laaiplek : Marine Products, Laaiplek.

(iv) Lamberts Bay : Lamberts Bay Holdings Ltd.

(v) Saldanha Bay:

(a) Sea Harvest.

(b) Southern Sea Fishing Enterprises (Pty) Ltd.

(c) Saldanha Bay Canning Company.

(vi) St Helena Bay:

(a) Suid Oranje Visserye Beperk.

(b) St Helena Bay Fishing Enterprises.

(c) Sandy Point Canning Company.

(d) West Point Fishing Company.

REFERENCES

1. Ishikawa, Tadao and Ikegati, Yoshikazu *"Control of Mercury Pollution in Japan and the Minamata Bay Cleanup"*, *J Water Poll. Control Fed.*, 1980, 52(5), 1013.
2. Beccari, M. WHO Water Quality Bulletin, 1982, 7(3), 135.
3. Strahler, A.N. and Strahler, A.H. *"Environmental Geoscience : Interaction Between Natural Systems and Man"*, Hamilton Pub. Co., Santa Barbara, California, 1973, p. 34.
4. Shannon, L.V. *S.Afr. J. Sci.*, 1972, **68**, 124.
5. Martin, A.K. *S.Afr. J. Sci.*, 1981, **77**, 547.
6. Schumann, E.H., Perrins, L.A. and Hunter, I.T. *S.Afr. J. Sci.*, 1982, **78**, 238.
7. Lutjeharms, J.R.E. *S.Afr. J. Sci.*, 1981, **77**, 231.
8. Malan, O.G. and Schumann, E.H. *S.Afr. J. Sci.*, 1979, **75**, 136.
9. Pearce, A.F., Schumann, E.H. and Lundie, G.S.H. *S.Afr. J. Sci.*, 1978, **74**, 328.
10. Harris, T.F.W. *S.Afr. J. Sci.*, 1964, **60**, 237.
11. Johnston, R. *"Marine Pollution"*, Academic Press, London, New York, San Francisco, 1976, p. 5.
12. Begg, G. *"The Estuaries of Natal"*, Natal Town and Regional Planning Report, 1978, Vol 41, pp. 254-264.
13. Oliff, W.D., Livingstone, D.J. and Stone, V.C. *Wat. Pollut. Control*, 1969, 68(5), 560.
14. Stander, G.J., Oliff, W.D. and Livingstone, D.J. *Wat. Pollut. Control*, 1968, 67(2), 143.
15. Brooks, N.H. *"Diffusion of Sewage Effluent in an Ocean Current"*, Proc 1st Internat. Conf. on Waste Disposal in the Marine Environment, Pergamon Press Ltd., Oxford, 1959, p. 246.
16. Sharp, J.J. Proc. Instn. Civ. Engrs., Part 2, 1978, **65**, 935.
17. Agg, A.R. and White, W.R. Proc. Instn. Civ. Engrs., Part 2, 1974, **57**, 1.
18. Eagle, G.A., Greenwood, P.G., Hennig, H.F.K.O. and Orren, M.J. *S.Afr. J. Sci.*, 1979, **75**, 453.
19. Orren, M.J., Fricke, A.H., Eagle, G.A., Greenwood, P.J. and Gledhill, W.J. *S.Afr. J. Sci.*, 1979, **75**, 456.
20. Fricke, A.H., Eagle, G.A., Gledhill, W.J., Greenwood, P.J. and Orren, M.J. *S.Afr. J. Sci.*, 1979, **75**, 459.
21. Atkins, G.R. *Wat. Pollut. Control*, 1971, **70**, 130.

Chapter 18 THE USE OF LAND FOR THE DISPOSAL OF INTRACTABLE OR POOR QUALITY EFFLUENTS

"The old order changeth, yielding place to new, . . ."

Alfred, Lord Tennyson: Morte d'Arthur

Early methods of sewage disposal consisted of the following:

(i) Discharge into rivers;
(ii) Discharge into the sea;
(iii) Disposal on land.

Land disposal centred round the irrigation of land by various methods which included the growing of crops for human consumption and pasturage for dairy and beef cattle.

Resort was had to land disposal of effluents by some industries denied discharge of their effluent into a sewerage system or a river and by others geographically so placed by the nature of their activities that exigency demanded disposal on land adjoining their operations.

Such industries include the following: Fermentation industry, the yeast industry, the chemical industry, wattle extract industry, tanning industry, pesticide manufacturing industry, the mining industry, hydrometallurgical industries, the sugar industry, the iron and steel industry, fruit and vegetable canning industry, the wine industry, the cellulose fibre industry, feedlots.

Usually pond systems which act as preliminary treatment units or reservoirs form part of the land disposal systems. In many cases (notably in the tanning and wattle extract industries) pond systems or lagoons alone have been used solely as evaporation units and, to a certain extent, slimes dams in the case of the mining and hydrometallurgical processing industries.

Today, the use of sewage for the irrigation of crops for human consumption or the irrigation of pasturage for livestock is prohibited in the Republic and pond systems are allowed only for daily sewage flows not exceeding 700 m^3. This is really a concession to small local authorities unable to muster the finance for a modern sewage purification works.

It is necessary to emphasize that in a country such as South Africa that every effort should be made to prevent wastage of water and to reclaim water for reuse (cf. Chapter 14 – *"The Hierarchical Use of Water in South Africa: Portents for the Future"*).

Industrialists faced with the disposal of intractable wastes often seek solutions to their problems through solar evaporation methods – or, where economic profit may result from by-products, they may resort to multiple effect evaporation on the factory site.

SOME CASE HISTORIES AND RELEVANT INFORMATION

(i) Disposal of Starch Factory Wastewater and Molasses Slop

One of the industries which came into being at the time of the First World War was a starch manufacturing company which became established in Germiston in a situation east of the town; starch, glucose, dextrin, etc. were produced from maize.

By arrangement with the Germiston Municipality the wastewater was disposed of by irrigation onto an area of ploughed land which sloped down to a stream fed by water from the Witwatersrand Gold Mining Company Limited and forming a headwater of the Elsburg Spruit. The ground in the irrigated area was systematically ploughed and every effort was made to prevent runoff.

Many years later a fermentation industry was set up by another company near the site of the starch factory with the intention of using maize as feedstock. Very shortly after start-up the company switched (permanently) to molasses as feedstock – for the production (initially) of alcohol and dry ice. Yeast and vinegar were also produced. During World War II a large variety of products were produced including acetone, ethyl alcohol, butyl alcohol, glycerine, dry ice, etc. The waste molasses slop was disposed of, together with the starch manufacturing company's wastes, on to the aforementioned land which had come to be called Germiston's "Slop Farm".*

However, in the process of time, runoff took place from the Slop Farm into the Elsburg Spruit during rainstorms. This resulted in the instigation of a Supreme Court interdict by a farmer in Elsburg seeking to restrain the Germiston Municipality from

*Provision was made on a section of the Slop Farm for the disposal of slop water, sanitary pail contents and abattoir wastes.

disposing wastes on the Slop Farm.

Also, with the development of Germiston the Council planned to use the Slop Farm land for a new housing development for Blacks. Thereupon, the "starch factory" adopted a "bottled-up process"* and evaporated the steep liquor wastes by triple-effect evaporation to produce a cattle feed. With suitable pH adjustment and metering of the treated effluent the Germiston Council duly accepted the factory wastewater for discharge into the municipal sewers leading to the Rondebult Sewage Purification Works.

Later on the fermentation industry effectively produced a well-known cattle feed from its waste molasses slop so enabling the Germiston Council to terminate disposal operations on the Slop Farm and, in due course, to proceed with its projected housing development.

(ii) Disposal of a Tannery's Effluent

A tannery started up at a site on the banks of the Moreletta Spruit, in country surroundings, some distance from Pretoria. Over a substantial period of years Pretoria has developed considerably and the stage was reached where the tannery site was within the built-up industrial area of Silverton. This tannery has become one of South Africa's major tanneries (cf. Chapter 15 – *"Tanning and the Treatment and Disposal of Tannery Effluents"*).

Initially, a pond system was used for disposing of the combined tannery effluent by evaporation and as this disposal facility became inadequate the temptation was ever present to breach the walls of the ponds and allow the contents to discharge into the Moreletta Spruit when in spate during rainstorms. So, under pressure, the company controlling the tannery increased its effluent disposal potential by providing further ponds on land it had acquired in the neighbourhood. Notwithstanding, the company – later – was faced with a considerable public outcry concerning the unpleasant odour created by the ponds.

In due course, the tannery switched from salted hides to fresh hides thereby considerably reducing the sodium chloride content of the effluent and an air-flotation process was developed thereby making the effluent acceptable for discharge into the Pretoria City Council's sewerage system.

(iii) Disposal of Pulp and Paper Mill Effluent

The effluent from pulp and paper mills is unsuitable for direct discharge into a river. Consequently, land disposal has been resorted to by mills in the Transvaal. (cf. Chapter 15 – *"The Cellulose Fibre Industry: Problems and Achievements in the Control of Pollution from Wastewaters"*.)

At one very large mill the effluent is treated with gypsum and dolomitic lime to ensure a Sodium Adsorption Ratio (SAR) not greater than 9 and control of the sodium concentration is maintained.

The treated effluent is irrigated onto a large area of land planted with Kikuyu grass which serves as a pasturage for beef cattle (which are sold for slaughter). Spray irrigation is used. Ammonium sulphate is added to the effluent as a fertilizer.

Boreholes have been constructed at a number of points on the mill's property to monitor any increase in salt content of the groundwater which could affect the water flowing in the Elands River. This is important since this water is used downstream by citrus farmers (Citrus trees are sensitive to high salt concentrations). (cf. Chapter 14 – *"The Hierarchical Use of Water in South Africa: Portents for the Future"* and Chapter 15 – *"The Cellulose Fibre Industry: Problems and Achievements in the Control of Pollution from Wastewaters"*.)

A company at Estcourt, in Natal, manufactures hardboard from hardwood pulp. The mill effluent, after filtration and clarification is pumped to two irrigation farms where Kikuyu grass is grown. Precautions are taken to prevent runoff into the Bushman's River.

(iv) Disposal of Effluent from an Integrated Iron and Steel Works:

Some of the effluent arisings from a large iron and steel plant at Newcastle in Natal are disposed of by means of a series of ponds followed by spray irrigation. (cf. Chapter 15 – *"The Iron and Steel Industry – Control of Pollution Arisings"*.)

Kikuyu grass is grown and harvested for sale as animal fodder. A large mobile spray irrigation system is systematically operated to regularly irrigate the total grassed area.

(v) Disposal of Effluent from Sugar Mills

In many cases mill effluent is pumped to anaerobic dams and, thereafter, used for irrigating canefields. (Details for particular mills are given in Chapter 15 – *"Progress in the Control of Pollution in the Sugar Industry in South Africa"*.)

(vi) Disposal of Effluent from a Fruit and Vegetable Canning Plant

A fruit and vegetable canning plant in the Eastern Transvaal overcame its effluent disposal problem by using its water entitlement from the adjoining river to dilute the factory effluent to the extent that the mixture was satisfactory for the irrigation of its croplands. Had the water quota been used for irrigation the problem of purifying the effluent for discharge into the river would have had to be faced.

*The "bottled-up process" involves, *inter alia*, –
(1) Recirculation of process water within the process;
(2) Evaporation of a portion of this recirculated water as steep water.

(vii) Disposal of Wattle Extract Wastes

These wastes are disposed of in evaporation ponds – as is the case with effluents from many tanneries. Surveillance of the disposal area takes place to monitor seepage which may arise.

(viii) Disposal of Effluent from a Pesticide Factory

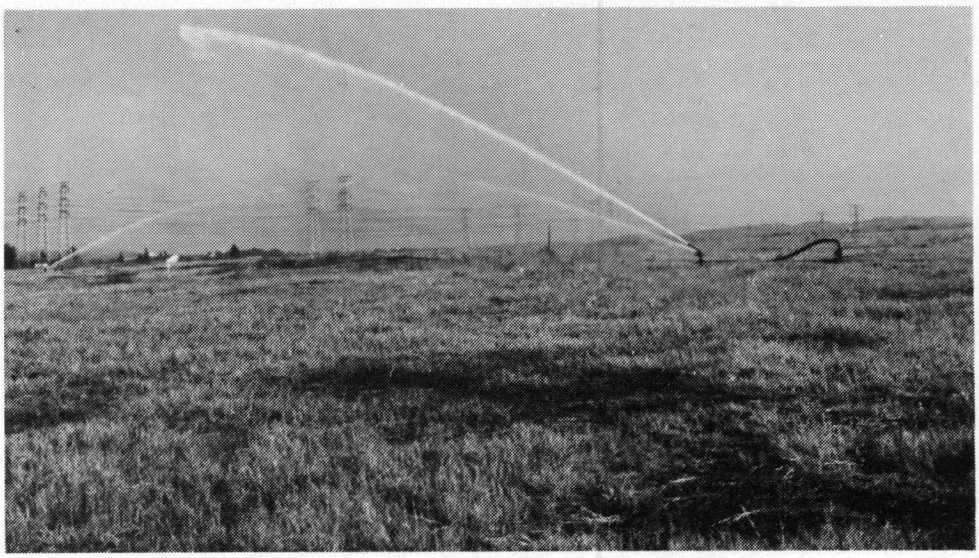
A herbicide factory in the Eastern Cape, near the coast, disposes of effluent into ponds. A systematic investigation has revealed that through seepage and other consequences of the company's operations the aquatic life in the nearby estuary has been adversely affected.

(ix) Disposal of Winery Effluent

Winery effluent is disposed of by a system of broad irrigation with ploughing or by spray irrigation. (cf. – Chapter 15 – *"Wine and Brandy Production and the Disposal of Attendant Wastes"*.)

(x) Disposal of Effluent Containing Nitrate

A well-known and long-established explosives and chemical industry situated at Northrand near Johannesburg has been concerned with the elimination of nitrate in its effluent to reduce the nutrient load on the Hartbeespoort Dam.



Effluent spraying operations of AECI's Modderfontein factory.

One method, used initially, by this industrial company was the judicious and systematic spraying of an area of veld to improve the natural grass coverage and to graze beef cattle on the pasturage provided. (Refer to photograph for method of spraying).



Algae plant for nitrate removal from effluent – AECI, Modderfontein factory.

(xi) Disposal of Maize Products Manufacturing Waste

A plant in the Meyerton area which manufactures products from maize disposes of its saline effluent on agricultural land sewn to maize and other crops.

(xii) Disposal of Cattle Feedlot Waste

The runoff (during rainstorms) from open feedlot enclosures is collected in a series of dams and later used for irrigating agricultural land sewn to crops used in the feeds supplied to the cattle.

This procedure is followed by a large well-established feedlot near Middelburg, Transvaal.

(xiii) Disposal of Waste Activated Sludge and Digested Sludge from Sewage Purification Works

Middelburg, Transvaal disposes of the wasted mixed liquor suspended solids from the town's activated sludge plant by discharge onto ploughed land. This is a practice which has been commonly used overseas and requires that areas of application should be allowed to dry out and be re-ploughed for further use. The method relies on seepage and evaporation of the liquid phase and further decomposition of the solids due to soil organisms and changes due to sunlight, etc.

Disposal of digested sludge on ploughed land is practised by a number of local authorities including Pretoria, Pietermaritzburg and Germiston – however, the *modus operandi* is different in each case.

Johannesburg relies on sun drying of sludge in paddocks covered with a shallow layer of sludge. Lengthy drying periods are employed – it having been found that this procedure is effective in destroying the ova of *Ascaris lumbricoides*.

Some municipalities use lagoons for disposing of digested sludge or surplus activated sludge. In the latter case, the lagoon contents are not allowed to dry out – being topped-up regularly in order to prevent the dissemination of unpleasant odour.

Comment: The beneficial use of effluent for the irrigation of crops and pasturage as well as for other productive activities is to be commended.

The retention of effluent in dams for re-use in processing plants such as takes place in the mining and hydrometallurgical industries is a satisfactory arrangement.

However, storage or evaporation dams must be so constructed as to prevent seepage and overflow in cases where ions inimical to the aquatic environment are present in effluents. Slimes dams should be constructed in accordance with the *"Handbook of Guidelines for Environmental Protection"* issued by the Chamber of Mines of South Africa (cf. Chapter 15: *"The Mining Industry: Handling and Disposal of Effluents Arising from Mining and Mineral Recovery Operations"*).

Reliance on solar evaporation, solely, for disposing of large volumes of effluent is not acceptable. However, in many instances where intractable effluents have to be disposed of it is the only economic way out. But such effluents should be confined to as small a daily volume as possible. This can be effected by ensuring that such effluents are not diluted with other effluents in the factory drainage system and should be isolated therefrom.

Evaporation ponds for intractable wastes containing ions and soluble matter inimical to the aquatic environment should be provided with a suitable impervious lining (e.g. butyl rubber sheeting) and be further provided with an under-drainage system leading to a sump to collect any leakage/seepage. Provision should be made to pump any seepage/leakage back to an evaporation pond.

In built-up areas effluents should be treated to render them suitable for discharge into a municipal sewerage system. In some cases this involves the manufacture of by-products from wastes which would otherwise be inherent in the effluent.

Where irrigation is practised great care should be taken to ensure that the land being irrigated is situated at a safe distance from any river to prevent seepage and runoff from gaining access to such river. Adequate provision of cut-off canals should be made to prevent the ingress to the irrigation area of flood waters during rainstorms.

The perfunctory disposal of conservancy tank contents and slop water on selected areas of the veld as practised by some of the smaller local authorities can lead to intensive fly breeding of the housefly *Musca domestica*.

Fly breeding can also take place when incompletely digested sludge is disposed of on land or sludge drying beds.

Chapter 19 TREATMENT OF SEWAGE AND DISPOSAL OF EFFLUENT FROM SMALL COMMUNITIES, CARAVAN PARKS, SEASIDE RESORTS, HOSTELS, HOTELS, ETC.

I. TREATMENT OF SEWAGE FROM SMALL COMMUNITIES

A small community may be regarded as one giving rise to an average daily flow of domestic sewage not exceeding 700 m^3. Under normal local authority conditions this would represent a contributary population of approximately 5 000. The Department of Water Affairs allows oxidation pond systems for the treatment of sewage flows up to 700 m^3/day.

Note: For information on the design of oxidation pond systems as well as conventional sewage purification plant process units reference should be made to *"A Guide to the Design of Sewage Purification Works"*, published by the Institute of Water Pollution Control – Southern African Branch.

Reference should also be made to CSIR Special Report WAT 34 – Pretoria, 1963, *"A Guide to the Use of Pond Systems in South Africa"* by Meiring P G J, Drews R J L C, van Eck H and Stander G J.

Oxidation Ponds: An acceptable arrangement for dealing with average "strength" domestic sewage is a pond system consisting of one primary pond with a retention period of 20 days followed in series, by a secondary pond having a retention period of 10 days and this, in turn, followed by three tertiary ponds in series, each with a retention period of 5 days.

An irrigation/storage dam with a retention period of not less than 10 days requires to be provided to meet eventualities during periods of incessant rain when effluent cannot be disposed of by irrigation.

After 3 to 5 years a new primary pond requires to be put into use and the used pond allowed to dry out and the dried sludge removed and satisfactorily disposed of – after which both primaries may be used in parallel (until desludging becomes necessary – in which event the desludging shall be done alternately).

To prevent unsightly "floatables" from entering the pond system the incoming sewage should be screened and the screenings buried or incinerated. In some cases detritus removal should be practised.

The final effluent may be used for the irrigation of timber trees and fodder crops; the fodder crops, e.g. lucerne, must be harvested and dried before being fed to animals.

The effluent from a pond system is not suitable for direct discharge into a watercourse. However, with further approved treatment the effluent may be rendered bacteriologically fit for discharge into a river. Notwithstanding, the requirements of gazetted announcements must be met e.g. a final effluent of General or Special Standard quality and phosphate removal depending on the catchment area in which the oxidation pond system is situated.

The pond area should be adequately fenced to prevent the ingress of small as well as large animals; the fence should have a gate which must be locked to prevent the entrance of unauthorized persons. It is considered advantageous to surround the pond area with a belt of fast-growing evergreen trees – preferably varieties which absorb considerable moisture such as eucalyptus.

No boreholes or wells should be allowed within a distance of 800 m from the nearest pond.

Pond systems can only be installed where suitable sites are available; where this is not the case resort may be had to the provision of other methods of purification such as biological filtration or activated sludge methods, the plants for which occupy relatively much less space. At present, the favoured extended aeration versions of the activated sludge process are the Huisman or Orbal system and the Pasveer Ditch system.

Drews and Denysschen,[1] in dealing with sewage treatment works for small communities, have given an account of design faults, operational shortcomings of units of small works and have suggested measures for improving plant performance.

Conventional Sewage Purification Works using Biological Filters: A "conventional" sewage purification works is regarded as one with the following sequence of process units, viz:

Screen(s);
Detritus channels;
Primary sedimentation tank(s);
Biological filter(s) (with 1,829 m depth of media);
Humus tank(s).

Process units for the treatment of settled raw sludge from the primary sedimentation tank(s) include sludge digester(s) and sludge drying beds. Settled humus may be returned to the incoming sewage at the head of the works. Biological filters with 3,658 metre depth of media are favoured in some cases as these give a better performance per unit volume of media.

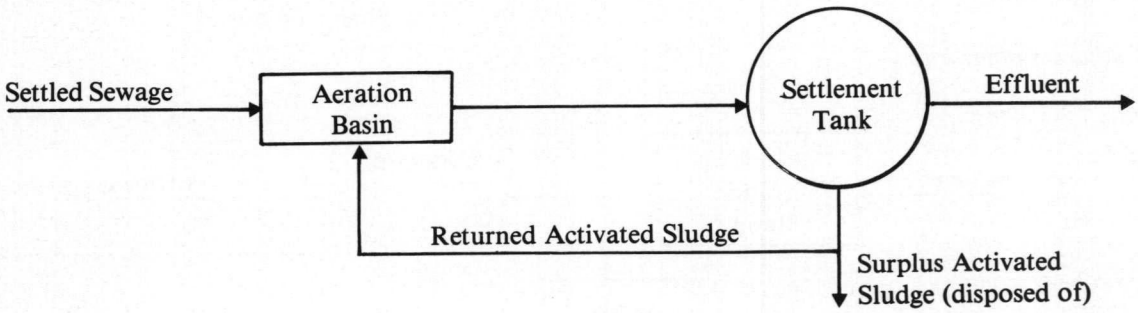
The most desirable site for a conventional sewage purification works is one that allows for gravity flow throughout the plant. A good example of this is the large-scale "Vlakplaats" Sewage Purification Works of the Boksburg Municipality.

Activated Sludge: Since the discovery in Manchester, in 1914, of the Activated Sludge Process by the two chemists Ardern and Lockett, many variations of the process have been evolved. These include the following:

(1) Conventional plug flow;
(2) Conventional completely mixed system;
(3) Step aeration;
(4) Contact stabilization;
(5) Extended aeration;
(6) Oxygen aeration.

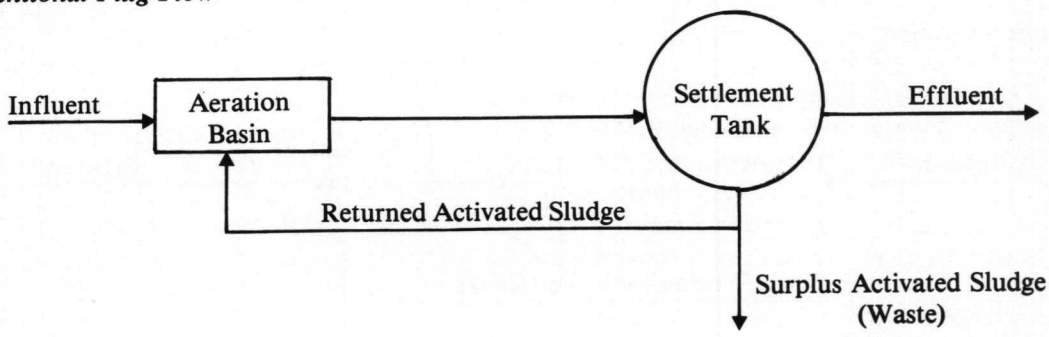
The activated sludge process as originally applied to the treatment of sewage was a continuous flow process wherein sewage after screening, detritus removal and sedimentation was caused to flow into an aeration basin/tank or system of deep channels/compartments where aeration by various techniques occurred (Refer to Chapter 1). In this aeration basin or convoluted system with an aeration time of 4 to 8 h an active biomass ("activated sludge") was built up. The treated sewage then passed into a settlement tank/clarifier. The clarified effluent after disinfection was suitable for discharge into a watercourse. A portion of the settled activated sludge was returned to the aeration basin, compartments or channels to ensure an optimum concentration of Mixed Liquor Suspended Solids (MLSS); the remainder, surplus to this biomass requirement, was disposed of – in many cases on land or given further treatment by anaerobic digestion together with the raw primary sludge and in some cases aerobic digestion.

The process is diagramatically shown as follows:

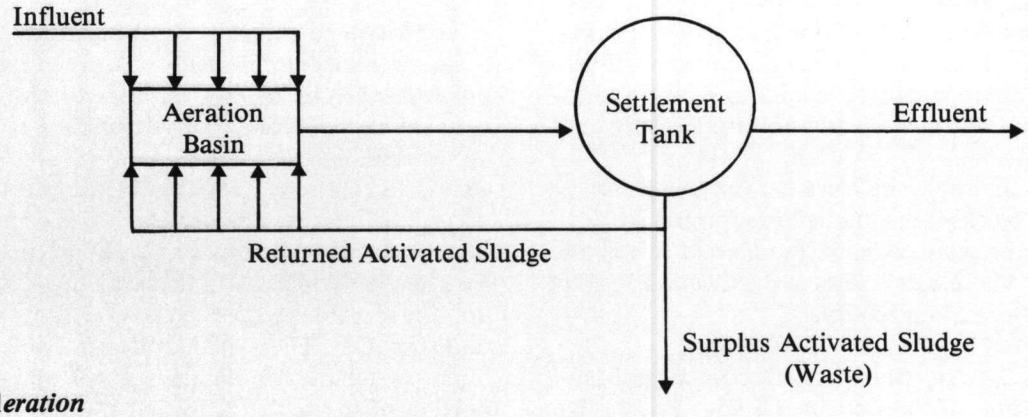


The six variations of the process are diagrammatically illustrated as follows:

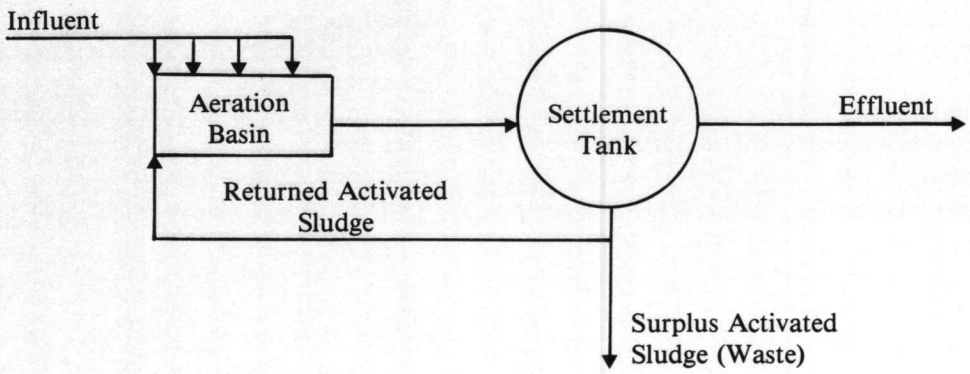
(1) ***Conventional Plug Flow***



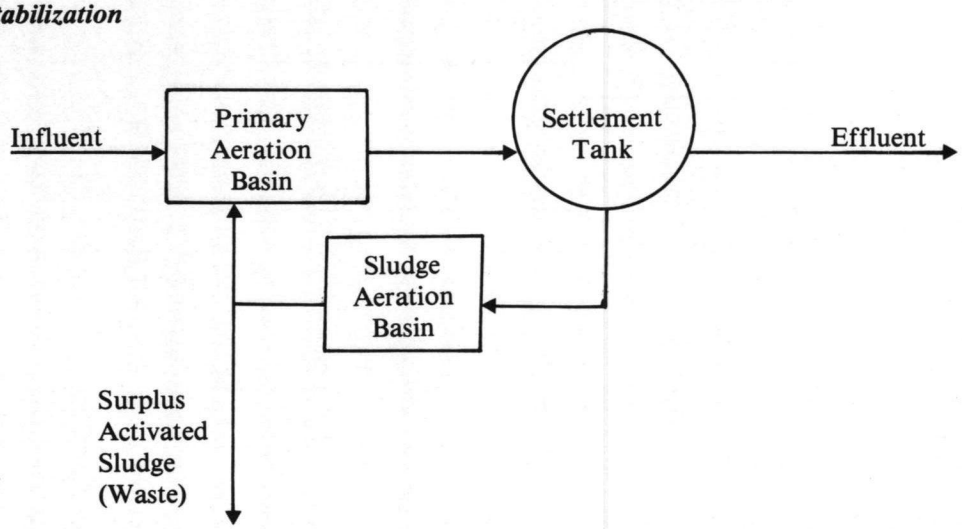
(2) ***Conventional Completely Mixed System***



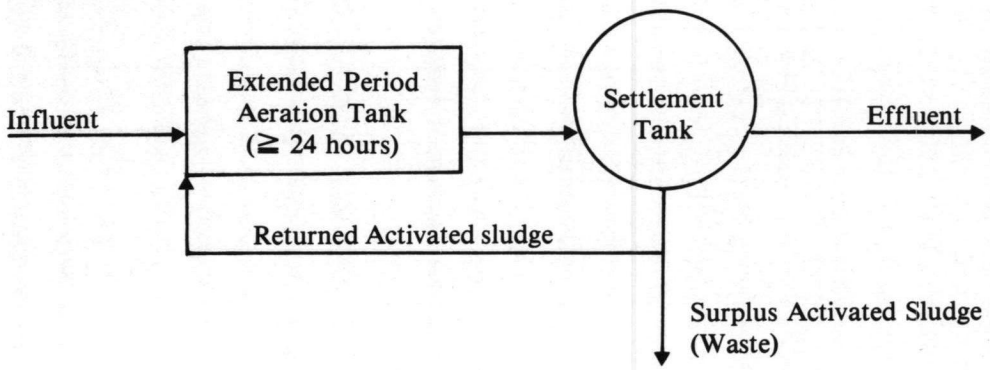
(3) ***Step Aeration***



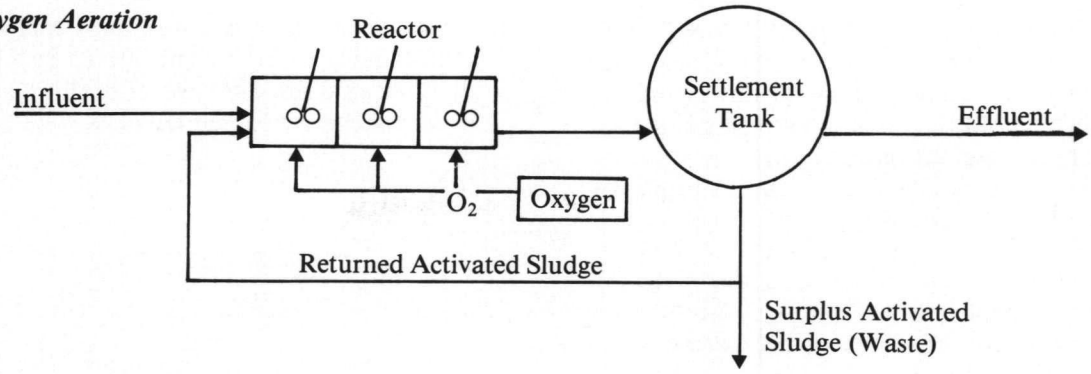
(4) ***Contact Stabilization***



(5) ***Extended Aeration***



(6) ***Oxygen Aeration***



Note: The completely mixed activated sludge process differs from the conventional plug flow process in that the influent wastewater together with returned activated sludge is fed to the aeration basin along its entire length and not only at the influent end.

In step aeration the influent wastewater is fed into the aeration basin along its length but the returned activated sludge is fed in at the inlet end of the aeration basin.

The contact stabilization process involves an initial short period aeration stage (up to 1 h) where clotting of colloids, adsorption and assimilation of organic matter by the activated sludge takes place. This is followed by settlement of the activated sludge in a settlement tank: the settled activated sludge is then treated in a stabilization basin where it receives aeration for 3 to 6 h. Thereafter, the re-aerated (stabilized) sludge is passed back to the initial aeration basin.

Due to the short aeration period given initially soluble organic matter is not always as effectively removed as with conventional activated sludge methods.

The extended aeration activated sludge process has been applied to the treatment of raw sewage which has only received screening and detritus removal. It allows for a very long aeration time – up to 30 h (commonly 24 h). Due to the fact that a large aeration basin is required extended aeration plants have become popular for small sewage purification works and for package units.

Details of package units have been given in *"Technical Memorandum on Activated-Sludge Sewage-Treatment Installations providing for a long period of Aeration"*, published by the Ministry of Housing and Local Government, London, H M Stationery Office, 1969.

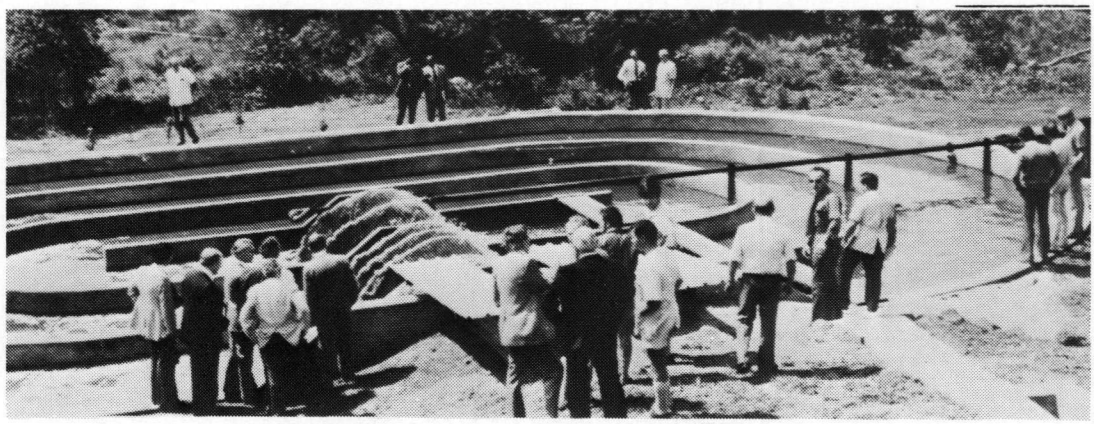
The use of pure oxygen in place of air in an activated sludge plant could allow a reduction in size of the aeration basin or extend the life of an existing plant. A lot would depend on the cost of oxygen needed and the exigent nature of the problem to be overcome.

An activated sludge plant operating efficiently produces a sparklingly clear effluent and does not give rise to unpleasant odour. However, in South Africa, the disposal of surplus/waste activated sludge has proved a problem due to the presence of *Ascaris lumbricoides* (roundworm) ova* which are not destroyed by the processing.

Many package units have been built to treat sewage by the activated sludge process. However, Turvey[2] has pointed out that of a variety of plants in operation in South Africa the performance was found to be poor due, *inter alia*, to unsatisfactory supervision and neglect.

Orbal Activated Sludge Plants: The National Institute for Water Research has issued a *"Guide for the Operation of Orbal Activated Sludge Units"*.[3] This should be consulted as well as the *"Operators*

*Refer to Chapter 3 in regard to the viability of *Ascaris lumbricoides* in sewage purification processes.

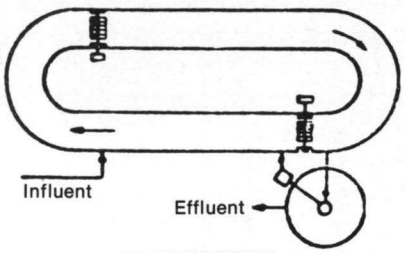


Orbal wastewater treatment plant (Elim Hospital).

*Handbook on Sewage Purification".** Many orbal units have been commissioned in South Africa ranging in size for the treatment of sewage flows from 180 to 6 800 m^3/day. Most of the orbal plants in operation are of the extended aeration type.

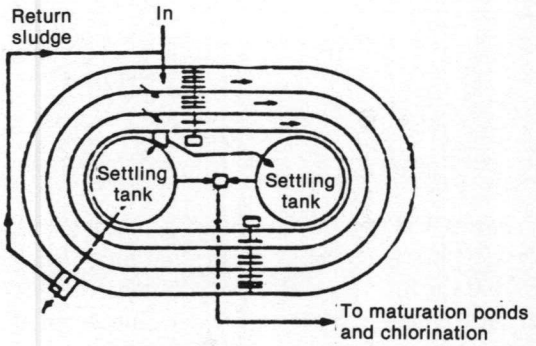
The following diagrams illustrate the principles of operation of three types of plant, viz:

(1) *Pasveer Ditch:* Consisting of a single shallow endless aeration channel, two cage rotors (rotary vane aerators) and one activated sludge settlement tank.



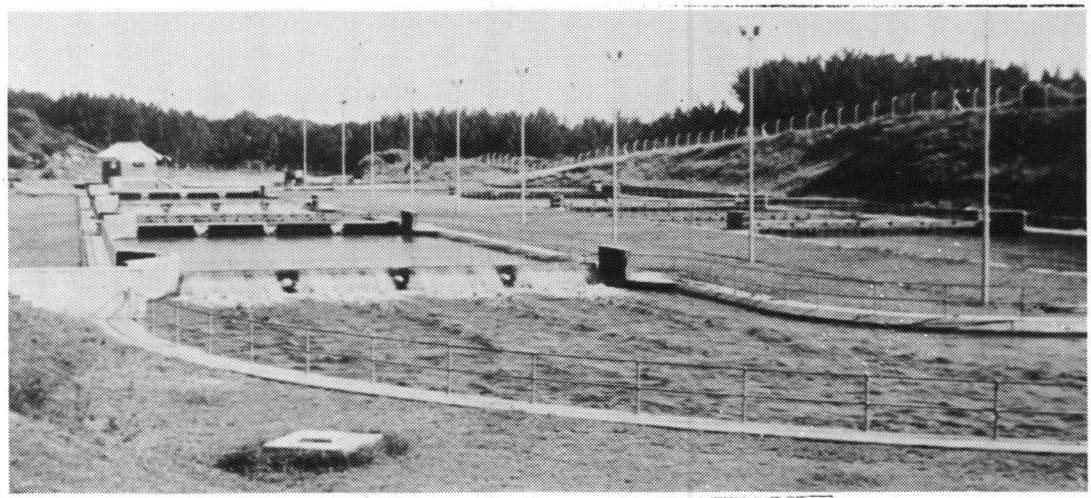
PASVEER DITCH

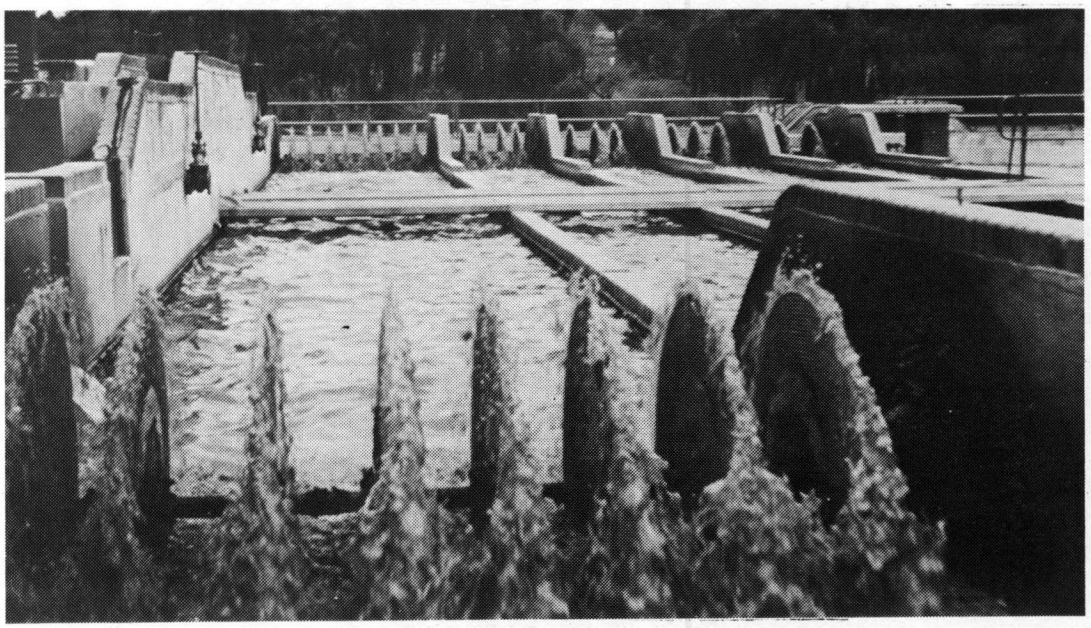
(2) *Orbal Plant:* This can have 3 or 4 endless adjacent channels (oval in plan) aerated by a bank(s) of rotating discs with two centrally placed activated sludge settlement tanks.



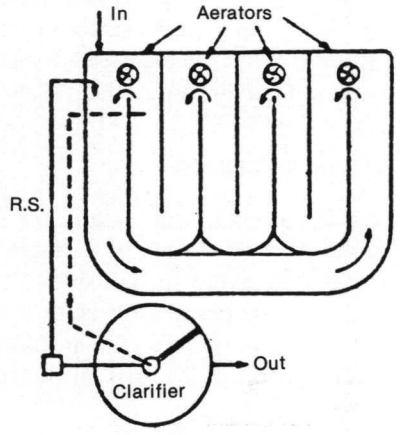
ORBAL PLANT

** "Operators Handbook on Sewage Purification"* published by the Institute of Water Pollution Control (Southern African Branch).


Pasveer Ditch Plant (Ezikhawini).


Huisman Plant

(3) *Carrousel Plant:* This has been developed from the Pasveer Ditch concept in an attempt to save space and expenditure on larger plants. The plant consists of a number of connecting channels which are aerated by large aerators; the aerators are so arranged to cause the mixed liquor to move around in one direction through the channels sequentially. A settlement tank is provided.



CARROUSEL PLANT

Recent Variations of the Activated Sludge and Biological Filtration processes: Due to the need to remove nutrients – which when present in effluent lead to the eutrophication of impoundments – much investigation and research has been directed towards the elimination of phosphate (in particular) and nitrate from sewage effluents discharged into rivers feeding impoundments.

These process modifications are dealt with in Chapter 13.

II TREATMENT OF SEWAGE FROM CARAVAN PARKS AND SEASIDE RESORTS

The purification of sewage and disposal of effluent from caravan parks, seaside and other resorts which are subject to a considerable influx of residents or sojourners during holiday seasons suffer from the same problem, viz. the inability of their sewage purification plants to deal with the surges in flow that take place. In this connexion it is well to note that the number of contributors at a well-known resort in the Cape at one stage during the summer season was about 16 times that during the normal off-season periods.

Therefore, a scheme has to be devised whereby the sewage can be economically treated during off-season periods and provision is made to deal with holiday periods.

It would seem obvious that a buffering mechanism must be available to take care of peak flows. This can be provided by installing a pond system to work in combination with the sewage purification works. During the periods of greatly increased flow the excess flow which is beyond the capability of the sewage purification plant, should be diverted to the pond system together with a portion of the final effluent from the plant – on a continuous basis – until the end of the holiday season. Subsequently, during conditions of low flow the ponds' contents may be recycled through the plant if this is necessary.

However, only effluent of General Standard quality must be discharged into a watercourse. Effluent discharged direct into the sea must conform with the Guidelines of the Department of Health for the permissible utilization and disposal of treated sewage effluent (cf. Appendix 2).

Chemical treatment of the sewage during the holiday periods will not serve as a panacea to solve the problem as the plant will be considerably hydraulically overloaded. Chemical treatment of the excess flow only will not result in an effluent of General Standard quality unless expence is not a deciding factor.

The problem of seasonal increases is not perculiar to holiday resorts; it occurs with seasonal industries such as the sugar industry where the general procedure adopted by the industry is to discharge mill effluents and purified sewage effluents into a large pond or set of ponds which serve as a "reservoir" for the distribution of the combined effluent for irrigation or for treatment in an activated sludge or biofiltration plant (cf. Chapter 15: *"Progress in the Control of Pollution in the Sugar Industry in South Africa"*).

In any case, it would be a well-considered plan to allow for over-designing of the sewage purification works as normal flows are bound to increase with increase in popularity of a resort.

III THE TREATMENT OF SEWAGE FROM HOSTELS, HOTELS, ETC.

It has been common practice for hotels, hostels and other institutions (e.g. hospitals) in situations isolated from established sewerage systems to install septic tank-French drain combinations for disposing of sewage. Latterly this has given way to the installation of package units or small sewage purification works for the treatment of wastewater.

Gross[4] has described *A Septic Tank Disposal System* and considers that for proper clarification, the sewage must be retained in the tank for a period of about 48 h based on an average daily use of water of 189,27 litres (50 US gallons) per person. He has pointed out the advisability of building oversize.

Malan[5] considers that the retention time of sewage in a septic tank should not be less than 24 h based on a sewage flow of c. 68 to 90 litres (15 to 20 gallons) per person per day for Blacks and c. 136 to 182 litres (30 to 40 gallons) per person per day for Whites.

He has given the following estimates of flow for various establishments:

Sewage Flows for Various Sized Houses

Number of Bedrooms*	Sewage Flow (ℓ/day)
2	682 (150 gal.)
3	909 (200 gal.)
4	1 137 (250 gal.)
5	1 364 (300 gal.)

*Servants' quarters in most households can be taken as equivalent to one bedroom.

Malan considers that the design of a household septic tank system should not be based on the number of occupants at any particular time but rather on the number of bedrooms – as given above.

He states, further, that for establishments other than households, the sewage flow should preferably be gauged, or it may be estimated from readings of the water meter. When flow data are not available

Estimates of Sewage Flows from Various Establishments

Type of establishment	*Litres per person per day*
Boarding houses	113,7 (25 gal.)
(Additional kitchen wastes for non-resident boarders)	22,7 (5 gal.)
Hotels without private baths	113,7 (25 gal.)
Hotels with private baths	136,4 (30 gal.)
Restaurants (toilet and kitchen wastes per patron)	13,7 – 22,7 (3 – 5 gal.)
Tourist camps or caravan parks with central bathhouse	90,9 (20 gal.)
Day schools	36,4 (8 gal.)
Day workers at offices/shift	90,9 (20 gal.)
Hospitals	341 – 568,3 + (75 – 125 + gal.)
Factories (volume per person per shift, exclusive of industrial wastes)	136,4 (30 gal.)
Swimming baths	9,1 (2 gal.)
Motels (per bed space)	90,9 (20 gal.)
Drive-in theatres (per car space)	9,1 (2 gal.)
Airports (per passenger)	9,1 (2 gal.)
Service stations (per vehicle served)	9,1 (2 gal.)

flows (estimated) in the foregoing table may be taken as the expected quantities.

Also, he has stressed the need for cleaning out of accumulated sludge and scum from a septic tank timeously on a regular basis.

Location of Septic Tanks and Percolation Systems

The Rand Water Board's sanitary requirements applicable to riparian properties adjacent to the Vaal River Barrage Reservoir, Vaal Dam and tributaries of the Vaal River include the location of septic tanks and percolation systems which are as follows:

PERCOLATION SYSTEMS

The effluent from septic tanks shall flow into percolation systems (French drains) of a design approved by the Board and having subsoil sidewall infiltration areas based on the permissible rates of application of effluent corresponding to the measured water percolation rates in test holes sunk in the subsoil at the percolation field sites.

The infiltration area for a house not exceeding 200 square metres shall be not less than 14 square metres; for a house of greater area the Board will, on application, specify the required infiltration area.

The above requirements shall also apply in the case of 'two-pipe' systems in which kitchen and bathroom wastewaters by-pass the septic tanks and enter separate French drains or soak pits of a design and capacity approved by the Board, after passing through effective grease traps.

LOCATION OF SEPTIC TANKS AND PERCOLATION SYSTEMS

Septic tanks and their associated percolation systems (French drains) shall be situated –

(i) not less than the following distances from the full supply water line –

Houses, flats, chalets, hotels, camps and caravan parks	**Distance**
Systems serving up to 2 dwelling units	50 m
Systems serving 3 to 10 dwelling units	100 m
Systems serving 11 to 12 dwelling units	150 m

In addition, the percolation systems shall be so situated that the area available between the percolation system and the full supply water line is, in the opinion of the Board, adequate to ensure complete evapotranspiration of the effluent. In general this is based on a figure of 250 square metres for each person that can be accommodated.

In the case of hotels, two bedrooms shall be taken as equivalent to one 'dwelling unit';

(ii) at positions where the normal water table is not

less than 2 metres below ground level;

(iii) at positions above the expected high flood level (available from the Board in the case of the Barrage reservoir and from the Department of Water Affairs in the case of Vaal Dam).

Notwithstanding (i), (ii) and (iii) above, should it be found that the effluent from the percolation system is finding its way into Vaal Dam, the Barrage reservoir or the tributaries concerned, such further measures as the Board may require shall be taken to eliminate such discharge into the reservoir, the dam or the tributaries concerned.

The location, capacity, design and construction of septic tanks and percolation systems shall be subject to written approval by the Board. The Board shall have the right of regular access for inspection.

Rotating-Disc Unit (RDU)

Pretorius[6] has shown how Rotating-Disc Units can be used for treating septic tank effluent. The RDU contains a series of closely spaced, parallel discs mounted on a shaft which is supported just above the wastewater to be treated. The lower parts of the discs dip into the wastewater. When the discs are slowly rotated (0,5 – 15 rev./min.) a biological slime forms on the surface of the wetted discs (as is the case with the media in a percolating filter). Due to the alternate dipping and withdrawal of the disc surfaces from the wastewater, oxidation of the adsorbed nutrients takes place.

Pretorius[6] points out that many variations of the RDU exist such as rotary tubes trickling filters and "Bio-Drum" Units. One advantage of a RDU is that is can be completely enclosed by a semi-cylindrical cover and so can be used in close proximity to buildings without causing a nuisance. Furthermore, the electric power required to drive a set of discs is not great and operation of the RDU is reasonably silent.

To obtain complete nitrification Pretorius recommends the use of two sets of discs – the first set placed at the septic tank for the carbon-oxidation stage followed by the second set, arranged in two stages to effect oxidation of organic and ammoniacal nitrogen to nitrate.

Pretorius[6] has given the following design data for a RDU in combination with a septic tank to treat the sewage from 100 contributors:

Design Data for 100-person Plant

Flow	136 ℓ/person day
COD	120 g/person day
BOD	54 g/person day
Nitrogen	60 mg N/ℓ effluent

Load and Performance Data

Septic Tank:	
Average hydraulic retention time	36 h
Volume of scum and sludge accumulated (1 year desludging intervals)	0,1816 m^3/person
Total volume of septic tank	38,5 m^3
COD removal	80 per cent of COD in crude sewage

Rotating-disc Unit for Carbon Oxidation

COD removal rate	22 g COD/m^2 day 1 m^2 disc area/ person day
Disc area	110 m^2
Disc diameter	1 m
Number of discs	75
Disc spacings (depend on thickness of material)	not less than 20 mm apart
Rotation rate	5 – 10 rev/min
COD removal	75 per cent
Final COD	55 mg/ℓ
Final BOD	<10 mg/ℓ

Rotating-disc Unit for Nitrogen Oxidation

Nitrate formation rate	2 g nitrate N/m^2 day 4 m^2 disc area/ person day
Disc area	400 m^2
Disc diameter	1,5 m
Number of discs	112 (in two stages)
Disc spacing	not less than 1 cm
Rotation rate	5 – 10 rev/min
Recirculation pump (centrifugal)	170 ℓ/h
Final effluent	no ammonia

Pretorius[6] has recommended that in designing a septic tank the suggestions made by Malan[5] should be followed. A 36-h hydraulic detention time should be provided. However, where a RDU is added to a septic tank about double the amount of sludge accumulation indicated by Malan[5] must be provided for. In desludging, sufficient sludge should be left behind in the septic tank (at least a 10 cm layer) to act as seed for the continuing anaerobic digestion.

Pretorius[6] states that the disc area needed for carbon oxidation is c. 1 m^2/person and for nitrogen oxidation c. 4 m^2/person.

If the final effluent is to be disposed of in a soil percolation system only carbon-oxidation is required. However, if effluent of General Standard quality is required he recommends that the final effluent, together with its suspended solids be recirculated in the ratio of 3:1 (i.e. effluent:flow).

IV EFFLUENT QUALITY ASSESSMENT WITH PARTICULAR REFERENCE TO SMALL DOMESTIC SEWAGE PURIFICATION WORKS

Introduction

A small local authority, council, board, corporate body or an individual may be faced with the problem of lack of funds and facilities as well as employees not possessing the necessary knowledge and expertise to sample and analyse flow liquors and effluents from a sewage purification works.

This immediately presents a problem to the Department of Water Affairs in the exercise of its surveillance of effluent quality in relation to the obligations of those concerned under any permit issued in terms of the Water Act (Act 54 of 1956) as amended by Act No. 96 of 1984.

If, for example, an operating sewage treatment facility calls for the production of an effluent of General Standard quality, problems of correct sampling and analysis immediately arise and, in many cases, a veritable impasse is reached mainly due to lack of funds, laboratory facilities and qualified staff or, alternatively, a geographical situation remote from available competent laboratories either of another local authority or industry or public analytical laboratories. In such latter cases those concerned are beset with transport problems. In order to assist those responsible and, at the same time, ensure that the sewage purification works operates satisfactorily and discharges an effluent of the required quality, the problem arises of setting out certain tests which can be performed easily by sewage works operators lacking a training in chemistry.

Whilst such tests are not legally laid down as is the case with those set out in Government Notice No. 553 of 5 April, 1962, nevertheless, such alternative tests could serve equally well for control purposes in regard to the quality of the effluent discharged from a sewage purification works.

It must be emphasized that although the South African Bureau of Standards (SABS) has laid down certain quality standards and, also, the methods by which these shall be determined, there are other methods which may be employed to achieve the same purpose and if these are within the compass of those responsible they should be encouraged to use them and not default as they tend to do. In which event only less frequent "check analyses" by the SABS methods need to be carried out.

This procedure should prove more satisfactory as the tendency has been one of lack of implementation of permit conditions by poorly motivated local authorities and others thereby making the Department's requirements rather ineffectual.

Sampling (in General)

From the foregoing it will be realized that if a sewage treatment facility in a remote area and those reponsible for its operation wish to transport samples to a convenient and satisfactory laboratory capable of carrying out sanitary analyses, considerable time may elapse between the time of sampling and the start of the analyses by the chemical laboratory.

This being so, if simple inexpensive tests capable of performance by an operator at the sewage purification works can be devised such tests must serve a useful purpose.

Furthermore, it is imperative that samples should not be allowed to stand for any length of time before subjecting them to analysis.

This will be appreciated when we realize that sewage is an ever-changing mixture of substances in solution and suspension. The complex unstable organic substances in human and household wastes soon decompose in the presence of numerous bacteria which enter the sewers with them.

The composition of sewage from a community changes rapidly from time to time on account of the fluctuating quantities of constituents contributed and the entrance of more or less ground water, surface water and storm water into the sewers. Night sewage is much "weaker" than that arriving at the sewage works during the day. The flow varies and peaks are noticeable at certain times due to the location of the sewage purification works in relation to the sewerage system and also due to the habits of the contributors. The composition of sewage arriving at a sewage purification works also varies from hour to hour and depends directly upon the activities of the contributing population (cf. Addendum I which gives a graphical representation of the variations of flow and "strength" of sewage which can take place).

Likewise, variations in the composition of sewage occur from day to day. This is particularly noticeable on Sundays when there is a reduction in industrial activity and household activities are somewhat attenuated and Mondays when extra wastewater from household water occurs. The composition and volume also vary according to the time of the year (e.g. summer and winter). Temperature effects also come into play, for example raised temperatures due to exposed outfall sewers over sewer-bridges or otherwise above ground, hot discharges into connecting sewers together with lengthy periods of passage in the main outfall sewer to the sewage purification works can lead to septic sewage. Such septic sewage will contain hydrogen sulphide and mercaptans which are malodorous compounds containing sulphur.

From the foregoing it is obvious that great care and attention must be paid to obtaining representative samples and to have these examined immediately.

As far as the Department of Water Affairs is concerned the permits issued state that, at all times, an effluent shall conform with certain quality requirements. This allows the Department's Water Pollution

Control Officers to take samples of effluent at any time and have them analysed by the SABS to ascertain whether they conform with the quality requirements laid down.

However, as far as the operation of a sewage purification works is concerned we require to know the daily performance of a plant. This being so, it is usual to take 24-hourly composite samples.

It should be emphasized that there is no ideal or correct method of sampling. However, in assessing the performance of a plant, "grab" or "spot" samples taken at arbitrary times are not considered satisfactory and may lead to erroneous conclusions.

To reiterate, there is no ideal, absolute or perfect method of sampling sewage flow liquors and to obtain truly representative samples over a 24-h period would involve the taking of aliquots at hourly or halfhourly intervals, and noting the flow at the time of sampling and then taking a sub-aliquot of each aliquot proportional to the flow at the time of sampling the aliquot, and mixing these immediately after a 24-h period to give a day's composite sample. Authoritative views on the sampling of sewage and effluents, etc. have been given by the following two bodies, as follows:

- *Ministry of Health (Great Britain):* In its publication entitled, *"Methods of Chemical Analysis as Applied to Sewage and Sewage Effluents"* (H M Stationary Office, London, 1929 and subsequent editions) it is stated, *inter alia* as follows:

  "The importance of good sampling cannot be over-rated, as upon this the whole of the deductions depend which are ultimately drawn from the figures of analysis. With regard to samples generally, every care should be taken to draw them in such a way as to maintain the true proportion of suspended solid to liquid. All samples, more especially, effluents, should be drawn quietly, i.e. without unnecessary aeration. Further, it is often advantageous to note the temperature of a sample when drawn . . ."

  "When hourly samples of sewage, etc. are being taken, to be afterwards mixed in sets of 24 samples each, a wide-necked bottle of about 300 cc capacity should be filled *completely* every hour and then set aside in a cool place; at the end of 24 hours these sub-samples should be mixed for the final sample in proportions corresponding to the rates of flow at the respective hours as determined by gauge. If circumstances do not permit of gauging then the sub-samples can be mixed in equal volumes, and subsequent allowance made, as far as possible, when reviewing the figures of analysis, for the different factors which tend to cause the mixed sample to be either stronger or weaker than a true average sample taken according to rates of flow . . ."

  ". . . If a sample cannot be examined on the day it arrives at the laboratory, it should if possible be kept in an ice box."

- *American Public Health Association Inc.: "Standard Methods for the Examination of Water, Sewage and Industrial Wastes"*:

  "The standard method comprises collection of a composite sample over a 24-h period. In many cases it may be advisable to composite individual samples over a 1-h, 2-h, or 4-h period, or to divide the sample to represent shift work, or to extend it to cover the complete cycle of operation including all special, variable or periodic discharges at irregular intervals, including Saturday and Sunday clean-ups. This is particularly true with industrial wastes . . ."

  "Samples of sewage, effluents, and wastes should be analysed as soon as possible after collection. . ."

  "Samples for the determination of relative stability and biochemical oxygen demand must be free from all preservatives. When samples are composited, the samples or the composite sample must be chilled immediately to 3° to 4°C and kept at this temperature during the compositing period . . ."

From the foregoing it is clear that the simplest, most convenient, acceptable method of sampling is to take equal aliquots every hour for 24 hours and mix all these 24 aliquots after the final aliquot has been taken to give a composite sample for a particular day. This constitutes fairly general local practise. The "time-of-start" of sampling is a matter of convenience but is usually the start of the morning shift (06h00 – 07h00).

To ensure that day-to-day variations are taken care of it is a commonly used procedure to take 24-hourly composites every eight (8) days which means that over a year samples will have been taken on each day of the week (in rotation).

Compromise Sampling for Small Sewage Purification Works

In the case of small local authorities and others employing, for example, only one or two operators during one shift only (e.g. daytime) it is difficult or impossible to take 24-hourly composite samples (except by the use of automatic samplers). In the circumstances, therefore, it is considered that since the purpose of sampling and analysis is to ensure that the effluent is satisfactory in terms of the permit conditions laid down by the Department of Water Affairs it is considered advisable to err on the side of safety. This being so, the problem requires to be rationalized and an acceptable alternative decided upon. It is felt that this should be a "snap" or "grab" sample taken during the period of maximum effluent flow and tests should be done on this immediately. This ensures that the samples are taken at approximately the same time each day and during maximum hydraulic loading of continuous process units.

Control Tests for Small Works

(1) *Relative Stability*

The simplest test to estimate the quality of the final effluent from a small sewage purification works treating domestic sewage only is the methylene blue "Relative Stability" test. This basically consists in adding a small aliquot of a methylene blue (double zinc salt) solution to a fixed volume of effluent in a narrow-necked clear glass bottle which is glass stoppered and set aside in a cool cupboard. This is observed at least once every day and the number of days noted for the blue colour to disappear. Should the colour be retained for 21 days the effluent is regarded as 100 per cent stable and of very satisfactory quality.

In practice it has been found that for a well-purified effluent decolorization does not occur within a period of 12 days (i.e. a Relative Stability Number of 94 per cent). If decolorization takes place within 5 days the effluent is unsatisfactory. For details of the test refer to Addendum II.

Relative stability may be defined as the per cent ratio of oxygen available as dissolved oxygen, nitrite, and nitrate oxygen to the total oxygen required to satisfy the biochemical oxygen demand (BOD).

The determination of relative stability has somewhat fallen out of use. But for small plants with limited laboratory facilities, however, the stability towards methylene blue fulfills a very useful service in indicating the satisfactory operation of the biological oxidation processes. It does, in fact, perform a "stop-gap" function regardless of its limitations, one of which is that the reduction of the methylene blue depends, somewhat, on the amount of oxygen already dissolved in the effluent.

The method, of course, is inapplicable if bactericidal substances that cannot be removed are present. Samples tested must be free from chlorine, calcium hypochlorite, bisulphites, copper salts or other germicides.

Where chlorination is practised at a sewage purification works the test would have to be applied to effluent sampled just prior to chlorination.

A modified methylene blue test was proposed by W R Wooldridge of the London School of Hygiene and Tropical Medicine (*Biochemical Journal*, 1933, 27(1), 193 – 201, cf. Addendum III). However, this is rather more elaborate and refined and is not recommended in the circumstances though it does illustrate the great importance of enzymes in the purification of sewage.

(2) *Settleable Solids*

This should be carried out by settling 1 ℓ of sample in an Imhoff cone and noting the volume of sedimented material after one hour's settlement. The result is expressed as mℓ/ℓ.

Samples of overflows from sedimentation tanks (clarifiers), humus tanks, and activated sludge settlement tanks should be taken once a week during periods of maximum flow and examined by this method.

A sample of the final effluent should also be subjected to the same test – though for a good effluent, this is not necessary.

The aim in operation of the plant units should be to achieve settleable solids figures not exceeding 2 mℓ/ℓ.

(3) *pH Value*

This may be conveniently carried out by a colorimetric method either using a small colorimeter or pH test papers.

This determination should be carried out once per week on supernatant liquor ("middle-third-liquor") withdrawn from each digester and on filtrates of samples of digested sludge filtered through coarse filter paper.

The aim should be to maintain a pH value in a digester of between 7,0 and 7,2 and certainly not below 7,0. Otherwise it will be necessary to add lime to a digester.

The pH value of the final effluent need only be determined once per month; this should be in the range 6,8 to 8,2 and preferably not lower than 7,0, though the pH value of the water supply in an area may influence this.

(4) *Settleability of Activated Sludge*

This is performed by allowing 1 ℓ of activated sludge taken from an aeration unit to settle for 30 min in a 1 000 mℓ graduated measuring cylinder and noting the volume of settled sludge.

(The sedimentation volume should not be allowed to fall below 30 per cent of the total (1 000 mℓ) of original sample volume. Further, it should not be allowed to exceed 60 per cent.)

Activated sludge in good condition should settle rapidly and concentrate well, leaving a sparklingly clear supernatant liquor.

Where facilities are available in a well-equipped chemical laboratory the "Sludge Volume Index" (SVI) may be determined. This is defined as the volume in millilitres occupied by 1 g of activated sludge after settling the aerated liquor for 30 min (as indicated) above.

The settled sample, after thorough mixing, or the original sample is taken to determine the suspended solids and this is reported as per cent by weight (dried solids) or mg/ℓ.

Then the SVI is determined as follows:

$$\text{SVI} = \frac{\text{per cent settling by volume}}{\text{per cent suspended matter}}$$

$$= \frac{\text{m}\ell \text{ settled sludge} \times 1\,000}{\text{mg}/\ell \text{ suspended matter}}$$

Good sludge has an index of less than 100 mℓ/g.

Laboratory Facilities

Suitable accommodation should be provided in a special small brick structure or other adequate building at the sewage purification works. In both cases the room/space used should maintain an equable temperature throughout any day and be provided with a ceiling at an adequate height.

All that is required in this small laboratory is a small work/laboratory bench about 91 to 100 cm in height and about 2,5 to 3,0 m long with cupboard space below and two shelves (about 1,5 m long and about 25 cm wide) placed conveniently above the working area of the bench. The bench should be provided with a sink and running water.

A suitably insulated cupboard is required to accommodate about a dozen 150 mℓ glass stoppered bottles (for the relative stability test).

A wall bracket should be provided for 3 Imhoff cones (plastic).

Equipment and Chemicals

Equipment:

1 straight-edge plastic beaker (250 mℓ)
2 straight-edge plastic beakers (500 mℓ)
1 straight-edge plastic beaker (1 000 mℓ)
4 Imhoff cones (1 000 mℓ, plastic)
1 wooden filter stand (for six filter funnels)
3 7-cm diameter plastic filter funnels
1 15-cm diameter plastic filter funnel
6 boxes coarse (No. 1 – No. 3 grade Whatman) filter paper 11,5 cm dia.
1 measuring flask (1 000 mℓ)
2 measuring cylinders (plastic, 1 000 mℓ)
2 measuring cylinders (plastic, 500 mℓ)
3 Winchester quart bottles with stoppers
2 bacteriological pipettes (graduated, 1 mℓ)
2 bacteriological pipettes (graduated, 2 mℓ)
1 bacteriological pipette (graduated, 5 mℓ)
2 glass cloths
6 plastic cassettes of pH paper (pH range to be covered 5,0 – 10,0)
1 reagent glass bottle (500 mℓ)
2 reagent glass bottles (250 mℓ)
15 narrow neck, clear glass bottles with ground glass stoppers (150 mℓ)

Chemicals

10 g methylene blue (double zinc salt)
Distilled water (25 ℓ)

Note: The methylene blue solution should be made up as a stock in a Winchester quart bottle – a volume of 1 ℓ will suffice. This should be done in another laboratory by a competent chemist or chemical analyst.

0,5 g of methylene blue should be made up in 1 ℓ of distilled water. An aliquot is then transferred to a 250 mℓ reagent bottle for use.

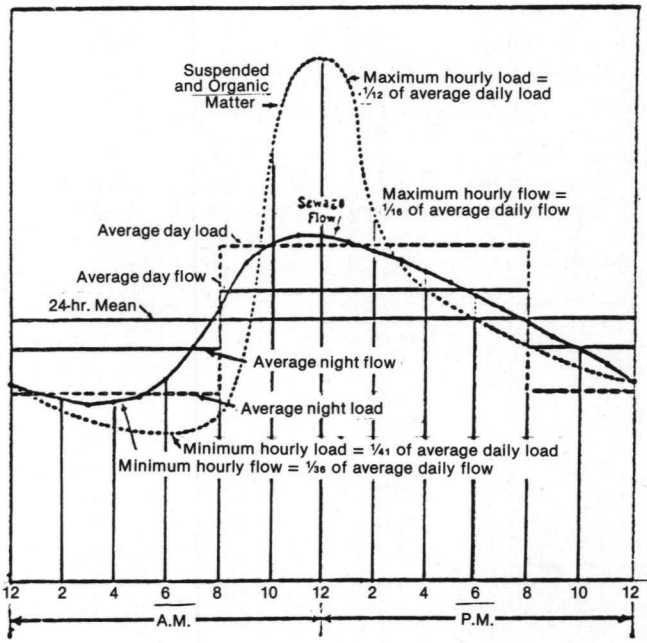
Infrequent Check Analyses

When samples are taken for despatch to other laboratories – some distance from the sewage purification works – for infrequent "check" analysis it is necessary to exercise certain precautions to ensure that they are reasonably well preserved at the time of analysis.

In practice a representative sample of the final effluent should be prepared at a convenient time and care taken to ensure that the sample is maintained at 3 to 4°C. This can be done by keeping the sample (in a Winchester quart bottle or other suitable non-breakable container e.g. plastic) in a refrigerator or ice-box prior to dispatch (in an insulated container) to the laboratory by the quickest possible route.

Methods of sampling and preservation of samples recommended by the "US Environmental Protection Agency", Cincinnati, Ohio, USA are given in Addendum IV.

ADDENDUM I



Hourly variation in flow and strength of sewage.

ADDENDUM II

The time required to exhaust the oxygen available in a sample under definitely controlled temperature conditions, as indicated by decolorization of methylene blue at the incidence of putrescence, is a measure of the relative stability.

The method is inapplicable in the presence of free chlorine, calcium hypochlorite, bisulphites, copper salts, or other germicides.

Reagents

Methylene blue. Dissolve 0,5 g of the double zinc salt or commercial variety in water and dilute to 1 litre.

Procedure

The sample, without shaking to increase the dissolved oxygen, is gently poured into a clear glass-stoppered bottle of approximately 150-mℓ capacity. 0,4 ml of the methylene blue solution is added, preferably below the surface of the liquid. The stopper is carefully replaced without entraining bubbles of air, and the bottle then placed in an incubator at 20°C (± 2°C) for 21 days, or until decolorization occurs.

Calculation

The relative stability numbers may be calculated from the theoretical relation.

$S = 100\ (1 - 0{,}794^t)$, in which S is the stability expressed in percentage and t is the time in days required for decolorization at 20°C (± 2°C); or the relative stability may be read from a table.

The relative stability test is carried out on final effluents.

Relative Stability Numbers

Time Required for Decolorization (20°C)	Relative Stability S	Time Required for Decolorization (20°C)	Relative Stability S
Days	Per cent	Days	Per cent
0,5	11	8,0	84
1,0	21	9,0	87
1,5	30	10,0	90
2,0	37	11,0	92
2,5	44	12,0	94
3,0	50	13,0	95
4,0	60	14,0	96
5,0	68	16,0	97
6,0	75	18,0	98
7,0	80	20,0	99
		21,0	100

ADDENDUM III

A Modified Methylene Blue Test for the Examination of Sewage and Sewage Effluents

In a paper by Wooldridge entitled *"The Stability Test of Sewage and its Relation to Enzyme Activity"* (*Biochem. J.*, 1933, 27(1), 193 – 201) the author makes out a case for an improved methylene blue test which he considers is more accurate and not so time-consuming. He states, *inter alia*:

". . . Firstly the time taken for the methylene blue reduction to take place will depend to some extent on the amount of oxygen already dissolved in the sewage and secondly the concentration of methylene blue is so low that any error produced as a result of the variability in the amount of oxygen dissolved will be very significant, especially as the reducing system is generally such a weak one, taking several days for completion. These sources of error can be avoided by using the Thunberg technique, adding a larger concentration of methylene blue and shortening the time required for reduction by incubating at a higher temperature."

"A modified stability test is described. The period of the test is shortened by incubation at 45° and by the addition of washed sludge and a hydrogen donator such as formate. The sewage is incubated in vacuum tubes together with 1 cc of 1/5 000 methylene blue solution, formate and washed sewage, and the time required for complete reduction of the dye is compared with that of a control tube not containing the sewage."

He further states, "The reducing power of crude sewage towards methylene blue is shown to depend largely upon the enzymic activity of suspended matter in the sewage.

The sludge, besides possessing a marked reducing power of its own, also activates substances present in solution as hydrogen donators. Both reducing effects are destroyed by heating sludge to 100°C for 15 minutes."

Note: The modified test of Wooldridge would have a limited practical application in sewage laboratories doing routine analysis but is more of use as a practical tool in research.

Wooldridge also emphasizes that "As boiled crude sewage and sewage sterilized by passage through a Seitz filter exert little or no reducing effects themselves, although they will still act as sources of hydrogen donators to the suspended matter, it appears that the reduction of the methylene blue is entirely the result of this enzymic system".

ADDENDUM IV

Methods of Sampling and Sample Preservation

(As proposed by US Environmental Protection Agency, Cincinnati, Ohio, USA)

Sample Preservation

Absolute preservation of samples, either domestic sewage, industrial wastes or natural waters, is a practical impossibility. Regardless of the nature of the sample, complete stability for every constituent can

never be achieved. At best, preservation techniques can only retard the chemical and biological changes that inevitably continue after the sample is removed from the parent source. The changes that take place in a sample are either chemical or biological. In the former case, certain changes occur in the chemical structure of the constituents that are a function of physical conditions. Metal cations may precipitate as hydroxides or form complexes with other constituents; cations or anions may change valence states under certain reducing or oxidizing conditions; other constituents may dissolve or volatilize with the passage of time. Metal cations may also absorb onto surfaces (glass, plastic, quartz, etc.), such as iron and lead. Biological changes taking place in a sample may change the valence of an element or a radical to a different valence. Soluble constituents may be converted to organically bound materials in cell structures, or cell lysis may result in release of cellular material into solution. The well-known nitrogen and phosphorus cycles are examples of biological influence on sample composition. Therefore, as a general rule, it is best to analyse the samples as soon as possible after collection. This is especially true when the analyte concentration is expected to be in the low $\mu g/\ell$ range.

Methods of preservation are relatively limited and are intended generally to:

(1) Retard biological action;
(2) Retard hydrolysis of chemical compounds and complexes;
(3) Reduce volatility of constituents; and,
(4) Reduce absorption effects.

Preservation methods are generally limited to pH control, chemical addition, refrigeration and freezing.

Note: The recommended preservative for various constituents is given in the following Table. These selections have been based on the accompanying references and on information supplied by various Quality Assurance Coordinators. As more data become available, these recommended holding times will be adjusted to reflect new information. Other information provided in the Table is an estimation of the volume of sample required for the analysis, the suggested type of container, and the maximum recommended holding times for samples properly preserved.

Recommendations for Sampling and Preservation of Samples According to Measurement[1]

Measurement	Vol. req. (mℓ)	Container[2]	Preservative	Holding Time[3]
Physical properties				
Colour	50	P G	Cool, 4°C	24 hours
Conductance	100	P G	Cool, 4°C	24 hours[4]
Hardness	100	P G	Cool, 4°C HNO_3 to pH <2	6 months[5]
Odour	200	G only	Cool, 4°C	24 hours
pH	25	P G	Determine on site	6 hours
Residue:				
Filterable	100	P G	Cool, 4°C	7 days
Non-filterable	100	P G	Cool, 4°C	7 days
Total	100	P G	Cool, 4°C	7 days
Volatile	100	P G	Cool, 4°C	7 days
Settleable matter	1 000	P G	None required	24 hours
Temperature	1 000	P G	Determine on site	No holding
Turbidity	100	P G	Cool, 4°C	7 days
Metals				
Dissolved	200	P G	Filter on site HNO_3 to pH <2	6 months[5]
Suspended	200	P G	$HNO_3$to pH <2	6 months[5]
Mercury:				
Dissolved	100	P G	Filter on site HNO_3 to pH <2	38 days (glass) 13 days (hard plastic)
Total	100	P G	HNO_3 to pH <2	38 days (glass) 13 days (hard plastic)
Inorganics, Non-metallics				
Acidity	100	P G	None required	24 hours

Measurement	Vol. req. (mℓ)	Container[2]	Preservative	Holding Time[3]
Alkalinity	100	P G	Cool, 4°C	24 hours
Bromide	100	P G	Cool, 4°C	24 hours
Chloride	50	P G	None required	7 days
Chlorine	200	P G	Determine on site	No holding
Cyanides	500	P G	Cool, 4°C NaOH to pH 12	24 hours
Fluoride	300	P G	None required	7 days
Iodide	100	P G	Cool, 4°C	24 hours
Nitrogen Ammonia	400	P G	Cool, 4°C H_2SO_4 to pH <2	24 hours
Kjeldahl, Total	500	P G	Cool, 4°C H_2SO_4 to pH <2	24 hours[6]
Nitrate plus Nitrite	100	P G	Cool, 4°C H_2SO_4 to pH <2	24 hours[6]
Nitrate	100	P G	Cool, 4°C	24 hours
Nitrite	50	P G	Cool, 4°C	48 hours
Dissolved Oxygen:				
Probe	300	G only	Determine on site	No holding
Winkler	300	G only	Fix on site	4 – 8 hours
Phosphorus:				
Ortho-phosphate, Dissolved	50	P G	Filter on site Cool, 4°C	24 hours
Hydrolysable	50	P G	Cool, 4°C H_2SO_4 to pH <2	24 hours[6]
Total	50	P G	Cool, 4°C H_2SO_4 to pH <2	24 hours[6]
Total, Dissolved	50	P G	Filter on site Cool, 4°C H_2SO_4 to pH <2	24 hours[6]
Silica	50	P only	Cool, 4°C	7 days
Sulphate	50	P G	Cool, 4°C	7 days
Sulphide	500	P G	2 mℓ zinc acetate	24 hours
Sulphite	50	P G	Determine on site	No holding
Organics				
BOD	1 000	P G	Cool, 4°C	24 hours
COD	50	P G	H_2SO_4 to pH <2	7 days[6]
Oil and Grease	1 000	G only	Cool, 4°C H_2SO_4 or HCl to pH <2	24 hours
Organic carbon	25	P G	Cool, 4°C H_2SO_4 or HCl to pH <2	24 hours
Phenolics	500	G only	Cool, 4°C H_3PO_4 to pH <4 1,0 g $CuSO_4/\ell$	24 hours
MBAS	250	P G	Cool, 4°C	24 hours
NTA	50	P G	Cool, 4°C	24 hours

1. A general discussion on sampling water and industrial waste water may be found in ASTM, Part 31, pp. 72 – 82 (1976), Method D-3370.
2. Plastic (P) or Glass (G). For metals, polyethylene with a polypropylene cap (no liner) is preferred.
3. Holding times listed above are recommended for properly preserved samples based on currently available data. It is recognized that for some sample types, extension of these times may be possible while for other types, these times may be too long. Where transport regulations prevent the use of the proper preservation technique or the holding time is exceeded, such as the case of a 24-h composite, the final reported data for these samples should indicate the specific variance.
4. If the sample is stabilized by cooling, it should be warmed to 25°C for reading, or temperature correction made and results reported at 25°C.
5. Where HNO_3 cannot be used because of transport restrictions, the sample may be initially preserved by icing and immediately delivered to the laboratory. Upon receipt at the laboratory, the sample must be acidified to a pH <2 with HNO_3 (normally 3 mℓ 1:1 HNO_3/ℓ is sufficient). At the time of analyses, the sample container should be thoroughly rinsed with 1:1 HNO_3 and the washings added to the sample (volume correction may be required).
6. Data obtained from National Enforcement Investigations Center, Denver, Colorado, support a four-week holding time for this parameter in Sewerage Systems (SIC4952).

ADDENDUM V

Other Simple Quality Assessment Tests

Suspended Solids

(1) *Filter Paper Method*

As an alternative to the Gooch crucible method of determining suspended solids in an effluent a rough comparative method which may be used in substitution thereof consists in filtering a fixed volume of effluent through a filter paper and comparing the extent of discoloration of the filter paper with the stains displayed on filter papers from previous tests.

The method may be calibrated by having a number of tests done gravimetrically on the effluent from time to time.

The filtration is carried out under suction in a Büchner funnel using analytical grade filter paper or glass fibre paper.

(2) *Optical Method*

For this method a flat bottomed transparent glass or plastic tube some 61 cm in length is required. To the outside of the tube's bottom a white paper disc is affixed. A black cross with a line thickness of 1 mm is drawn on the disc and this should be visible when looking down the tube placed vertically under uniform lighting conditions.

Effluent is then poured gradually into the vertically held tube until the black cross is no longer visible; the distance of the meniscus of the effluent in the tube from the bottom of the effluent column is then noted. This depth should exceed 300 mm for satisfactory effluents.

Permanganate Value

The Oxygen Absorbed from acid permanganate in 4 h at 26,7°C is commonly used in sewage works practice as one of the yardsticks for assessing the quality of an effluent and as a rough indicator of the oxidizable organic content of a wastewater. However, it suffers from the fact that under the conditions of the test oxidation is not complete and conclusions can be upset when readily oxidizable substances such as nitrite and sulphite are present in the test sample.

The SABS has outlined the procedure to be followed in carrying out this test. This calls for the services of a competent analyst or laboratory technician in a reasonably well equipped laboratory.

The following is an approximate method which has been used as a "field" test:

Approximate Method for Determining Permanganate Value

To each of four (4) identical glass cylinders add the following:

50 mℓ effluent;
2 mℓ sulphuric acid (25 per cent) (1 vol. H_2SO_4:3 vol. distilled water).

To three of the tubes add sequentially 2, 4, 6 mℓ $^N/_{80}$ potassium permanganate ($KMnO_4$) solution; then mix the contents of each tube well.

Allow the tubes to stand for 30 min; after which note the presence or disappearance of the pink colour and estimate the permanganate value from the following table:

No. of Tubes Showing Pink Colour after 30 min	*Permanganate Value Estimated range, mg/ℓ*
3	0 – 13
2	11 – 23
1	21 – 38
0	>32

Ammonia Content*

Allow the sample of effluent to settle to obtain a clear sample. To a Nessler cylinder add 2 mℓ of sample using a pipette. Now add 25 mℓ (ammonia free) distilled water followed by 1 mℓ of 10 per cent sodium hexametaphosphate† solution and make up to a final mixed volume of 50 mℓ with further distilled water.

Finally, add 2 mℓ Nessler's‡ reagent and after about 10 min compare the colours which develop with standard discs§ or prepared standards.‖

*i.e. Free and saline ammonia or so-called ammoniacal N (NH_3) as opposed to albuminoid N (NH_2).

†Sodium hexamataphosphate is a complexing agent which prevents the precipitation of cations responsible for temporary hardness in the sample.

‡*Nessler's Reagent*
Preparation: Place 70 g KI in a Winchester bottle and add 200 mℓ distilled water. Pour in enough saturated $HgCl_2$ solution to leave a faint excess. Add 960 mℓ of 25 per cent NaOH and then more $HgCl_2$ solution to give a yellow precipitate. Dilute to 2 ℓ and allow the mixture to stand for a day or so before using the resulting clear solution.

§Obtainable from scientific equipment and chemicals supply houses.

‖Alternatively, a stock solution of ammonium chloride containing 3,821 g NH_4Cl/ℓ should be made up or otherwise obtained. 1 mℓ stock solution ≡ 1 mg N. Daily standards can be made from this stock solution using Nessler's reagent.

ADDENDUM VI

Relative Stability Tests for Effluents

In a thesis presented to the University of the Witwatersrand in December 1955, J G Mortimer made a comparison of the various "Relative Stability" tests which have been suggested for assessing the quality of a sewage effluent. He has shown that the methylene blue "Relative Stability" test as used by sewage works operators is the most suitable of all the indicator methods.

He has concluded that the methylene blue "Relative Stability" test as applied to purified sewage effluents gives a fairly accurate assessment of the suitability of an effluent for discharge into a stream.

He investigated the following stability tests:

(1) The ordinary methylene blue "Relative Stability" test (cf. Addendum II).
(2) Methylene green and indigo carmine by the method of Clark and Adams (*J. Amer. Chem. Soc.*, 1908, 30, 1037).
(3) Methylene green according to Dickinson and Weir (*Analyst*, 1940, 65, 289).
(4) Methylene blue, methylene green, thionin, indigo carmine and brilliant cresyl blue by the accelerated method of Hopper and Briscoe (*Sew. Works J.*, 1944, 16, 558).

Mortimer concludes that due to the poor colour intensities displayed by indigo carmine and brilliant cresyl blue in the concentrations specified, no significance can be attached to the results obtained using these dyes, since it is almost impossible to determine the end point with accuracy. Therefore, he rejected these methods.

He further concludes, if an indicator method is to be used, then, it seems that the ordinary methylene blue test is the most satisfactory. The methylene green and methyl orange (according to Dickinson and Weir), and accelerated Hopper and Briscoe tests are much more rapid but their results do not correlate with the methylene blue test. He considers that if quick provisional results are required they can be used.

However, he concludes that an assessment of the "Relative Stability" of an effluent may be made in two hours using a Barcroft respirometer. (But such an elaborate type of apparatus – which measures oxygen uptake – would only be available in more advanced laboratories; although most biochemical laboratories make frequent use of either the Barcroft or Warburg types of respirometers.)

Phelps (Geological Survey Water Supply Paper 229, 1909) considered the reaction between methylene blue and an effluent as being a first order reaction.

A first order reaction may be written in the simple form:

$$\log \frac{a}{x} = kt$$

Where a is the initial concentration of the substance undergoing change, x is the concentration at time t, and k is the velocity constant.

By rearrangement we have:

$$\log x = \log a - kt$$

and since log a and k are constants, the graph of log x against t should be a straight line of slope k. The equation given by Phelps, Mortimer avers, is $\log x = \log a - k^t$; where t appears as a superscript and this he states is incorrect.

He concludes from his investigations that it is likely that the reactions studied in the methylene blue "Relative Stability" test are of an autoinhibitory first order reaction and not just a simple first order reaction.

REFERENCES

1. Drews, R.J.L.C. and Denysschen, J.H. *"Sewage Treatment Works for Small Communities – a Need for Careful Design and Operation"*, International Conference on Water Pollution Control in Developing Countries, Bangkok, Thailand, 21 – 26 February, 1978.
2. Turvey, L.G.S. *Wat. Pollut. Control*, 1975, 74(2), 193.
3. Drews, R.J.L.C. *"Guide for the Operation of Orbal Activated Sludge Units"*, CSIR Guide K36, Pretoria, 1976.
4. Gross, E.R. New Jersey Agricultural Experiment Station, New Brunswick, N.J. Circular 381, December 1938.
5. Malan, W.M. *"A Guide to the Use of Septic Tank Systems in South Africa"*, CSIR Research Report 219, Pretoria, 1964.
6. Pretorius, W.A. *"The Rotating Disc Unit: A Waste-Treatment System for Small Communities"*, *Wat. Pollut. Control*, 1973, 72(6), 721.

Chapter 20 WATER BOARDS AND THEIR FUNCTIONS

A community water system has been defined by Wolman and Bosch[1] "as an integrated system that delivers a safe water, in ample quantity, into the household of every member of the community".

How this has been achieved in South Africa, by the agency of water boards, is conveniently illustrated in the case of the Republic's largest water supply organization – the Rand Water Board.

Rand Water Board

The Rand Water Board's creation and development is best comprehended by a study of the early history of Johannesburg and the gold mining industry.

According to Neame[2] "Before Johannesburg was two years old it was growing so fast that the provision of a proper water supply, lighting and public transport became urgent".

James Sivewright (later Sir James Sivewright) was granted a concession by the Government to "lay pipes through the streets of Johannesburg in order to supply the inhabitants thereof with water". As a consequence, in July 1887, he promoted the Johannesburg Waterworks, Estate and Exploration Company. Preceding Sivewright (in May 1887) a number of speculators bought land in Old Doornfontein and formed a waterworks and land company.

The early effort to supply Johannesburg with piped water was not a financial success and some time later the Sivewright concession was acquired by Barney Barnato's Johannesburg Consolidated Investment Company, Limited.

Leyds[3] states that the company built a dam near Ellis Park sportsfield and pumped water to a reservoir at the corner of Saratoga Avenue and Harrow Road. In 1895 a severe drought and consequent water shortage were experienced. The quality of the water was unsuitable for drinking without prior boiling. In many cases water was conveyed to the higher parts of the town by mule-drawn water-carts and the cost to users was two shillings and sixpence per bucket!

Not only was the quality poor but the quantity was meagre and this resulted in numerous complaints being made to the Sanitary Board. As a result the Government appointed a commission in 1895 to examine "in what way Johannesburg can be provided with good and pure drinking water".

However, due to the geologist Dr David Draper, a stable water supply was found from boreholes which were sunk in 1898 on the farm Zuurbekom some seventeen miles (c. 27 km) south west of Johannesburg. The Zuurbekom pumping station was commissioned in 1899. The quality of the water was satisfactory and the supply (c. 340 000 m^3/day) adequate at the time.

The continuing need to provide a better water supply and the 1895 Commission's recommendation that a public body be created to replace the companies then operating for profit, resulted in the appointment of the Witwatersrand Water Supply Commission on November 4, 1901.

After its tenure of investigation of three months the Commission reported in favour of the establishment of a body to be called the Rand Water Board, charged with the duty of supplying water to municipalities and the mines from Randfontein to Springs.

Thereafter, the Rand Water Board Incorporation Ordinance No. 32 of 1903 was passed on May 7, in the Legislative Assembly in Pretoria.

Originally, there were eleven members of the board, viz. the Chamber of Mines, 5 representatives; Johannesburg Municipality, 3 representatives; Germiston-Boksburg area, 1; Springs area, 1; Krugersdorp-Roodepoort area, 1. The disposition of representatives has changed and the Department of Water Affairs has a supervisory concern.

On July 27, 1923 the Vaal River Barrage was opened thereby augmenting the water supply of the Rand Water Board. Augmentation is a continuing necessity to adequately provide pure wholesome water to the board's vast and expanding area of distribution.

According to a Rand Water Board illustrated brochure (1985) the Board's original area of supply was 4 548 km^2 but is now 17 000 km^2 and includes the cities of Johannesburg, Pretoria, Germiston and Roodepoort, and the towns of Benoni, Brakpan, Springs, Nigel, Krugersdorp, Randfontein and Vereeniging.

The above local authorities together with the gold mines and the South African Transport Services are the Board's foundation consumers. The role of the Rand Water Board is that of a regional bulk supplier of potable water. The provision of raw water to the Board is the responsibility of the Government and

the distribution of water to industries and households is the responsibility of the local authorities.

The present limits of supply include Rustenburg and Mabopane to the north, Carletonville to the west, Sasolburg to the south and Sasol II (Secunda) to the east.

The "Vaal River System" serving as the main water resource for the Board includes the Vaal River Barrage, Vaal Dam 80 km upstream from the barrage, the Grootdraai Dam at Standerton, the Sterkfontein Dam situated in the Orange Free State just over the border from Natal. The Sterkfontein Dam is filled by water pumped from the Tugela River in Natal and also from the Woodstock Dam on the Tugela which serves as a feeder-reservoir for the Sterkfontein Dam during periods of low flow in the river. An additional resource, of course, is the Zuurbekom aquifer.

The Rand Water Board has operated in terms of powers acquired through a number of special parliamentary enactments.

Regional Water Supply Corporations

Hall[4] states that the conception of water boards had its origin in Natal where Ordinance 21 of 1945 established Regional Water Supply Corporations for the province.

Prior to this, municipalities in the other provinces, either by private statutes or general Municipal Ordinances, were authorized to obtain water for use in their areas of jurisdiction.

The Water Act (Act 54 of 1956) adopted the set-up evolved in Natal as a framework for the establishment of water boards; thus enabling the creation of regional authorities to coordinate the use of natural water supplies and render these available to a number of separate urban and rural communities within their areas of jurisdiction.

The Act provides for the creation of water boards which are able to effect combined schemes for the supply of water to agricultural, urban, and industrial users – thus enabling the most effective use of unexploited water resources in a particular region.

Water boards are autonomous bodies in terms of the Act. They have their own staff and funds but are subject to a measure of control by the Department of Water Affairs.

The following are lists of (a) Regional Water Services Corporations and (b) Water Boards which have been established:

(a) Regional Water Services Corporations in Natal established by Proclamation in terms of Ordinance No. 27 of 1963 of Natal

These include the following:

Corporation	Proclamation	Registered Address
North East Zululand R.W.S.	203/1974	Mtubatuba
Amanzimtoti R.W.S.	26/1946	Amanzimtoti
Pinetown R.W.S.	9/1947	Pinetown
Lower South Coast R.W.S.	46/1946	Port Shepstone
Dundee-Glencoe R.W.S.	21/1947	Dundee
North Coast R.W.S.	61/1963	Overport
Umzinto R.W.S.	114/1949	Umzinto

(b) Water Boards established throughout the Republic

These include the following:

Water Board	Registered Address
Albany-Coast	Boesmansriviermond
Duivenhoks	Heidelberg (CP)
Kalahari-West	Upington
Karos-Geelkoppan	Upington
Magalies (formerly Vaalkop)	Rustenburg
Mhlatuze	Richard's Bay
OFS Gold Fields	Bothaville
Pelladrift	Johannesburg
Phalaborwa	Phalaborwa
Rand Water Board	Johannesburg
Rûensveld	Heidelberg (CP)
Springbok	Nababeep
Umgeni	Pietermaritzburg

Also included are –

The Chief Director: Board of Curators of National Parks..	Pretoria
The Director: National Botanical Gardens of South Africa.....	Claremont

Further, we have

Western Transvaal Regional Water Services Company ..	Stilfontein

Water Boards operate in terms of legislation set out in Chapter VII, Sections 107 to 137 (inclusive) of the Water Act (Act No. 54 of 1956) as amended by Water Amendment Act, 1984 (Act No. 96 of 1984).

In terms of Section 136 of Act 54 of 1956 no regional water supply corporation shall be constituted under the provisions of the Water Supply Ordinance, 1945 (Ordinance No. 21 of 1945) of Natal, without the prior approval of the Minister of Water Affairs.

On this matter, the Water Amendment Act, 1984 (Act No. 96 of 1984) states – "No regional water services corporation shall be constituted under the provisions of the Water Services Ordinance, 1963 (Ordinance No. 27 of 1963) of Natal, without the prior approval of the Minister".

It states further that – "The Minister may at any time if he deems it expedient in the public interest recommend to the State President that the provisions

of this Chapter* be applied to any water services corporation constituted under the provisions of the said Ordinance".

It is to be expected that in applying the principle of *dominus fluminis*† the Central Government would require control of water resources in all provinces. The above provision, therefore, accords with this principle.

Functions, Powers and Duties of Water Boards

The following are the functions, powers and duties of water boards as set out in Section 110 of Act 54 of 1956. These provisions have not been substantially altered by subsequent legislation. Minor substitutions to sub-sections 1(a) and 1(b) have been made in terms of the Water Amendment Act, 1984 (No. 96 of 1984). These do not materially alter the substantive nature of these provisions –

110.(1) A water board shall have power –

(a) to establish, construct, purchase or otherwise acquire and to maintain and control any scheme to provide and supply water for use for urban, industrial or agricultural purposes to local authorities, departments of State, including the South African Railways and Harbours Administration and any provincial administration, or other persons within the area for which such water board has been established;

(b) to appoint such engineers, technical officers and other officers, workmen and servants as it may deem requisite at such salaries, wages and allowances as may, with the approval of the Minister given after consultation with the Public Service Commission, be prescribed by by-laws under section one hundred and thirty-six*;*

(c) to raise money by way of loans;

(d) to acquire by purchase, lease or otherwise, land or rights or interests in land, water rights, and rights to property of any description, and to control or otherwise beneficially use any property or rights so acquired;

(e) to acquire by purchase, lease or otherwise or to construct, and to maintain, alter or improve offices, buildings, machinery, plant, conduits water-channels, cisterns, meters, watercocks, culverts, pipe-lines, water works, reservoirs, dams, filter-beds, wells, shafts, railway sidings, embankments, roads, bridges, vehicles and any other apparatus or works required for or in connection with any scheme referred to in paragraph (a);

(f) to exchange, let, sell or hypothecate any of the property or plant acquired or constructed under paragraph (d) or (e);

(g) to cause surveys, plans, sections, maps, drawings and estimates to be made by or through its officers, servants or agents;

(h) to cause entry to be made by or through its officers, servants, or agents duly authorized thereto upon any land for the purpose of making plans and surveys thereof, the investigation of any water supply on or under such land, or investigations, as to the suitability of any site for the construction of storage or other works in relation to the supply of water and any such survey or investigation made may include investigations into the purity and chemical composition of any such water;

(i) to enter into contracts with local authorities, the Government, including the South African Railways and Harbours Administration and any provincial administration, companies and other persons for the supply of water within the area for which the board has been established;

(j) subject to the provisions hereinafter contained as to prices, to make and recover charges for water supplied;

(k) to purchase or otherwise acquire supplies of water;

(l) to insure with any company or person against any losses, damage, risks and liabilities which the board may incur;

(m) to lay or carry through, over, under or across any land, public or private or any public road, public place or outspan, either within or without the area in which water is to be supplied, and from time to time repair and maintain any pipes for the supply of water with any necessary valves, cocks, meters or other accessories in connection therwith and for that purpose to enter upon any such land, road or place;

(n) to establish a pension fund for its employees and to contribute to such a fund in accordance with by-laws made under section one hundred and thirty-six.

(2) A water board shall from time to time on the direction of the Minister enter into such contracts of insurance under paragraph (l) of subsection (1) as the Minister may require.

(3) A water board shall in the exercise of the powers conferred by paragraph (h) of sub-section (1), have power –

(a) to search, dig, excavate, bore or carry out any works or investigations which may be necessary for the discovery, gauging or measurement or the establishment of the chemical composition of any water rising from any spring, well or fountain, or flowing in any river, watercourse or channel;

(b) to take any steps necessary to determine the levels, direction of flow or chemical composition of any water contained in or flowing in any underground reservoirs or channels; and

(c) to search, dig, excavate, bore and carry out

*Chapter VII of the Water Act (Sections 107 – 137) as amended by Act 96 of 1984.

†Refer to Chapter 9 – *"Water Rights"*.

any works necessary to determine the suitability of any site for the construction of storage or other works in relation to the supply of water,

and may for any such purpose enter upon any land: Provided that no entry shall be made into any building or upon any enclosed space attached to a dwelling, except with the consent of the occupier thereof.

(4) *In the exercise of the powers conferred upon a water board by paragraphs (h) and (m) of sub-section (1) and sub-section (3), as little damage as possible shall be caused, and such compensation as may be agreed upon, or failing agreement determined by a competent court, shall be paid by the said board for all damage so caused or otherwise the said board shall repair any such damage.*

(5) *The provisions of sub-section (7) of section* one hundred and forty-one *shall* mutatis mutandis *apply with reference to the exercise of any of the powers mentioned in paragraph (m) of sub-section (1) of this section in relation to any such road as is referred to in the first-mentioned sub-section.*

Sub-section (7) of section *one hundred and forty-one* applies to Irrigation Boards. With the necessary corrections as applying to Water Boards it may be taken to read as follows:

A Water Board desiring to construct a water work for the conveyance of or the drainage or disposal of water shall not construct such work across a road for the construction maintenance, repair or control of which a provincial administration, divisional council or other lawfully constituted body is responsible unless such Water Board has obtained the written permission of the said administration, council or body, and the said Water Board shall construct such water work in accordance with such conditions as to construction, maintenance and repair as the said administration, council or body may impose in granting the said permission.

A number of the provisions which have applied to Irrigation Boards also apply to Water Boards but these are concerned with delineating the *modus operandi* of an autonomous body and its relationship to and the requirements of the Minister and nominated officers of his Department (Water Affairs).

Water Boards and Irrigation Boards are established on different bases. Water Boards are concerned with the bulk supply of potable water to consumers whilst Irrigation Boards are concerned with the apportionment and lawful and equitable use of water in an irrigation district.

An Irrigation Board deals, *inter alia*, with such matters as the following:

(1) The protection of the sources of the water of any public stream in the irrigation district assigned to it;
(2) Preventing the wastage of water in any public stream in such district;
(3) Preventing loss of public water by leakage into subterranean channels;
(4) Preventing the unlawful abstraction of or storage of public water or subterranean water; or causing to be removed any obstruction unlawfully placed in a public stream; and to prevent any unlawful act calculated to diminish the quantity of water in any part of a public stream;
(5) Supervising the state of all public streams in the irrigation district under its control;
(6) Investigating and recording the quantities of water used by irrigators as well as the times of usage thereof;
(7) Constructing or otherwise acquiring waterworks for the drainage of land and the irrigation of scheduled areas;
(8) Controlling the distribution of water from a Government waterwork;
(9) Subject to the provisions of the Water Act – supplying water under its control to local authorities and other users.

Establishment of Water Boards

In terms of section 108 of the Water Act a water board is established when it is deemed by the Minister to be expedient or desirable to create a combined scheme for supplying water for urban, industrial or agricultural purposes to a number of consumers in a particular area, or on completion or the commencement of a Government waterwork.

Upon receiving a recommendation from the Minister the State President may arrange to proclaim for such area a water board and assign a name to such board.

A water board is a corporate body capable of performing all acts that are necessary in the exercise of its powers and the performance of its functions (q.v.).

REFERENCES

1. Wolman, A. and Bosch, H.M. *J. Amer. Water Wks. Assoc.*, 1963, 55(8).
2. Neame, L.E. *"City Built on Gold"*, Central News Agency Limited, South Africa.
3. Leyds, G.A. *"A History of Johannesburg"*, Nasionale Boekhandel Beperk, 1964.
4. Hall, C.G. *"Hall on Water Rights in South Africa"*, Fourth Edition, Juta and Co. Limited, Cape Town, Wynburg, Johannesburg, Durban, 1974, p. 235.

Appendix A.1 REGIONAL STANDARDS FOR WASTEWATER OR EFFLUENT*

The following are the requirements to which wastewater or effluent produced by or resulting from the use of water for industrial purposes† shall conform after purification:

1. SPECIAL STANDARD

Quality standards for wastewater or effluent arising in the catchment area draining water to any river specified in Schedule I or a tributary thereof at any place between the source thereof and the point mentioned in the Schedule, in so far as such catchment area is situated within the territory of the Republic of South Africa.

1.1 *Colour, Odour or Taste:*
The wastewater or effluent shall not contain any substance in a concentration capable of producing any colour, odour or taste.

1.2 *pH:*
Shall be between 5,5 and 7,5.

1.3 *Dissolved Oxygen:*
Shall be at least 75 per cent saturation.

1.4 *Typical (faecal) Coli:*
The wastewater or effluent shall contain no typical (faecal) coli per 100 mℓ.

1.5 *Temperature:*
Shall be a maximum of 25°C.

1.6 *Chemical Oxygen Demand:*
Not to exceed 30 mg/ℓ after applying the chloride correction.

1.7 *Oxygen Absorbed:*
The oxygen absorbed from acid N/80 potassium permanganate in 4 h at 27°C shall not exceed 5 mg/ℓ.

1.8 *Conductivity:*
1.8.1 Not to be increased by more than 15 per cent above that of the intake water.
1.8.2 The conductivity of any water, wastewater or effluent seeping or draining from any area referred to in section 21 (6) of the aforementioned Water Act shall not exceed 250 mS/m (determined at 25°C).

1.9 *Suspended Solids:*
Not to exceed 10 mg/ℓ.

1.10 *Sodium Content:*
Not to be increased by more than 50 mg/ℓ above that of the intake water.

1.11 *Soap, Oil or Grease:*
None.

1.12 *Other Constituents:*
1.12.1 Constituents:

Constituents	Maximum concentration in milligrams per litre
Residual chlorine (as Cl)	Nil
Free and saline ammonia (as N)	1,0
Nitrates (as N)	1,5
Arsenic (as As)	0,1
Boron (as B)	0,5
Total chromium (as Cr)	0,05
Copper (as Cu)	0,02
Phenolic compounds (as phenol)	0,01
Lead (as Pb)	0,1
Soluble ortho phosphate (as P)	1,0
Iron (as Fe)	0,3
Manganese (as Mn)	0,1
Cyanides (as CN)	0,5
Sulphides (as S)	0,05
Fluoride (as F)	1,0
Zinc (as Zn)	0,3
Cadmium (as Cd)	0,05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05

1.12.2 The wastewater or effluent shall contain no other constituents in concentrations which are

*In terms of Government Notice No. R991 of 18 May, 1984. These requirements have been prescribed in terms of section 21(1)(a) of the Water Act (Act 54 of 1956) and supersede those prescribed in terms of Government Notice No. R553 of 5 April, 1962.
†"Use for industrial purposes" includes use for the purpose of waterborne sanitation.

poisonous or injurious to trout or other fish or other forms of aquatic life.

2. SPECIAL STANDARD FOR PHOSPHATE

Wastewater or effluent arising in the catchment area within which water is drained to any river specified in Schedule II or a tributary thereof at any place between the source thereof and the point mentioned in the schedule, in so far as such catchment area is situated within the territory of the Republic of South Africa shall not contain soluble ortho phosphate (as P) in a higher concentration than 1,0 mg/ℓ.

3. GENERAL STANDARD

Quality standards for wastewater or effluent arising in any area other than an area in which the SPECIAL STANDARD is applicable, as described in paragraph 1.

3.1 *Colour, Odour or Taste:*
The wastewater or effluent shall not contain any substance in a concentration capable of producing any colour, odour or taste.

3.2 *pH:*
Shall be between 5,5 and 9,5.

3.3 *Dissolved Oxygen:*
Shall be at least 75 per cent saturation.

3.4 *Typical (faecal) Coli:*
The wastewater or effluent shall not contain any typical (faecal) coli per 100 mℓ.

3.5 *Temperature:*
Shall be a maximum of 35°C.

3.6 *Chemical Oxygen Demand:*
Not to exceed 75 mg/ℓ after applying the chloride correction.

3.7 *Oxygen Absorbed:*
The oxygen absorbed from acid N/80 potassium permanganate in 4 h at 27°C shall not exceed 10 mg/ℓ.

3.8 *Conductivity:*
3.8.1 Not to be increased by more than 75 mS/m (determined at 25°C) above that of the intake water.
3.8.2 The conductivity of any water, wastewater or effluent seeping or draining from any area referred to in section 21 (6) of the aforementioned Water Act shall not exceed 250 mS/m (determined at 25°C).

3.9 *Suspended Solids:*
Not to exceed 25 mg/ℓ.

3.10 *Sodium Content:*
Not to be increased by more than 90 mg/ℓ above that of the intake water.

3.11 *Soap, Oil or Grease:*
Not to exceed 2,5 mg/ℓ.

3.12 *Other Constituents:*
3.12.1 Constituents:

Constituents	Maximum concentration in milligrams per litre
Residual chlorine (as Cl)	0,1
Free and saline ammonia (as N)	10,0
Arsenic (as As)	0,5
Boron (as B)	1,0
Hexavalent chromium (as Cr)	0,05
Total chromium (as Cr)	0,5
Copper (as Cu)	1,0
Phenolic compounds (as phenol)	0,1
Lead (as Pb)	0,1
Cyanides (as CN)	0,5
Sulphides (as S)	1,0
Fluoride (as F)	1,0
Zinc (as Zn)	5,0
Manganese (as Mn)	0,4
Cadmium (as Cd)	0,05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05

3.12.2 The sum of the concentrations of the following metals shall not exceed 1 mg/ℓ:Cadmium (as Cd), chromium (as Cr), copper (as Cu), mercury (as Hg) and lead (as Pb).
3.12.3 The wastewater or effluent shall contain no other constituents in concentrations which are poisonous or injurious to humans, animals, fish other than trout, or other forms of aquatic life, or which are deleterious to agricultural use.

4. METHODS OF TESTING

All tests shall be carried out in accordance with methods prescribed by and obtainable from the South African Bureau of Standards, referred to in the Standards Act, No. 30 of 1982, as listed in Schedule III.

Note

(a) Further information and elucidation may be obtained from the Director-General: Environment Affairs, Private Bag X313, Pretoria, 0001.
(b) Government Notices R. 553 of 5 April 1962, R. 969 of 22 June 1962 and R. 1567 of 1 August 1980 are hereby withdrawn.

SCHEDULE I

CATCHMENT AREAS WITHIN THE TERRITORY OF THE REPUBLIC OF SOUTH AFRICA IN WHICH WASTEWATER OR EFFLUENT MUST BE PURIFIED TO COMPLY WITH THE SPECIAL STANDARD

	Division or district
1. Hout Bay River to tidal water	Cape.
2. Eerste River to tidal water	Stellenbosch.
3. Lourens River to tidal water	Stellenbosch.
4. Steenbras River to tidal water	Caledon.
5. Berg and Dwars River to their confluence	Stellenbosch.
6. Little Berg River to Vogelvlei weir	Tulbagh.
7. Elands and Sonderend Rivers to their confluence	Caledon.
8. Witte River to confluence with Breede River	Paarl, Wellington, Worcester, Tulbach.
9. Dwars River to Ceres divisional boundary	Ceres.
10. Olifants River to the Ceres divisional boundary	Ceres.
11. Helsloot and Smalblaar (or Molenaars) Rivers to their confluence with Breede River	Paarl and Worcester.
12. Hex River to its confluence with Breede River	Ceres and Worcester.
13. Van Stadens River to tidal water	Port Elizabeth.
14. Buffalo River from the Ciskei border to where it enters the King William's Town municipal area	King William's Town.
15. Swart Kei and Klipplaat Rivers to their confluence	Tarka, Queenstown and Cathcart.
16. Bongola River to Bongola Dam	Queenstown.
17. Kubusie River to the Stutterheim municipal boundary	Stutterheim.
18. Langkloof and Kraai Rivers to their confluence	Barkly East.
19. Little Tsomo River to the Transkei border	St Marks.
20. Xuka River to the Elliot district boundary	Elliot.
21. Tsitsa and Inxu Rivers to their confluence	Maclear, Mount Fletcher, Tsolo and Qumbu.
22. Mvenyane and Umzimvubu Rivers to the Transkei border	Matatiele, Mount Currie and Mount Ayliff.
23. Umzimhlara River to the Transkei border	Mount Currie.
24. Ingwangwana River to its confluence with Umzimkulu River	Umzimkulu, Mount Currie, Polela and Underberg.
25. Umzimkulu and Polela Rivers to their confluence	Underberg and Polela.
26. Elands River to the Pietermaritzburg-Bulwer main road	Impendle.
27. Umtamvuma and Weza Rivers to their confluence	Bizana and Alfred.
28. Umkomaas and Isinga Rivers to their confluence	Impendle, Polela and Underberg.
29. Lurane River to its confluence with the Umkomaas River	Polela.
30. Sitnundjwana Spruit to its confluence with the Umkomaas River	Impendle.
31. Inudwini River to the Polela district boundary	Polela.
32. Inkonza River to the bridge on the Donnybrook-Creighton road	Polela and Ixopo.
33. Umlaas to the bridge on District Road 334 on the farm Maybole	Richmond.
34. Umgeni and Lions Rivers to their confluence	Impendle and Lions River.
35. Mooi River to the road bridge at Rosetta	Estcourt and Lions River.
36. Little Mooi and Hlatikula Rivers to their confluence	Estcourt.
37. Bushmans River to Wagendrift Dam	Estcourt.
38. Little Tugela River and Sterkspruit to their confluence	Estcourt.
39. M'Lambonjwa and Mhlawazeni Rivers to their confluence	Bergville.
40. Mnweni and Sandhlwana Rivers to their confluence	Bergville.
41. Tugela River to its confluence with the Kombe Spruit	Bergville.
42. Inyamvubu (or Mnyamvubu) River to Craigie Burn Dam	Umvoti.
43. Umvoti River to the bridge on the Seven Oaks-Rietvlei road	Umvoti.
44. Yarrow River to its confluence with the Karkloof River	Lions River.
45. Incandu and Ncibidwane Rivers to their confluence	Newcastle.
46. Ingogo River to its confluence with the Harte River	Newcastle.
47. Pivaan River to its confluence with Soetmelkspruit	Utrecht.
48. Slang River and the Wakkerstroom to their confluence	Utrecht and Wakkerstroom.

49.	Elands and Swartkops Rivers to their confluence	Belfast and Carolina.
50.	All tributaries of the Komati River between Nooitgedacht Dam and its confluence with and including Zevenfontein Spruit	Belfast and Carolina.
51.	Seekoeispruit to its confluence with Buffelspruit	Carolina.
52.	Crocodile River and Buffelskloofspruit to their confluence	Belfast and Lydenburg.
53.	All tributaries of the Steelpoort River down to its confluence with and including the Dwars River	Lydenburg, Belfast, Middelburg, Groblersdal.
54.	Potspruit to its confluence with the Waterval River	Lydenburg.
55.	Dorps River (or Spekboom River) to its confluence with the Marambanspruit	Lydenburg.
56.	Ohrigstad River to the Ohrigstad Dam	Lydenburg.
57.	Klein-Spekboom River to its confluence with the Spekboom River	Lydenburg.
58.	Blyde River to the Pilgrim's Rest municipal boundary	Pilgrim's Rest.
59.	Sabie River to the Sabie municipal boundary	Pilgrim's Rest.
60.	Nels River to the Pilgrim's Rest district boundary	Pilgrim's Rest.
61.	Houtbosloop River to the Lydenburg district boundary	Lydenburg and Pilgrim's Rest.
62.	Blinkwaterspruit to Longmere Dam	Nelspruit.
63.	All streams flowing into Ebenezer Dam on the Great Letaba River	Pietersburg and Letaba.
64.	Dokolewa River to its confluence with the Politzi River	Pietersburg and Letaba.
65.	Ramadiepa River to the Merensky Dam on the farm Westfalia 223, Letaba	Letaba.
66.	Pienaars River and tributaries up to Bophuthatswana Boundary	Pretoria, Cullinan and Warmbaths.

SCHEDULE II

CATCHMENT AREAS WITHIN THE TERRITORY OF THE REPUBLIC OF SOUTH AFRICA IN WHICH WASTEWATER OR EFFLUENT MUST BE PURIFIED TO CONTAIN NO SOLUBLE ORTHO PHOSPHATE (AS P) IN A HIGHER CONCENTRATION THAN 1,0 MILLIGRAM PER LITRE

(i) Vaal River upstream and inclusive of the Bloemhof Dam;
(ii) Pienaars and Crocodile Rivers upstream of their confluence;
(iii) Great Olifants River upstream and inclusive of the Loskop Dam;
(iv) Umgeni River upstream of the influence of tidal water;
(v) Umlaas River upstream of its point of discharge into the sea;
(vi) Buffels River upstream and inclusive of the Bridle Drift Dam;
(vii) Berg River upstream of the influence of tidal water.

SCHEDULE III

EFFLUENT ANALYSIS: SABS STANDARD TEST METHODS

	Reference number of SABS
Ammonia – free and saline	217
Arsenic	200
Bacteriological – faecal coliform, etc.	221
Boron	1 053
Cadmium	201
Calcium hardness	216
Chemical oxygen demand	1 048
Chloride	202
Chlorine – residual	1 052
Chromium – total	1 054
Chromium VI	206
Colour	198
Conductivity	1 057
Copper	203
Cyanide	204
Fluoride	205
Hardness – total	215
Iron	207
Lead	208
Magnesium	1 071
Manganese	209
Mercury	1 059
Nitrate plus nitrite	210
Nitrite	219
Oil and grease	1 051
Oxygen absorbed	220
Oxygen demand (chemical)	1 048
Oxygen dissolved	1 047
pH	11
Phenolic compound	211
Phosphate – ortho	1 055
Selenium	1 058
Sodium	1 050
Solids – suspended	1 049
Sulphate	212
Sulphide	1 056
Turbidity	197
Zinc	214

Appendix A.2 DEPARTMENT OF HEALTH GUIDE: PERMISSIBLE UTILIZATION AND DISPOSAL OF TREATED SEWAGE EFFLUENT

This guide sets out the present policy of the Department of Health. Any person intending to use treated effluent must obtain prior permission to do so from the Regional Director concerned.

This guide is applicable only to treated sewage effluent which is mainly of domestic origin and contains little or no industrial effluent.

The following matters are dealt with in this guide, viz. –

A. Classification of treated effluents.
B. Directives for the use of treated effluent for irrigation purposes.
C. Directives for other uses of treated effluents.
D. Methods of disposal and discharges of treated effluents.
E. General directives and precautionary measures.

(A) CLASSIFICATION OF TREATED EFFLUENTS (SEWAGE PURIFICATION WORKS)

PS – Primary and Secondary Treatment – Humus Tank Effluent

Conventional sewage purification according to accepted design criteria.* This includes screening and primary settling followed by biological purification such as the biological filter-bed process or activated sludge process. Secondary treatment also includes the settling or clarification after biological or alternative purification methods.

PST – Primary, Secondary and Tertiary Treatment

Final effluent complies with the GENERAL STANDARD,† with the E. coli *count relaxed to a maximum of 1 000* E. coli*/100 mℓ.*

In addition to the above-mentioned primary and secondary or equivalent treatment one or more tertiary treatments, viz. land treatment, maturation pond, filtration, chlorination or other types of disinfection, etc., should be applied.

STD – Primary, Secondary and Tertiary Treatment
(Compare with PST)

Final effluent complies with the GENERAL STANDARD,† viz. inter alia *NIL* E. coli*/100 mℓ.*

SP-STD – Advanced Purification

Final effluent complies with at least the SPECIAL STANDARD† and the quality compares favourably with that recommended for drinking water.

In addition to the above-mentioned primary, secondary and tertiary treatment, advanced purification also includes special physico-chemical purification or other advanced techniques.

OD – Oxidation Pond System

Final effluent contains a maximum of 1 000 E. coli*/100 mℓ.*

The pond system should be designed according to a recognized standard* and operated in a nuisance-free manner. The combined retention time of the primary pond and approximately 4 secondary ponds should usually be at least 45 days. This system should drain into an irrigation dam of which the reserve storage capacity during dry weather conditions is at least 12 days. Unless sufficient space is available and the ponds are sufficiently remote from built-up areas, this system is not recommended for communities with a population exceeding 5 000.

Every oxidation pond system which is *not* able to deliver effluent of the above-mentioned quality should, for the purpose of this guide, be regarded on its merits as no more than equivalent to PS.

Septic Tank Effluent
(Primary settling and limited biological purification)

This effluent must undergo further secondary and tertiary or equivalent treatment before it may be utilized for the purposes indicated in this guide.

For the direct use or disposal, only nuisance-free land treatment or irrigation of fenced-in plantations will be permitted on its merits.

*DESIGN CRITERIA
Design criteria such as those set out in *"A Guide to the Design of Sewage Purification Works"* of the Institute of Water Pollution Control (IWPC), Southern African Branch (November 1973).

†GENERAL AND SPECIAL STANDARD
Quality requirements for purified sewage effluent as laid down by the Department of Water Affairs – see Government Notice R553 in *Government Gazette Extraordinary* of April 1962, and any amendments thereto. (*E. coli* = typical or faecal coli.)

The above classification of treated sewage effluent types is used in the following tables

(B) DIRECTIVES FOR THE UTILIZATION OF TREATED EFFLUENT FOR IRRIGATION

Irrigation of	PS – Primary and Secondary	PST – Primary, Secondary and Tertiary	STD – General Standard	SP-STD – Advanced Purification	OD – Oxidation Pond System
1. Vegetables and crops consumed raw by man excluded					
Lawns at swimming pools, nursery schools, children's playgrounds	Not permissible	Not permissible	Not permissible	Any type of irrigation permissible	Not permissible
2. Crops for human consumption which are **not** eaten raw (vegetables, fruit, sugar-cane)	Not permissible	Any type of irrigation permissible	Any type of irrigation permissible	Any type of irrigation permissible	Any type of irrigation permissible on its merits
Cultivation of cut flowers (see also 6)		Effective draining and drying before harvesting is essential			Effective draining and drying before harvesting is essential
3. Fruit trees and vineyards for the cultivation of fruit which is eaten raw by man (see 2 – fruit which is not eaten raw)	Not permissible	Flood irrigation permissible Drip and micro-irrigation permissible on their merits provided fruits are not directly exposed to spray Effective draining and drying before harvesting Fallen fruit is unsuitable for human consumption	Any type of irrigation permissible	Any type of irrigation permissible	Flood, drip and micro-irrigation permissible on their merits provided fruits are not directly exposed to spray Effective draining and drying before fruits are harvested Fallen fruit is unsuitable for human consumption
4. Grazing for cattle excluding milk-producing animals (see 5)	Not permissible	Any type of irrigation permissible but not during grazing Grazing permissible only after effective draining and drying – no pools Not permissible as drinking water for animals	Any type of irrigation permissible Permissible as drinking water for animals	Any type of irrigation permissible Permissible as drinking water for animals	Any type of irrigation permissible but not during grazing Grazing permissible only after effective draining and drying – no pools Not permissible as drinking water for animals

Irrigation of	PS – Primary and Secondary	PST – Primary, Secondary and Tertiary	STD – General Standard	SP-STD – Advanced Purification	OD – Oxidation Pond System
5. Grazing for milk-producing animals [definition of milk – Section I(XV) of the Health Act 1977 (Act 63 of 1977)]	Not permissible	Not permissible	Any type of irrigation permissible Permissible as drinking water for animals	Any type of irrigation permissible Permissible as drinking water for animals	Not permissible
6. Crops not for grazing, but utilized as dry fodder Crops cultivated for seed purposes only Tree plantations Nurseries – cut flowers excluded (see 2) Any park or sportsfield only during development and before opening thereof	Any type of irrigation permissible on its merits No over-irrigation or pool forming No smell nuisance Properly fenced No public allowed No meat animals, milk-producing animals or poultry allowed	Any type of irrigation permissible (see also 4 and 5)	Any type of irrigation permissible	Any type of irrigation permissible	Any type of irrigation permissible on its merits (see also 4 and 5)
7. Parks and sportsfields (see 6) Lawns at swimming pool excluded (see 1)					
(i) Parks, only for beautifying flowerbeds, traffic islands etc. – i.e. not a recreation area	Only flood irrigation permissible No sprinkler irrigation permissible No public during irrigation	Flood irrigation permissible Sprinkler irrigation permissible on its merits No public during irrigation	Any type of irrigation permissible No public during irrigation	Any type of irrigation permissible	Flood irrigation permissible Sprinkler irrigation permissible on its merits No public during irrigation

Irrigation of	PS – Primary and Secondary	PST – Primary, Secondary and Tertiary	STD – General Standard	SP-STD – Advanced Purification	OD – Oxidation Pond System
7. (ii) Sportsfields where limited contact is made with the surface, e.g. golf courses, cricket, hockey and soccer fields, etc.	Not permissible	Any type of irrigation permissible No over-irrigation and no pool forming No public or players during irrigation Public and/or players admitted only after effective draining and drying	Any type of irrigation permissible No over-irrigation and no pool forming No public and/or players during irrigation	Any type of irrigation permissible	Flood irrigation permissible Sprinkler irrigation permissible on its merits No over-irrigation and no pool forming No public and/or players during irrigation Public and/or players admitted only after effective draining and drying
(iii) Sportsfields where contact is often made with the surface, e.g. rugby fields, athletics tracks, etc. Schoolgrounds Public parks – special children's playgrounds excluded (see 1)	Not permissible	Flood irrigation permissible Sprinkler irrigation permissible on its merits No over-irrigation and no pool forming No public or players during irrigation Public and/or players admitted only after effective draining and drying	Any type of irrigation permissible No over-irrigation and no pool forming No public or players during irrigation Public and/or players admitted only after effective draining and drying	Any type of irrigation permissible	Only flood irrigation permissible Sprinkler irrigation not permissible No over-irrigation and no pool forming No public or players during irrigation Public and/or players admitted only after effective draining and drying

IRRIGATION – GENERAL REMARKS AND PRECAUTIONS

(a) In order to obviate the irrigation system causing a nuisance in time, evidence must be produced that the type of soil and the size of the surface as well as the type of crop concerned are suitable for irrigation with the proposed quantity and quality of effluent.

(b) The piping used for effluent must be markedly different from the piping used for drinking water in respect of colour, type of material and construction. This precaution is necessary in order to obviate accidental cross-coupling of piping.

(c) In order to prevent persons from unwittingly drinking effluent water or washing with it, the taps, valves and sprayers of the irrigation system must be so designed that only authorized persons can open them or bring them into operation.

(d) Every water point where uninformed persons could possibly drink effluent water must be provided with a notice in clearly legible English, Afrikaans and appropriate languages of the indigenous Blacks indicating that it is potentially dangerous to drink the water.

(e) The expression "after effective draining and drying" in the above-mentioned table means that the particular act may take place only when no pools or drops of effluent are evident in the irrigation area concerned.

(f) All possible precautions should be taken to ensure that no surface or underground water is contaminated by the irrigation water, especially where the latter does not comply with the General Standard. Excessive irrigation must therefore be avoided and the irrigation area protected against stormwater by means of suitable contours and screening walls.

(g) Sprinkler irrigation shall be permitted only if **no** spray is blown over to areas where such irrigation is forbidden. In this connection the quality of the effluent, the use of such adjoining area and its distance from the irrigation area must be taken into consideration before sprinkler irrigation is permitted.

(C) DIRECTIVES FOR OTHER USES OF TREATED EFFLUENT

Other Uses of Effluents	PS – Primary and Secondary	PST – Primary, Secondary and Tertiary	STD – General Standard	SP-STD – Advanced Purification	OD – Oxidation Pond System
1. Industrial and sundry uses not mentioned in this guide	Permissible on merits in exeptional cases only	Each case will be treated on its merits The emphasis will be on the *E. coli* count In general the effluent must be free from parasitic ova, pathogenic organisms, toxic substances, etc.			Permissible on merits in exceptional cases only
2 .Food industry (also cooling water)	Not permissible	Not permissible	Not permissible	Not permissible	Not permissible
3. Mines and industries: ore treatment, dust control, etc.	Permissible on merits in exceptional cases only	Permissible on merits provided human contact is excluded	Permissible	Permissible	Permissible on merits in exceptional cases only
		All taps and water draw-off points in the effluent distribution system must be provided with clearly legible notices in English, Afrikaans and appropriate languages of the Blacks indicating that the water is **not** suitable for human consumption			
4. Human washing purposes	Not permissible	Not permissible	Not permissible	Permissible on merits Clearly legible notices must be displayed indicating that the water is **not** fit for human consumption or food preparation	Not permissible
5. Flush toilets	Not permissible	Permissible on merits In order to prevent the use of effluent for unauthorized purposes, no other draw-off bibcocks shall be affixed to effluent mains			Not permissible

Other Uses of Effluents	PS – Primary and Secondary	PST – Primary, Secondary and Tertiary	STD – General Standard	SP-STD – Advanced Purification	OD – Oxidation Pond System
6. Dust control on roads	Not permissible	Permissible Excessive spraying and pool forming must be avoided No surface or underground water may be polluted		Permissible	Not permissible
		No smell nuisance may be created Any direct human contact with the spray must be prevented as far as is practicable Steps must be taken to ensure that no effluent is used directly or indirectly for domestic purposes Containers used for the transportation of effluent must not be used thereafter for the transportation of drinking water before they have been effectively cleaned and disinfected			

General remarks: It is compulsory that the necessary precautionary measures be taken with each of the above-mentioned uses in order to prevent the use of the treated effluent for drinking or domestic purposes. In addition, it is also compulsory that the material and/or the colour of the effluent pipeline be such as to prevent accidental cross-coupling with drinking water pipelines. See also (b) under the heading "Irrigation – General Remarks and Precautions". (*vide ante*).

(D) METHODS OF DISPOSAL AND DISCHARGE OF TREATED EFFLUENT

Methods of Disposal and Discharge of Effluents	PS – Primary and Secondary	PST – Primary, Secondary and Tertiary	STD – General Standard	SP-STD – Advanced Purification	OD – Oxidation Pond System
1. Discharge into rivers and watercourses, excluding estuaries, dams and lagoons – (see 2)	Not permissible	Permissible on merits with due regard to local circumstances such as the dilution factor in the river or stream, rainfall, etc. The permissibility of discharge must be determined with due regard to the use of the river water downstream The discharge point must be determined with due regard to the position of water abstraction point(s) for domestic purposes lower down the river The effluent must contain no harmful substances in concentrations dangerous to health	Permissible, provided the effluent contains no harmful substances in concentrations dangerous to health	Permissible	Not permissible
2. Discharge into estuaries, dams, lakes, lagoons or other masses of water (sea excluded – see 3)	Not permissible	Permissible on merits if reasonable assurance exists that the quality and volume are such as not to cause nuisances or health hazards Once mixed with the effluent the water must not become less suitable for domestic use and/or recreation The effluent must contain no harmful substances in concentrations dangerous to health	Permissible, provided the effluent contains no harmful substances in concentrations dangerous to health	Permissible	Not permissible

Methods of Disposal and Discharge of Effluents	PS – Primary and Secondary	PST – Primary, Secondary and Tertiary	STD – General Standard	SP-STD – Advanced Purification	OD – Oxidation Pond System
3. Discharge into the sea	Only permissible beyond the surf zone The discharge point must be determined with due regard to the quality and volume of effluent, the sea currents, the distribution and dilution of effluents, and the proximity of present and future bathing areas		Permissible Discharge into the surf zone must be determined with due regard to the proximity of present and future bathing areas and the effect on the quality of sea-water in such area	Permissible	Permissible on merits as for PS and PST
	No coastal area may be polluted with effluents containing substances which are potentially dangerous or harmful to health The discharge of effluent must not cause any nuisance or have any effect on marine life which may adversely affect man directly or indirectly				
In most cases the influence of the above-mentioned discharges is not directly predictable. It would therefore usually be required that the necessary investigations be made to determine such influence with reasonable certainty.					

(E) GENERAL DIRECTIONS AND PRECAUTIONARY MEASURES

(a) The sewage purification works must be efficiently operated by adequately trained personnel at all times and must, as far as is reasonably practicable, not be overloaded.

(b) The person or authority in charge of the purification works must satisfy himself that the quality of the final effluent will at all times be in accordance with the directives as set out in this guide.

(c) Regular control tests of representative final effluent samples must be made at least quarterly and records must be kept of such tests.

(d) The person or authority in charge of the works must ensure that the quality of the final effluent and the use thereof comply with the directives set out in this guide – also when such effluent is utilized by another person or body. The supply and utilization of effluent must be terminated if the directives set out in this guide are not complied with.

(e) A person or body using the final sewage effluent for a purpose set out in this guide, but not undertaking the purification himself, must satisfy himself that only permissible utilization practices are maintained and must forthwith discontinue the use thereof should he become aware of any deviation from the directives contained in this guide.

(f) Compliance with the requirements for the utilization of purified sewage effluent as set out in this guide is the individual and joint responsibility of both the supplier and the user of the final effluent.

(g) In the case of a use qualified in this guide as permissible on merit, it will be necessary for the relevant uses and methods of use to be thoroughly motivated and investigated. In the majority of such cases, stricter supervision and control of the system as well as the quality of the effluent will be required in order to prevent the development of any nuisance or condition dangerous to health.

Appendix A.3 REGULATIONS FOR THE ERECTION, ENLARGEMENT, OPERATION AND REGISTRATION OF WATER CARE WORKS

DEPARTMENT OF WATER AFFAIRS

No. R. 2834 **27 December 1985**

REGULATIONS IN TERMS OF SECTION 26 READ IN CONJUNCTION WITH SECTION 12A OF THE WATER ACT, 1956 (ACT 54 OF 1956), FOR THE ERECTION, ENLARGEMENT, OPERATION AND REGISTRATION OF WATER CARE WORKS.

The Minister of Water Affairs has in terms of section 26, read in conjunction with section 12A of the Water Act, 1956 (Act 54 of 1956) made the regulations in the Annexure hereto.

ANNEXURE

1. DEFINITIONS

In these regulations, unless the context otherwise indicates, "the Act" means the Water Act, 1956 (Act 54 of 1956) and any expression to which a meaning has been assigned in the Act shall have the same meaning.

2. APPLICATION FOR REGISTRATION

(a) The owner of a water care working operation on the date of commencement of these regulations shall within 90 days of such date apply for the registration of such work.
(b) The owner of a water care work to be put into operation after the date of commencement of these regulations shall apply for the registration of such work before it is commissioned.
(c) An application for registration shall be directed to the Director-General on a form obtainable from him with the following information:
    (i) in respect of the work concerned, the particulars referred to in Schedule I or II, as the case may be; and
    (ii) in respect of each person (excluding an unskilled labourer) employed or to be employed for the operation of the said work, his full names, identity number or other proof of identity, date of birth and the qualifications and experience referred to in Schedule III.

3. APPLICATION FOR A PERMIT

Any person requiring a permit for the erection of enlargement of a water care work or for the alteration of any process applied in any water care work and referred to in Schedule I or II, as the case may be, in a manner which may affect the classification of such work in accordance with Schedule I or II, shall apply for such permit to the Director-General on a form obtainable from him and furnish the particulars in respect of the work concerned referred to in Schedule I or II.

4. REGISTRATION

The Director-General shall –
(a) classify in accordance with Schedule I or II, as the case may be, every water care work in respect of which the particulars under regulation 2 have been furnished to him and in accordance with Schedule III every person in respect of whom the particulars under regulation 2 or 6 have been furnished to him;
(b) keep a register of particulars of every water care work in respect of which registration or a permit has been granted in terms of section 12A(4)(a) of the Act and of every person classified in accordance with regulation 4(a);
(c) issue a certificate of registration in respect of each such work and such person; and
(d) set out in the certificate of registration of a water care work the conditions determined in terms of section 12A(4) of the Act in respect of such work.

5. DISPLAY OF REGISTRATION CERTIFICATE

The owner of any water care work shall display in a prominent place on that work a copy of the certificate of registration issued under regulation 4(c) in respect of such work and the names and classifications in terms of regulation 4(b) of all persons employed on such work.

6. NOTIFICATION OF EMPLOYMENT OR TERMINATION OF EMPLOYMENT

The owner of any water care work shall in writing

notify the Director-General during January of each year of the employment or termination of employment on such work during the past year of any person referred to in Schedule III, stating, in the case of the employment of such person, the information referred to in regulation 2(b) in respect of such person.

7. EMPLOYMENT OF PERSONS

The owner of a water care work shall, as from the date fixed in terms of section 12A(2) of the Act, employ for the operation of such work the minimum number of persons of the classes prescribed in Schedule IV in respect of the work concerned: provided that the Director-General may allow fewer persons or persons with lower educational qualifications to be employed for the operation of any particular water care work for the period and subject to the conditions determined by him, if he is of opinion that, in the particular circumstances, the attainment of the objectives of these regulations will not be frustrated by such employment.

SCHEDULE I

CLASSIFICATION OF WATER CARE WORKS USED FOR THE PURIFICATION OR TREATMENT OF WATER FOR HUMAN CONSUMPTION OR FOOD PROCESSING

Rating

Class of works	E	D	C	B	A
Range of points	14 – 21	22 – 40	41 – 59	60 – 78	79 – 92

Points to be awarded at the discretion of the Director-General in accordance with the following criteria:

		Maximum
Population supplied	Up to 1 000	0
	1 001 to 2 000	4
	2 001 to 5 000	7
	5 001 to 15 000	11
	15 001 to 50 000	14
	Over 50 000	17
Quality of intake water	Fair, with little or no variation	6
	Seasonal variation	9
	Monthly variation	12
	Daily variation	18
	Hourly variation	30
Process	(a) Pumping and/or chlorination	4
	(b) (a) plus filtration	12
	(c) (b) plus flocculation and sedimentation or clarification	20
	(d) (c) plus adjustments*	28
	(e) (a) or (b) or (c) or (d) plus special treatment†	36
Designed capacity (cubic metres per day)	Up to 500	1
	501 to 2 500	3
	2 501 to 7 500	5
	7 501 to 25 000	7
	Over 25 000	9

*Adjustments: e.g. removal of CO_2, pH, stability or corrosion control, disinfection, etc.
†Special treatment: e.g. reverse osmosis, activated carbon, softening, demineralizing, fluoridation, etc.

SCHEDULE II

CLASSIFICATION OF WATER CARE WORKS USED FOR THE PURIFICATION, TREATMENT OR DISPOSAL OF EFFLUENT OR SEWAGE

Rating

Class of works	E	D	C	B	A
Range of points	5 – 9	10 – 19	20 – 29	30 – 39	40 – 68

Points to be awarded at the discretion of the Director-General in accordance with the following criteria:

		Maximum
Design capacity (megalitres per day)	Up to 1	1
	1 plus to 5	3
	5 plus to 20	7
	20 plus to 100	12
	Over 100	15
Concentration of raw effluent or sewage, as COD	Less than 700 mg/P	1
	700 mg/P and over	3
Process	Preliminary treatment with more than one mechanical item	2
	Primary sedimentation	2
	Anaerobic digestion	2
	Sludge drying beds	1
	Gas utilization (gasholder, boiler, etc.)	3
	Oxidation ponds (not tertiary use)	1
	Biofilters (Biof) or biodiscs	2
	Activated sludge (AS) – any form	6
	Tertiary treatment (e.g. sand filters)	4
	Maturation ponds	2
	Chlorination	3
	Mechanical or physical/chemical sludge treatment including stabilization and/or dewatering	5
	Nutrient removal (extra to AS or Biof)	3
	Complicating factors (gas engines, air filtration, etc.)	5
Sensitivity of water into which purified or treated effluent is discharged	Low – e.g. ocean or evaporation pond	1
	Medium – e.g. where the General Standard prescribed under section 21(1)(a) of the Act is applicable or the ocean near a swimming beach	4
	High – e.g. where the Special Standard prescribed under section 21(1)(a) of the Act is applicable or a trout stream or upstream of a potable water supply	8
Other factors which make the operation more or less complex		5 to –5

SCHEDULE III

CLASSIFICATION OF PERSONS (EXCLUDING UNSKILLED LABOURERS) ACCORDING TO EDUCATIONAL QUALIFICATIONS AND EXPERIENCE TO BE EMPLOYED FOR THE OPERATION OF WATER CARE WORKS

Minimum Requirements

Educational	Years Appropriate Experience					
	Class Trainee	I	II	III	IV	V
Std 6	0	—	—	—	—	—
Std 6 plus Maintenance Workers Certificate	0	4	—	—	—	—
Std 7 plus Maintenance Workers Certificate	0	3	—	—	—	—
Std 8 (or NTC I) plus Maintenance Workers Certificate Std 8 (or NTC I) plus Water and Wastewater Treatment Practice N1	0	2	5	—	—	—
NTC I in Water and Wastewater Treatment Practice	0	1½	4	—	—	—
Std 8 (or NTC I) plus Operators Certificate	0	1	3	9	—	—
Std 9 (or NTC II) plus Operators Certificate NTC II in Water and Wastewater Treatment Practice	0	½	2	7	15	—
Matric (or NTC III) plus Operators Certificate Matric (or NTC III) plus Water Treatment Practice N3 Matric (or NTC III) plus Wastewater Treatment Practice N3 NTC III in Water Treatment Practice NTC III in Wastewater Treatment Practice		0	½	3	8	15
National Diploma or National Techn. Diploma or NTC VI or 3 years B.Sc. (All in appropriate field)				0	2	6
Higher National Diploma or 4 years B.Sc. (Both in appropriate field)					0	4
Professional Engineer (Act 81 of 1968) in appropriate field, Natural Scientist (Act 55 of 1982) in appropriate field, Corporate Member of IWPC					0	3

Apprentices are regarded as equivalent to Std 8 or NTC I.
Artisans are regarded as equivalent to Matric or NTC III.

SCHEDULE IV

MINIMUM NUMBER OF PERSONS TO BE EMPLOYED FOR THE OPERATION OF A WATER CARE WORK

Work Class	Class and Number of Persons as Operators	Class of Person as Supervisor	Class of Person for Weekly Inspection*
E	1 × Trainee	I	II
D	1 × Trainee 1 × I 1 × I	II II	III III
C	1 × Trainee 2 × I 1 × II	III	IV
B	1 × Trainee 2 × I 1 × II 1 × III	IV	V
A	1 × Trainee 2 × I 1 × II 1 × III 1 × IV	V	—

Note: These are the minimum requirements for the *operation* of the various classes of works and do not include maintenance or laboratory personnel.

*If the owner of a water care work has no person of this class employed on that work, he shall appoint a consultant with the required qualifications as prescribed in Schedule III in respect of that particular class of person, to visit the work weekly.

Appendix A.4 RAINFALL AND EVAPORATION TABLES

The Department of Water Affairs and the Weather Bureau have numerous rainfall and evaporation stations situated throughout South Africa.

Evaporation is measured by means of a Symons tank or an A-pan/tank.

Gross Evaporation is the total evaporation, i.e. all the water which leaves the water body by the process of evaporation. Nett Evaporation is the total evaporation minus precipitation (rainfall).

Disposal of Effluent by Irrigation or by Evaporation in Ponds

Where wastewater or purified effluent is to be disposed of by irrigation or by evaporation in ponds, sufficient information on rainfall and evaporation in the specific area is required to determine whether the ponds will have sufficient evaporation capacity to prevent overflow or whether the irrigation areas are large enough to prevent runoff as a result of over-irrigation.

This document* provides such information. All the rainfall and evaporation figures given are annual averages. These were derived from rain-gauge and evaporimeter observations at the stations indicated over a sufficient number of years and are not likely to change significantly over an extended period of observation.

Two different types of evaporimeter tanks/pans have been used to determine evaporation, viz. the "A" tank and the "Symons" tank. Wherever possible values obtained by the "Symons" tank should be used since it is considered that evaporation in such tank is more closely related to actuality. Only the values given in the column with the heading "RESERVOIR m³/ha × year NET EVAP." should be used in assessing the adequacy of a pond system or irrigation area. Attention is drawn to the fact that a correction has been made to the figures in the column "mm/year GROSS EVAP." in order to obtain the more representative figures given in the column "RESERVOIR m³/ha × year NET EVAP.".

NB: It should be borne in mind that these evaporation figures are representative for normal (average) quality surface waters only and that wastewaters may contain salts, organics or other pollutants having surface active properties affecting evaporation thus resulting in much lower evaporation rates.

*Compiled by Mrs M P de Oliveira.

1975

PLACE	Station Ref. No.	Latitude	Longitude	SYMONS TANK			RESERVOIR m³/ha × year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
A: LIMPOPO RIVER								
Albasini Dam	A9E02	23° 06′	30° 17′	864	1 488	624	2 594	—
Bierspruit Dam	A2E12	24 54½	27 09	523	2 014	1 491	9 976	1969 – 70
Buffelspoort Dam	A2E05	25 47	27 29	743	1 742	999	5 722	—
Combro	A7E07	23 22	29 14	444	1 862	1 418	9 618	—
Doorndraai Dam	A6E01	24 17	28 46½	642	1 746	1 104	6 762	—
Du Toits Kraal	A6E05	24 34	28 46	644	1 662	1 018	6 108	—
Glen Alpine Dam	A6E04	23 12	28 42	472	2 282	1 810	12 509	—
Hartbeespoort Dam	A2E01	25 43¾	27 52	691	1 660	969	5 623	—
Jan Smuts Airport	A2E09	26 08	28 14	693	1 766	1 073	6 403	1965 – 66
Klein-Marico Dam	A3E03	25 31¼	26 08¾	665	1 989	1 324	8 367	—

PLACE	Station Ref. No.	Latitude	Longitude	SYMONS TANK			RESERVOIR $m^3/ha \times year$ NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Klipvoor Dam	A2E19	25 08	27 48½	755	1 975	1 220	7 361	—
Kosterrivier Dam	A2E15	25 42	26 54	716	1 811	1 095	6 513	—
Kroondal	A2E08	25 43	27 19	688	1 653	965	5 600	—
Lindley's Poort Dam	A2E04	25 29	26 41¼	673	1 848	1 175	7 222	—
Luphephe Dam	A8E02	22 38½	30 24½	290	2 308	2 018	14 525	1968 – 69
Macuville	A7E06	22 16	29 53	314	2 161	1 847	13 176	—
Marico Bosveld Dam	A3E01	25 27¾	26 23½	662	1 810	1 148	7 046	—
Njhelele Dam	A8E01	22 43¼	30 05½	577	2 831	2 254	15 604	1947 – 48
Pietersburg	A7E03	23 52	29 27	467	1 980	1 513	10 279	—
Pretoria University	A2E03	25 45	28 16	706	1 493	787	4 212	—
Rietvlei Dam	A2E02	25 52½	28 15¾	719	1 574	855	4 694	—
Roodeplaat	A2E07	25 37¼	28 32¾	667	1 748	1 081	6 527	—
Roodeplaat Dam	A2E13	25 37¼	28 22¾	668	1 776	1 088	6 729	—
Rustenburg Nature Reserve	A2E22	25 43	27 11¼	765	1 584	819	4 309	—
Rustenburg Platinum Mines	A2E21	—	—	717	1 573	856	4 706	—
Tshipise	A8E03	22 36½	30 09	336	2 432	2 096	1 500	—
Vaalkop Dam	A2E20	25 18½	27 28	665	2 023	1 358	8 624	—
Vaalwater	A4E01	24 17	28 06	597	1 687	1 090	6 767	—
Vischgat Dam	A5E02	23 37¾	28 09¼	555	2 285	1 730	11 702	—
Warmbad Dam	A2E06	24 51½	28 14¾	635	1 729	1 157	6 704	—
B: OLIFANTS RIVER								
Bronkhorstspruit Dam	B2E01	25 53¼	29 18	744	1 547	803	5 153	—
Buffelskloof Dam	B3E03	24 52½	30 16	708	1 853	1 145	8 003	—
Ebenezer Dam	B8E01	23 56½	29 59¼	1 136	1 418	282	183	—
Klaserie Dam	B7E03	24 31½	31 04	611	1 781	1 170	8 387	—
Klavervalley	B5E03	24 37	29 01	540	1 912	1 372	10 164	1970 – 71
Letsitele	B8E02	23 52	30 25¾	619	1 969	1 350	9 838	1970 – 71
Loskop Dam	B3E03	25 25¼	29 21½	669	1 888	1 219	8 678	—
Lydenburg	B4E01	25 06	30 28	721	1 428	707	4 414	—
Nuwe Doringpoort Dam	B1E01	25 53¼	29 18	629	1 740	1 111	7 874	1967 – 69
Ohrigstad Dam	B6E01	24 55	30 37	656	1 628	972	6 692	—
Roossenekal	B4E04	25 12	29 55½	815	1 711	896	5 778	—
Rust De Winter Dam	B3E04	25 13¼	28 31	678	1 979	1 301	9 329	1970 – 71
Shingwidzi	B9E01	23 06½	31 26¼	389	1 946	1 557	11 950	1970 – 71
Tonteldoos Dam	B4E02	25 16½	29 56½	711	1 717	1 006	6 866	1970 – 71
Tzaneen Dam	B8E03	23 48	30 10	1 037	1 389	352	936	—
Zebediela	B5E01	24 19	29 19	624	2 037	1 413	10 341	—
C: VAAL RIVER								
Allemanskraal Dam	C4E08	28° 17½′	27° 09′	569	1 808	1 239	9 570	—
Balkfontein	C2E10	27 24	26 30½	639	1 901	1 262	9 654	—
Barberspan (Scholtzrust)	C3E01	26 35	25 33	551	1 813	1 262	9 792	1969 – 70
Barberspan (Bird Research Station)	C3E03	26 34	25 35	462	2 134	1 672	13 391	1968 – 69
Bethlehem	C8E03	28 10	28 18	661	1 523	862	6 244	1970 – 71

PLACE	Station Ref. No.	Latitude	Longitude	SYMONS TANK			RESERVOIR m³/ha × year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Bloemhof Dam	C9E04	27 40½	25 37¾	562	2 123	1 561	12 298	—
Boskop Dam	C2E09	26 33¾	27 06½	610	1 790	1 180	9 008	—
Erfenis Dam	C4E02	28 30½	26 46½	535	2 039	1 504	11 859	—
Ermelo	C1E02	26 26	29 54	763	1 548	785	5 435	—
Geduld Demineralization Plant	C4E05	27 56	26 41½	509	2 182	1 673	13 326	1971 – 72
Harrismith Waterworks	C8E06	28 17	29 09½	679	1 659	980	7 212	—
J.B.M. Hertzog Airport	C5E08	29 06	26 18	569	1 840	1 271	9 840	—
Kafferrivier Dam	C5E01	29 25¼	26 08	526	1 709	1 183	9 164	—
Kalkfontein Dam	C5E02	29 29¾	25 13¼	424	1 866	1 442	11 509	—
Kestell	C8E07	28 19	28 42	682	1 637	955	6 996	—
Kimberley	C5E07	28 48	24 46	433	2 171	1 738	13 993	—
Koppies Dam	C7E01	27 15½	27 40½	593	1 969	1 376	10 688	—
Makwassie	C2E03	27 19	26 00	547	1 906	1 359	10 617	1969 – 70
Mazelspoort	C5E03	29 01¼	26 24	579	1 603	1 024	7 739	—
*Oog van Wonderfontein	C2E08	26 17¾	27 29¾	603	1 755	1 152	8 782	1969 – 70
Potchefstroom	C2E04	26 44	27 05	637	1 642	1 005	7 488	—
Rustfontein Dam	C5E04	29 16¼	26 36¾	510	1 696	1 186	9 214	—
St. Claire	C9E05	29 02¼	23 50¼	455	2 203	1 478	14 043	—
Sterkfontein Dam	C8E08	28 23¼	29 01	740	1 814	1 074	7 910	—
Vaal Dam	C1E01	26 53	28 07	694	1 716	1 022	7 543	—
Vaalharts Dam	C9E03	28 06½	24 56½	452	1 990	1 538	12 276	1970 – 71
Vaalriver Barrage	C2E01	26 46	27 41	685	1 433	748	5 245	—
Vliegekraal	C2E12	27 29¾	26 03¾	588	1 918	1 330	10 308	—
Zuurbekom	C2E07	26 18	27 48¾	658	1 511	853	6 173	—
D: ORANGE RIVER								
Alexander Bay	D8E03	28 34	16 32	42	2 066	2 024	17 485	1969 – 70
Aliwal North	D1E01	30 41	26 43	550	1 634	1 084	8 661	—
Boegoeberg Dam	D7E01	29 02¼	22 12¼	228	2 357	2 129	18 147	—
Brandvlei	D5E07	30 29½	20 30	196	2 634	2 438	20 868	1973 – 74
Carnarvon	D5E02	30 58	22 08	204	2 477	2 273	19 427	1972 – 73
Dordrecht	D1E03	31 22	27 03	622	1 601	979	7 655	—
Hendrik Verwoerd Dam	D3E01	30 37½	25 30¼	409	2 150	1 741	14 543	—
Hobhouse	D2E06	29 31	27 09	645	1 666	1 021	7 989	—
Kakamas	D7E02	28 46½	20 36½	139	2 717	2 578	22 157	1973 – 74
Molteno	D1E02	31 23	26 22	436	1 620	1 184	9 680	1973 – 74
Olifantshoek Dam	D4E02	27 57	22 44	323	2 136	1 813	15 282	1970 – 71
Orange Fish Tunnel	D3E02	30° 41′	25° 46′	362	2 218	1 856	15 603	1972 – 73
Oxbow Lake (Lesotho)	D1E04	28 46	28 36½	1 310	1 184	(– 126)	– 2 839	1969 – 70
P.K. le Roux Dam	D3E03	29 59¼	24 44	341	2 647	2 306	19 530	1970 – 71
Rietfontein	D4E01	26 44¼	20 02	174	2 906	2 732	23 445	—
Sakrivier Estates	D5E01	30 51	20 26	113	2 141	2 028	17 425	1969 – 70
Smartt Syndicate	D6E01	30 36¾	23 18½	252	2 305	2 053	17 457	—
*Oog van Wonderfontein	C2E11	26 18	27 28¾	722	1 618	896	6 436	1970 – 71

PLACE	Station Ref. No.	Latitude	Longitude	SYMONS TANK			RESERVOIR $m^3/ha \times year$ NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Sutherland	D5E03	32 24	20 40	282	1 811	1 529	12 875	—
Upington	D7E03	28 24	21 16	156	2 740	2 584	22 186	1969 – 70
Victoria West	D6E02	31 24	23 06¼	239	2 222	1 983	16 867	1969 – 70
Vioolsdrif	D8E01	28 47	17 40½	37	2 469	2 432	21 028	1972 – 73
Welbedacht	D2E07	29 54½	26 51½	590	1 913	1 323	10 679	1971 – 72
E: OLIFANTS RIVER (WESTERN CAPE)								
Vredendal	E3E02	31 41	18 29	141	1 721	1 580	14 179	—
F: NAMAKWALAND								
Grootmis	F3E03	29 38½	17 15	73	1 997	1 924	17 359	1970 – 71
Kamieskroon	F3E02	30 12⅓	17 56	159	2 268	2 109	18 953	1969 – 70
G: SOUTH-WESTERN CAPE								
Bien Donne	G1E04	33 50½	18 59	753	1 564	811	6 637	—
Bredasdorp	G5E01	34 32	20 02	460	1 472	1 012	8 734	1969 – 70
D.F. Malan (Airport)	G2E07	33 58	18 36	495	1 668	1 173	10 159	—
Elsenburg	G2E06	33 51	18 50	581	1 493	912	7 714	1973 – 74
Jonkershoek For. Res. (Biesievlei)	G2E11	33 59	18 57	1 160	1 341	181	547	—
Jonkershoek For. Res. (Manor House)	G2E13	33 58	18 56	966	1 280	314	1 935	1973 – 74
Jonkershoek For. Res. (Swartbrug)	G2E12	33 58	18 56	1 077	1 336	259	1 332	1973 – 74
Lamberts Bay	G3E01	32 05	18 18	182	1 540	1 358	12 130	1972 – 73
Lamberts Bay Norlier Proefplaas	G3E03	32 05	18 18	263	1 993	1 730	15 423	1973 – 74
Langebaan Phosphate Works (Amcor)	G1E05	32 57¼	18 06¾	268	1 898	1 630	14 513	1969 – 70
Lebanon	G4E03	34 09	19 08	804	1 398	594	4 624	1969 – 70
Molteno Reservoir (Cape Town)	G2E03	33 56¼	18 24¾	819	1 457	638	5 008	1973 – 74
Newlands	G2E05	33 58	18 27	1 529	1 280	(– 249)	– 3 695	—
Seekoeivlei	G2E14	34 05½	18 31	461	1 566	1 105	9 575	1970 – 71
Steenbras Dam	G4E01	34 11¼	18 51¼	999	1 450	451	3 145	—
Table Mountain	G2E04	33 58¾	18 24¼	1 544	991	(– 553)	– 6 463	1969 – 70
Voëlvlei Dam	G1E02	33 20½	19 02½	476	2 344	1 868	16 473	—
Wellington	G1E01	33 39	19 01	686	1 595	909	7 588	1969 – 70
Wemmershoek Dam	G1E03	33 50	19 05	814	1 526	712	5 683	1973 – 74
H: BREË RIVER								
Brandvlei Dam	H1E01	33° 42¼′	19° 27′	294	1 612	1 318	11 662	1970 – 71
Buffeljags Dam	H7E02	34 01¼	20 32	370	846	476	3 963	1968 – 69
Keisies Valley	H3E01	33 42	20 00	227	1 681	1 454	12 957	—
Robertson	H4E01	33 50	19 54	263	1 399	1 136	10 043	1973 – 74

PLACE	Station Ref. No.	Latitude	Longitude	SYMONS TANK			RESERVOIR $m^3/ha \times year$ NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
J: GOURITS RIVER								
Beaufort West Reservoir	J2E04	32 21	22 34½	198	2 467	2 269	20 202	1972 – 73
Floriskraal Dam	J1E03	33 17½	20 59½	143	2 140	1 997	17 812	—
Gamkapoort Dam	J2E06	33 18	21 38½	173	2 669	2 496	22 269	1972 – 73
Kammanassie Dam	J3E01	33 39¼	22 24	220	1 718	1 498	13 248	1971 – 72
Leeugamka Dam	J2E02	32 37¾	22 00½	150	2 345	2 195	19 585	1973 – 74
Stompdrift Dam	J3E03	33 30¾	22 35¼	253	2 056	1 803	15 957	1972 – 73
K: OUTENIQUA								
George	K3E01	33 58	22 25	807	1 089	282	1 087	1971 – 72
Hartebeestkuil Dam	K1E01	34 06	22 01	439	1 437	998	7 693	1973 – 74
Outeniqua (George)	K3E02	33 58¾	22 25¼	630	1 214	584	3 908	1973 – 74
Kromrivier Dam	K9E01	34 00	24 29½	713	1 394	681	4 591	—
L: GAMTOOS RIVER								
Beervlei Dam	L3E01	33 04½	23 29½	180	2 178	1 998	16 513	—
Langkloof	L8E02	33 46½	23 35¼	607	1 367	760	5 424	1972 – 73
Paul Sauer Dam	L8E01	33 45	24 35¼	426	1 272	846	6 435	1973 – 74
M: ALGOA								
Port Elizabeth Airport	M2E01	33 59	25 36	621	1 601	980	7 252	1969 – 70
N: SONDAGS RIVER								
Addo Citrus Res. Stn.	N4E01	33 34	25 42	402	1 412	1 010	8 018	1973 – 74
Mentz Dam	N2E01	33 12¾	25 09	243	1 729	1 486	12 310	1972 – 73
Van Ryneveldspas Dam	N1E01	33 14¼	24 31¾	322	1 994	1 672	13 779	—
P: BOESMANS RIVER								
Howisons Poort Dam	P3E01	33 23¼	26 29¼	613	1 281	668	4 684	—
Q: GROOT VIS RIVER								
Grassridge Dam (Cradock)	Q1E01	31 45½	25 28	283	1 992	1 709	16 027	1972 – 73
Grootfontein	Q1E02	31 29	25 02	349	2 079	1 730	16 191	1973 – 74
Lake Arthur	Q4E01	32 13½	25 49¼	287	1 803	1 516	14 198	1970 – 71
R: AMATOLA								
East London Airport	R4E01	33 02	27 50	908	1 371	463	1 499	1973 – 74
Fort Murray (Laing Dam)	R2E02	32 58¼	27 29¾	642	1 488	846	5 062	1971 – 72
Keiskamahoek	R1E01	32 41	27 09	642	1 334	692	3 874	1969 – 70
Nahoon Dam	R3E01	32 54¼	27 48½	721	1 358	637	3 268	1973 – 74
Rooikrans Dam	R2E03	32 45¼	27 19½	799	1 373	574	2 604	—

PLACE	Station Ref. No.	Latitude	Longitude	SYMONS TANK			RESER-VOIR $m^3/ha \times year$ NET EVAP.	Last Year of Observa-tion
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
S: GROOT KEI RIVER								
Dohne	S6E01	32° 31′	27° 28′	743	1 405	662	3 412	1973 – 74
Doorn River Dam	S2E02	31 30¾	27 19¾	676	1 690	1 014	6 281	—
Kubu Dam	S6E02	32 36½	27 17	932	1 503	571	2 278	1969 – 70
Kubisi Dam	S2E01	31 47¾	27 25¾	581	1 898	1 317	8 836	1973 – 74
Water Down Dam	S3E01	32 17¼	26 51½	481	1 566	1 085	7 274	1973 – 74
T: TRANSKEI								
Gilbert Eyles Dam	T5E01	30 43	30 09½	665	1 150	485	2 224	—
Matatiele	T3E01	30 20	28 48	706	1 570	864	5 055	1973 – 74
Umtata Owen Dam	T2E01	31 34¼	28 46	640	1 215	575	2 976	1969 – 70
U: SOUTHERN NATAL								
Albert Falls	U2E06	29 05¾	30 25½	861	1 316	455	1 545	—
Cedara	U2E02	29 32	30 17	845	1 198	353	794	1969 – 70
Chaka's Kraal	U3E03	29 27	31 12	963	1 326	363	602	—
Illovo Sugar Estates	U7E01	30 05¾	30 49½	1 009	1 575	566	2 064	1973 – 74
Louis Botha Airport (Durban)	U6E03	29 58	30 57	999	1 405	406	852	1973 – 74
Midmar Dam	U2E03	29 30	30 12	899	1 375	476	1 620	—
Mount Edgecombe	U3E01	29 42	31 03	940	1 259	319	315	1969 – 70
Nagle Dam	U2E04	29 35	30 37	774	1 122	348	918	1972 – 73
Nshongweni Dam	U6E02	29 52	30 44	748	1 027	279	445	1972 – 73
Umbogintwini	U6E01	30 01	30 54	1 001	1 265	264	– 249	1973 – 74
Windy Hill	U2E05	29 31	30 33	989	1 168	179	– 877	1972 – 73
V: TUGELA								
Cathedral Peak	V1E02	28 59	29 14	1 328	1 320	(– 8)	– 3 094	1973 – 74
Chelmsford Dam	V3E03	27 57¼	29 57	784	1 708	924	5 340	1968 – 69
Colenso	V1E01	28 44	29 50	718	1 575	857	4 974	—
Craigieburn Dam	V2E02	29 08	30 17	765	1 542	777	4 249	1969 – 70
Estcourt	V7E01	29 01	29 52	656	1 459	803	4 699	1971 – 72
Spioenkop	V1E06	28 40¾	29 31	541	1 695	1 154	7 670	1969 – 70
Van Reenen	V1E05	28 29¾	29 23	1 075	1 470	395	593	1969 – 70
Wagendrift Dam	V7E03	29 02¼	29 51½	951	1 775	824	4 187	—
W: ZULULAND								
Charter's Creek	W3E01	28 12	32 25	986	1 433	447	1 198	—
Hluhluwe Dam	W3E03	28 07	32 11	638	1 712	1 074	6 831	1970 – 71
Jericho Dam	W5E04	26 39	30 29	1 076	1 518	442	954	—
J.G. Strijdom Dam	W4E03	27 25	32 03¼	607	1 653	1 046	6 686	1967 – 68
Lake Sibaya	W7E02	27 22½	32 43	1 130	1 454	324	– 80	1973 – 74
Lister Point – False Bay Park	W3E02	27 58	32 23	507	1 529	1 022	6 729	1969 – 70
Malkerns Swaziland	W5E03	26 23	31 10	959	1 388	429	1 120	1973 – 74

PLACE	Station Ref. No.	Latitude	Longitude	SYMONS TANK			RESERVOIR m³/ha × year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Mbazwana	W7E01	27 28½	32 36	885	1 449	564	2 331	1969 – 70
Mtunzini	W1E01	28 57	32 17	1 364	1 861	497	721	—
Piet Retief	W5E01	27 00	30 48	905	1 271	366	758	1972 – 73
Pongola	W4E02	28° 27′	32° 17′	597	1 498	901	5 589	1973 – 74
Richards Bay	W1E02	—	—	338	475	137	285	1969 – 70
Vryheid	W2E01	27 46	30 47	875	1 461	586	2 524	1969 – 70
Westoe Dam	W5E05	26 30½	30 37¼	1 017	1 663	646	2 663	—
X: KOMATI								
Da Gama Dam	X3E04	—	—	1 449	1 387	(– 62)	– 3 787	—
Friedenheim (Nelspruit)	X2E11	25 26	30 59	913	1 660	747	3 680	—
Kafferkraal Dam	X1E06	25 53	30 36¼	909	1 690	781	3 951	1970 – 71
Lomati (Kaalrug)	X1E05	25 38	31 33	943	1 675	732	3 495	1970 – 71
Mhlati	X2E05	25 29	31 34	512	1 693	1 181	7 944	1970 – 71
Nelspruit	X2E01	25 27	30 58	808	1 385	577	2 607	1971 – 72
Nooitgedacht Dam	X1E03	25 57	30 04¾	755	1 836	1 081	6 618	1973 – 74
Primkop Dam	X2E12	23 33¼	31 04½	895	1 609	714	3 466	1973 – 74
Satara	X4E01	24 23¾	31 47	376	1 918	1 539	11 040	—
Shiyalongubu Dam	X1E04	25 45½	31 16	1 131	1 304	1 173	– 1 248	1969 – 70
Skukuza	X3E01	24 59	31 36	517	1 607	1 090	7 231	1968 – 69
Uitzoek	X2E06	—	—	1 092	1 484	392	531	1973 – 74
Witklip Dam	X2E10	25 16	30 55	1 319	1 275	(– 44)	– 3 351	—

1975

PLACE	Station Ref. No.	Latitude	Longitude	A TANK			RESERVOIR m³/ha × year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
A: LIMPOPO RIVER								
Bierspruit Dam	A2E12	24° 54½′	27° 09′	550	2 602	2 052	9 722	1969 – 70
Groendraai	A4E02	24 11½	27 57¾	525	2 325	1 800	8 351	1969 – 70
Hartbeespoort Dam	A2E01	25 43¾	27 52	714	2 103	1 389	5 163	1968 – 69
Jan Smuts Airport	A2E09	26 08	28 14	706	2 260	1 554	6 161	1973 – 74
Kosterrivier Dam	A2E15	25 42	26 54	715	2 184	1 469	5 626	—
Levubu	A9E03	23 05	30 17	921	1 957	1 036	2 238	1973 – 74
Louis Trichardt Reservoir	A7E04	22 20	30 03	590	2 117	1 527	6 484	1972 – 73
Macuville	A7E06	22 16	29 54	294	2 806	2 512	13 475	1972 – 73
Mara	A7E05	23 09	29 34	424	2 136	1 712	8 256	1973 – 74
Marico Bosveld Dam	A3E01	25 27¾	26 23½	683	2 242	1 559	6 286	—
Marnitz	A5E01	23 10	28 13	408	2 495	2 087	10 516	1973 – 74
Periurban	A2E16	25 45	28 16	634	2 430	1 796	7 876	1971 – 72
Pierans River	A2E23	25 20¼	18 19½	728	2 209	1 481	5 643	—

PLACE	Station Ref. No.	Latitude	Longitude	A TANK			RESERVOIR m³/ha × year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Pietersburg	A7E03	23 52	29 27	448	2 469	2 021	9 964	1973 – 74
Potgietersrus	A6E02	24 11	20 01	566	2 175	1 609	7 064	1973 – 74
Pretoria University	A2E03	25 45	28 16	760	2 025	1 265	4 246	—
Rietondale Proefplaas	A2E18	25 45	28 16	701	2 273	1 572	6 287	1969 – 70
Roodeplaat	A2E07	25 37¼	28 22¾	655	2 347	1 692	7 180	1973 – 74
Roodeplaat Dam	A2E13	25 37¼	28 22¾	736	2 208	1 472	5 557	—
Rustenburg	A2E08	25 43	27 19	657	2 111	1 454	5 779	1972 – 73
Rustenburg	A2E21	±24 56	±27 09	717	1 987	1 270	4 454	—
Sterk Rivier Proefplaas	A6E03	24 10	28 43	612	2 234	1 622	6 949	1969 – 70
Towoomba	A2E14	24 54	28 20	613	2 287	1 674	7 249	1973 – 74
Vaalwater	A4E01	24 17	28 06	581	2 085	1 504	6 387	—
B: OLIFANTS RIVER (TRANSVAAL)								
Doornhoek Tzaneen	B8E02	—	—	1 037	1 571	534	– 446	—
Klaserie Dam	B7E03	24 31½	31 04	611	2 086	1 475	7 067	—
Letsitele	B8E02	23 52	30 25¾	618	2 429	1 811	9 163	1970 – 71
Lydenburg	B4E01	25 06	30 28	672	1 761	1 089	4 404	1972 – 73
Ohrigstad Dam	B6E01	24 55	30 37	652	2 064	1 412	6 518	—
Phalaborwa Barrage	B7E04	24 03¼	31 09	493	2 495	2 002	10 830	1973 – 74
Phalaborwa Airport	B7E05	23 56	31 09	482	2 317	1 835	9 816	1971 – 72
Rust De Winter Dam	B3E04	25 13¼	28 31	655	2 296	1 641	7 953	—
Shingwidzi	B9E01	23 06½	31 26¼	434	2 212	1 778	9 633	1971 – 72
Zebediela	B5E01	24 19	29 19	615	2 410	1 795	9 073	—
C: VAAL RIVER								
Armoedsvlakte	C3E02	26 57	24 38	483	2 684	2 201	12 683	1973 – 74
Balkfontein	C2E10	27 24	26 30½	626	2 527	1 901	10 229	1973 – 74
Bethal	C1E04	26 27	29 29	707	1 841	1 134	4 943	1972 – 73
Bethlehem	C8E03	28 10	28 18	648	2 014	1 366	6 661	1973 – 74
Doornlaagte	C3E04	26 37	26 06	622	2 319	1 697	8 911	1973 – 74
Fauresmith	C5E06	29 46	25 19	457	2 607	2 150	12 440	1972 – 73
Frankfort	C8E02	27 16	28 29	642	2 033	1 391	6 845	1973 – 74
Hartswater	C3E06	27 43	24 47½	301	2 534	2 233	13 524	1969 – 70
Hoopstad	C4E03	27 50	25 54	506	2 420	1 914	10 731	1973 – 74
J.B.M. Hertzog Airport	C5E08	29° 06′	26° 18′	561	2 497	1 936	10 683	1973 – 74
Kimberley	C5E07	28 48	24 46	425	2 894	2 469	14 633	1973 – 74
Koopmansfontein	C3E08	28 12	24 04	432	—	—	—	—
Kroonstad Gaol	C6E03	27 40	27 15	—	—	—	—	—
Kroonstad Sewage Works	C6 E04	—	—	27	231	204	1 237	1972 – 73
Vaal Dam	C1E01	26 53	28 07	698	2 039	1 341	6 324	—
Plessisdraai	C4E12	27 59	26 08	—	—	—	—	Into operation Nov.
Potchefstroom	C2E04	26 44	27 05	637	2 139	1 502	7 587	1973 – 74
Standerton	C1E03	26 57	29 15	731	1 769	1 038	4 233	1973 – 74
Vaalharts	C3E07	27 57	24 50	443	2 271	1 828	10 388	1973 – 74

PLACE	Station Ref. No.	Latitude	Longitude	A TANK			RESERVOIR $m^3/ha \times year$ NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
D: ORANGE RIVER								
Alexander Bay	D8E03	28 34	16 32	390	2 549	2 159	13 200	1973 – 74
Aliwal North	D1E01	30 41	26 43	531	2 163	1 632	9 200	1970 – 71
Brandvlei	D5E07	30 28	20 29	248	3 061	2 813	18 054	—
Butha-Buthe (Lesotho)	D2E03	28 46	28 14	703	1 606	903	3 744	—
Carnarvon	D5E02	30 58	22 08	188	3 198	3 010	19 573	1972 – 73
De Aar	D6E03	30 39	24 04	290	3 033	2 743	17 447	1971 – 72
Fraserburg	D5E05	31 55	21 31	180	2 801	2 621	16 990	1972 – 73
Hobhouse	D2E06	29 31	27 09	634	2 167	1 533	8 197	—
Kuruman	D4E04	27 27½	23 26¼	442	2 110	1 668	9 735	1973 – 74
Letseng-La-Draai (Lesotho)	D1E07	28 58	28 51	720	1 533	813	3 084	1969 – 70
Mafeking	D4E03	25 52	25 38	542	2 504	1 962	11 378	1973 – 74
Maseru (Lesotho)	D2E05	29 79	27 29	614	1 681	1 067	5 137	1970 – 71
Mokhotlong (Lesotho)	D1E06	29 17	29 05	520	2 217	1 697	9 673	1973 – 74
Molteno	D1E02	31 23	26 22	275	1 846	1 571	9 634	1973 – 74
Ox-Bow Lake (Lesotho)	D1E04	28 43	28 37	1 304	1 593	289	– 2 354	1969 – 70
Pofadder	D8E02	29 07½	19 23½	107	3 203	3 096	20 417	1969 – 70
Prieska	D7E04	29 40	22 45	257	2 397	2 140	13 510	1973 – 74
Rietfontein	D4E01	26 44¼	20 02	205	3 673	3 468	22 590	—
Roma University (Lesotho)	D2E04	29 27½	27 44	625	1 579	954	4 343	1968 – 69
Sakrivier Estates	D5E01	30 51	20 26	99	3 082	2 983	19 685	1969 – 70
Sutherland	D5E03	32 24	20 40	249	2 243	1 994	12 557	—
Twee Rivieren	D4E05	26 28	20 37	226	3 399	3 173	20 542	1973 – 74
Upington	D7E03	28 24	21 16	177	3 792	3 615	23 668	1973 – 74
Van Wyksvlei Dam	D5E04	30 21	21 49	212	3 086	2 874	18 582	1973 – 74
Wepener	D2E02	27 02	29 44	637	2 152	1 515	8 066	1968 – 69
E: OLIFANTS RIVER (WESTERN CAPE)								
Calvinia Dam	E4E01	37 28	19 46	212	2 271	2 059	13 815	1968 – 69
Citrusdal	E1E02	32 32¾	18 58½	323	2 411	2 088	13 687	1968 – 69
De Keur	E1E03	19 18½	32 59¼	483	1 784	1 301	7 688	1968 – 69
Vredendal	E3E02	31 41	18 29	139	2 227	2 088	14 236	1973 – 74
F: NAMAKWALAND								
Grootmis	F3E03	29° 38½′	17° 15′	73	2 320	2 247	15 549	1969 – 70
Hondeklip Bay	F4E01	30 19	17 17	98	1 765	1 667	11 404	—
Kamieskroon	F3E02	30 12⅓	17 56	160	2 535	2 375	16 187	1969 – 70
O'Kiep	F3E01	29 36	17 52	160	3 240	3 080	21 134	1973 – 74
G: SOUTH-WESTERN CAPE								
Bien Donne	G1E04	33 50½	18 59	753	2 189	1 436	7 830	—
Bredasdorp	G5E01	34 32	20 02	503	1 689	1 186	6 821	1971 – 72
D.F. Malan Airport	G2E07	33 58	18 36	497	2 032	1 535	9 288	1973 – 74
Elgin	G4E02	34 08¼	19 01¼	916	1 518	602	1 491	—

PLACE	Station Ref. No.	Latitude	Longitude	A TANK			RESERVOIR $m^3/ha \times$ year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Groot Constantia	G2E10	34 01¾	18 24¾	967	1 834	867	3 199	—
Jonkershoek Forest Reserve	G2E12	33 58	18 56	1 077	1 641	564	744	1973 – 74
Lambert's Bay	G3E01	32 05	18 18	142	1 923	1 781	12 073	1972 – 73
Lebanon	G4E03	34 09	19 08	689	1 306	617	2 274	1968 – 69
Norlier Proefplaas	G3E03	32 05	18 18	229	2 200	1 971	13 147	—
Seekoeivlei	G2E14	34 05½	18 31	450	1 894	4 444	8 790	1970 – 71
Sewefontein	G3E02	32 30¾	18 53¼	478	2 116	1 638	10 067	—
Voëlvlei Dam	G1E02	33 20½	19 02½	462	2 571	2 109	13 420	—
Welgevallen	G2E08	33 56½	18 52¼	702	1 829	1 127	5 814	1969 – 70
H: BREË RIVER								
Brandvlei Dam	H1E01	33 42¼	19 27	259	2 055	1 796	11 829	1970 – 71
Brandvlei Prison	H1E03	33 34	19 25	479	1 828	1 349	8 037	—
Buffelsjags Dam	H7E02	34 01¼	20 32	369	1 058	689	3 734	1968 – 69
Hex Valley	H2E01	33 27½	19 39½	236	2 447	2 211	14 810	—
Keisies Valley	H3E01	33 42	20 00	227	2 123	1 896	12 626	—
Riversdale	H9E01	34 06	21 16	434	1 620	1 186	7 027	1973 – 74
Robertson	H4E01	38 50	19 54	259	1 754	1 495	9 717	1973 – 74
Wolseley	H1E02	33 27¼	19 12½	559	2 246	1 687	10 169	—
J: GOURITS RIVER								
Beaufort West Gaol	J2E03	32 21	22 35	242	2 779	2 537	16 940	1973 – 74
Matroosberg	J1E02	33 26	19 49	209	2 223	2 014	13 397	1973 – 74
Rooiheuwel Oudtshoorn	J3E04	33 38	22 15	201	2 104	1 903	12 648	1973 – 74
K: OUTENIQUAS								
George	K3E01	33 58	22 25	781	1 307	526	696	1971 – 72
George/Outeniqua	K3E02	33 58¾	22 25¼	630	1 523	893	3 612	1973 – 74
Kromrivier Dam (Churchill)	K9E01	34 00	24 29½	675	1 499	824	3 006	1968 – 69
L: GAMTOOS RIVER								
Langkloof	L8E02	33 47	23 35	607	1 841	1 234	5 912	1972 – 73
Willowmore	L3E02	33 17	23 30	234	2 028	1 794	10 859	1968 – 69
M: ALGOA								
Port Elizabeth Airport	M2E01	33° 59′	25° 36′	654	1 856	1 202	5 540	1973 – 74
Uitenhage	M1E01	33 42	25 15¾	588	1 542	954	4 156	—
N: SONDAGS RIVER								
Addo Citrus Research Station	N4E01	33 34	25 42	393	1 817	1 424	8 062	1972 – 73
Graaff-Reinet	N1E02	32 15	24 32	356	2 211	1 855	11 033	1973 – 74
Jansenville	N2E02	32 56	24 40	239	2 102	1 863	11 483	1972 – 73

PLACE	Station Ref. No.	Latitude	Longitude	A TANK			RESERVOIR m³/ha × year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Q: GROOT VIS RIVER								
Cradock	Q3E01	32 10	25 37	251	2 240	1 989	13 842	1972 – 73
Golden Valley	Q7E01	32 49	25 47	—	—	—	—	
Grootfontein	Q1E02	31 29	25 02	360	2 516	2 156	14 767	1973 – 74
Lake Arthur	Q4E01	32 13½	25 49¼	287	2 187	1 900	13 095	1970 – 71
Somerset East Power Station	Q8E01	32 44	25 35	573	1 970	1 397	8 651	1973 – 74
R: AMATOLA								
East London Airport	R4E01	33 02	27 50	936	1 699	763	820	1973 – 74
Fort Hare (Alice)	R1E02	—	—	634	1 630	996	3 426	1973 – 74
Rooikrans Dam	R2E03	32 45¼	27 19½	799	1 697	898	2 178	—
S: GROOT KEI RIVER								
Queenstown	S3E02	31 53	26 53	524	1 717	1 193	5 048	1972 – 73
T: TRANSKEI								
Gilbert Eyles Dam	T5E01	30 43	30 09	610	1 363	753	2 067	1973 – 74
Kokstad	T3E02	30 32	29 25	707	1 621	914	2 643	1968 – 69
Powerscourt	T5E03	30 37	30 01	880	1 581	701	673	1969 – 70
Sheeprun	T3E03	30 59	28 23	803	1 451	648	664	1973 – 74
Umtata	T2E02	31 35	28 43	699	1 395	696	1 368	1968 – 69
Umzimkulu	T5E04	30 44	30 27	904	1 578	674	415	1969 – 70
Waterford	T5E02	29 51	29 20	1 076	1 565	489	– 1 383	1973 – 74
U: SOUTHERN NATAL								
Albert Falls S.W.S.	U2E06	29 05¾	30 25½	861	1 734	873	1 780	—
Cedara	U2E02	29 32	30 17	874	1 546	672	523	—
Chaka's Kraal	U3E03	29 27	31 12	954	1 572	618	– 121	1973 – 74
Darnall	U5E02	29 16	31 22	951	1 767	816	1 077	1969 – 70
Doornkop	U5E01	29 13	31 14	964	1 823	859	1 283	1969 – 70
Gledhow	U4E03	29 22	31 17	1 027	1 998	971	1 701	1969 – 70
Gledale	U4E02	29 17	31 08	706	1 513	807	2 005	1969 – 70
Illovo Sugar Estates	U7E01	30 05¾	30 49½	1 015	1 634	619	– 360	—
Louis Botha Airport	U6E03	29 58	30 57	982	1 757	775	707	1973 – 74
Savenoaks	U4E01	29 13	30 35	981	1 794	813	937	1969 – 70
Tongaat	U3E02	29 33½	31 07½	925	1 867	942	1 937	1968 – 69
Windy Hill	U2E05	29 31	30 33	989	1 722	733	427	1972 – 73
V: TUGELA								
Cathedral Peak	V1E02	28° 59′	29° 14′	1 318	1 565	247	– 3 803	—
Chelmsford Dam	V3E02	27 57¼	29 57	778	2 280	1 502	5 881	1968 – 69
De Hoek	V1E03	29 00½	29 37½	723	1 973	1 190	4 592	1968 – 69 close

PLACE	Station Ref. No.	Latitude	Longitude	A TANK			RESERVOIR $m^3/ha \times$ year NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Estcourt	V7E01	29 01	29 52	720	1 853	1 133	3 903	1973 – 74 close
Muden	V2E01	28 59	30 22	643	1 867	1 224	4 757	1968 – 69
Newcastle	V3E01	27 45	29 56	853	1 665	812	1 446	1971 – 72
Wagendrift Dam	V7E03	29 02¼	29 51½	951	2 182	1 231	3 564	—
W: ZULULAND								
Amatikulu	W1E04	29 03	31 32	857	2 080	1 223	3 893	1969 – 70
Charter's Creek	W3E01	28 12	32 25	987	1 741	987	562	1972 – 73
Empangeni	W1E03	28 45	31 57	789	2 152	1 363	5 004	1969 – 70
J.G. Strydom Dam	W4E03	27 25	32 03¼	574	1 941	1 367	5 890	1967 – 68
Listers Point – False Bay Park	W3E02	27 58	32 23	503	1 669	1 166	4 970	1969 – 70
Makatini Research Station	W4E04	27 24	32 11	568	2 397	1 829	8 682	1973 – 74
Mbabane	W5E06	26 20	31 09	1 512	1 305	– 207	– 7 301	—
Mbazwana	W7E01	27 28½	32 36	885	1 864	979	2 319	1969 – 70
Mhlume	W6E01	26 05	31 45	695	2 138	1 443	5 860	1969 – 70
Mtunzini	W1E01	28 57	32 17	1 392	2 012	620	– 1 865	1971 – 72
Piet Retief	W5E01	27 00	30 48	903	1 655	752	886	1973 – 74
Pongola	W4E02	28 27	32 17	680	1 892	1 212	4 536	1973 – 74
Pongola	W3E05	27 23	31 27	543	1 899	1 356	5 948	1969 – 70
River View	W2E02	28 27	32 17	666	2 023	1 357	5 461	1969 – 70
X: KOMATI								
Barberton	X2E09	25 47	31 02	777	1 807	1 030	3 057	1971 – 72
Burgershall	X3E02	—	—	—	—	—	—	—
Carolina	X1E02	26 04	30 07	750	1 874	1 124	3 728	1973 – 74
Friedenheim	X2E11	25 26	30 59	—	—	—	—	—
Lomati	X1E05	25 38	31 33	945	1 988	1 043	2 461	1970 – 71
Mhlati	X2E05	25 29	31 34	491	2 178	1 687	8 140	1970 – 71
My Own	X2E07	25 42½	30 45¾	1 286	1 754	468	– 2 351	1973 – 74
Nelspruit	X2E01	25 27	30 58	716	1 820	1 104	3 742	1971 – 72
Skukuza	X3E01	24 59	31 36	498	1 987	1 489	6 926	—
Tenbosch	X2E04	—	—	506	2 311	1 805	8 787	1969 – 70
Uithoek	X2E06	—	—	1 094	1 741	647	– 508	—
Witklip Dam	X2E10	25 16	30 55	1 319	1 577	258	– 3 741	—
Z: NORTH OF REPUBLIC								
Francistown	Z0E07	27 30	21 13	403	2 822	2 419	12 879	1967 – 68
Gaberones	Z0E05	24 40	25 55	487	2 649	2 162	11 002	1967 – 68
Gesond	Z0E18	—	—	372	2 277	1 905	9 923	1967 – 68
Ghanzi	Z0E08	21 42	21 39	402	3 136	2 734	14 770	1967 – 68
Gobabeg	Z0E17	23 34	15 03	22	3 463	3 441	20 529	1967 – 68
Gobabis	Z0E13	22 28	18 58	358	3 091	2 733	14 940	1968 – 69
Grootfontein	Z0E21	19 36	18 07	702	2 771	2 069	9 583	1973 – 74

PLACE	Station Evap. No.	Latitude	Longitude	A TANK			RESERVOIR $m^3/ha \times year$ NET EVAP.	Last Year of Observation
				mm/year GROSS RAIN	mm/year GROSS EVAP.	mm/year NET EVAP.		
Haakiesdoorn	Z0E22	—	—	—	—	—	—	—
J.G. Strijdom Airport	Z0E19	—	—	379	2 653	2 274	12 106	1968 – 69 close
Katimo Mulilo	Z0E16	—	—	668	2 473	1 805	8 137	—
Keetmanshoop	Z0E04	—	—	133	3 830	3 697	21 618	1968 – 69
Mahalapye	ZOE02	23° 05′	26° 48′	478	2 479	2 001	10 073	1967 – 68
Mariental (SWA)	Z0E12	24 37	17 58	176	3 655	3 479	20 140	1968 – 69
Maun	Z0E06	19 58	23 25	475	3 144	2 669	14 068	1967 – 68
Omatjene	Z0E20	20 26	16 27	—	—	—	—	—
Outjo	Z0E14	—	—	401	2 891	2 490	13 312	1968 – 69
Shakawe	Z0E11	18 22	21 51	500	2 612	2 112	10 650	1967 – 68
Tsabong	Z0E10	26 03	22 27	266	3 220	2 954	16 633	1967 – 68
Tsane	Z0E09	24 01	21 53	329	3 206	2 877	15 919	1967 – 68
Tsumeb	Z0E15	—	—	536	2 141	1 605	7 468	1967 – 68 close