TECHNICAL GUIDE & PROJECT REPORT

NON-CONVENTIONAL DISINFECTION TECHNOLOGIES FOR SMALL WATER SYSTEMS

by

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Report to the Water Research Commission on the project "Research on Non-conventional Disinfection Technologies for Small Water Systems"

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EXECUTIVE SUMMARY

BACKGROUND

Conventional disinfection of water supplies for small communities by means of chlorination has given rise to considerable problems with respect to the sustainability of such systems, particularly in developing countries. The main reasons for this is the reliance on a chemical which is not readily available or the supply is undependable. Furthermore, the cost of supplying chlorine to small water supplies makes up a significant portion of the total operational cost, and may result in the supply becoming unaffordable. At the same time, when funds are not available, chlorination is usually one of the first cut-backs made to save costs. Institutional shortcomings also account for lack of reliability of these systems, including inadequate education, poor operator training, and inadequate arrangements for the purchase, transport and storage of chemicals.

A water supply system which is chlorinated intermittently is often considered worse than a supply which is not chlorinated at all. The reason for this is that people lose their built up immunity while using chlorinated water, and then are much more susceptible to infection once the chlorination is interrupted.

With the increasing density of small communities, and the problem of contamination of most of our water resources, it has become all the more important to find reliable, acceptable and affordable methods of supplying safe water to these communities. This research project is specifically aimed at the investigation of alternatives to conventional disinfection to find systems which will be appropriate to the circumstances prevailing in small communities.

AIMS

The primary aim of this project had been to identify those alternative disinfection techniques which could be more suited to the disinfection of small water supply systems. In particular the important characteristics of more suitable systems were identified, and then those systems which meet these characteristics were evaluated. In particular, aspects of their potential, comparative disinfection power, reliability, cost and operational needs were compared. The final product was a list of options, with their advantages, availability, and limitations, which could be promoted as alternatives to conventional chlorination systems.

The programme was to be carried out in two phases. In the first phase a comprehensive literature survey was carried out to identify alternative disinfection technologies in use in the world for the disinfection of water in small systems, excluding systems using chlorine gas or chlorine compounds. These alternative systems were then assessed for their possible usefulness for the disinfection of small water supplies in South Africa, particularly in the rural areas.

In the second phase, the three systems which best meet the selected criteria for sustainability were evaluated at the CSIR to assess how well they meet these criteria in practice, and to compare them with each other. The aim was to present this information in the form of a guide in which the systems would be described, relating inter alia to the following aspects:

- flows which can be treated;
- types of water for which the system is suitable;
- type of community for which it is most suited;
- size of water supply systems suitable for the particular system;
- pros and cons of each system.

MAJOR RESULTS AND CONCLUSIONS

In trying to find more reliable and acceptable ways of disinfecting water supplies in small communities, the present research has reviewed the state of the art, and after scanning through more than twenty disinfection technologies in use today, made a selection of the three most promising ones.

The researchers selected the following as being the best candidates for small community water supplies: UV radiation, MOGGOD systems and on-site hypochlorite production. All three have the following important characteristics when used with success in small communities (including remote rural areas):

ease of operation,
low cost (equipment, operation and maintenance),
reduced maintenance,
overall simplicity,
good disinfection properties,
independence of the need of importing any special chemical not usually available.

Actual tests carried out at the CSIR's testing site in Daspoort, Pretoria, confirmed that the selected technologies all met with the criteria which were considered to be crucial for use in small water systems.

MEETING OF OBJECTIVES AND PROPOSED FUTURE ACTIONS

The research has arrived at a successful point in which the primary aims of the project have been achieved: i.e. to select and evaluate alternative, more appropriate disinfection technologies to implement in the rural communities and small towns of South Africa. In particular three technologies were found to be suitable for this purpose.

It is believed that this study could make a significant contribution to changing people's perceptions with regard to the most appropriate disinfection systems for for small community water supplies. The standard use of chlorination technologies is not necessarily appropriate in such situations, and consideration should be given to those systems which will be more cost effective and reliable in these circumstances. This could give rise to the more effective assurance of water quality in small community supply systems, and at the same time make this more affordable to the communities themselves.

The future requirements for this programme are to test these alternative technologies in the environments they are intended for, and obtain information on their acceptance by the user communities, their reliability, and on their cost-effectiveness. In particular the programme will be able to identify eventual problems or drawbacks that they may have while in field operation.

RESEARCH NEEDS AND TECHNOLOGY TRANSFER

Following from this project, certain additional research needs have been identified:

1) There is a need to obtain a better assessment of existing problems and successes with disinfection practices in small water supply systems.

2) There is a need to further evaluate the alternative technologies identified in this study, with emphasis being placed on field evaluations.

3) Further development of the more promising technologies identified in this study (e.g. MIOX) to ensure their future availability, back-up support, and effectiveness in the Southern African context.

In addition, it is believed that certain of these technologies can immediately be utilised in the South African market, although further modifications and adaptations may arise in the future.

ACKNOWLEDGEMENTS

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"Research on Non-conventional Disinfection Technologies for Small Water Systems".

The project was undertaken by the Division of Water Technology, CSIR.

The invaluable support and advice of the steering committee constituted from various organisations in South Africa to provide direction to the project is gratefully acknowledged.

The dedicated enthusiasm of Felipe Solsona, previously of the CSIR and now with the World Health Organisation, in the undertaking of this research is highly appreciated.

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This report is in two parts:

PART I comprises a guideline document for the use of UV radiation, MOGGOD systems and hypochlorite generation.

PART II is the final project report to the Water Research Commission, *inter alia*, providing the background to the Technical Guide.

PART I : TECHNICAL GUIDE ON:

ALTERNATIVE DISINFECTION TECHNOLOGIES FOR SMALL WATER SUPPLIES: UV RADIATION, MOGGOD SYSTEMS, AND HYPOCHLORITE GENERATION

by

Development Services and Technology Programme

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1. INTRODUCTION

The protection and disinfection of water used for domestic purposes is a major health related operational aspect of water supply systems. Often in small water supply systems where funds are limited and operator skills are rudimentary, the quality of the water receives a low priority in the operation of the system. When funds are low, fuel for the pumps will be purchased in preference to chlorine chemicals for disinfection. Under such circumstances, the provision of sufficient water, albeit of a poorer quality, is probably the most appropriate solution. However, it is the aim of this technical guide to describe three other options which can be used for the disinfection of small water systems, especially in a situation of limited resources (both financial and skills).

It should be noted, however, that the protection of water supplies and attention to the other causes of water related diseases (provision of improved sanitation and health education) should also be viewed as being of vital importance in programmes for the provision of water supplies to small or larger communities.

The practice of disinfection of water supplies has been in general use since the beginning of the century in Europe and other developed countries, and has given rise to a substantial reduction in the occurrence of water related diseases in these countries. The most often used technology to achieve disinfection has been chlorination. This has traditionally meant the addition of chlorine gas or other chlorine compounds in controlled quantities to the water to be supplied to domestic users. This method of disinfection has proved to be reliable, appropriate and effective in most developed countries and now also in virtually every large town and city in the world.

Situations as described above do occur regularly in rural, small town and peri-urban areas of developing countries, and in such situations conventional chlorine can be considered as having being a failure. The primary reason for this failure, according to the World Health Organisation (WHO), is related to the problem of obtaining the chlorine chemicals in these small rural and informal urban settlements. In many cases the chemicals involved (chlorine gas, sodium hypochlorite, or calcium hypochlorite) are not readily obtainable by the community in the form and quantity required. Problems of cost, purchasing, transport, and of importation when the products are not produced in the country, are responsible for the failure of chlorine disinfection. The related problems of accurate dosing and residual monitoring without the necessary level of skills, equipment and instrumentation have also been significant in the lack of reliability of chlorination disinfection in small water systems.

Alternative disinfection technologies which have the following characteristics may be more appropriate than chlorine treatment:

- they must be affordable by the user community from both a capital cost and the ongoing operation and maintenance costs point of view;

- they must be simple to operate and maintain, yet also give reasonably accurate doses of the disinfectant;

- the materials or chemicals which are regularly required for ongoing operation should be readily available at close proximity to the place of usage.

The following three alternative methods of disinfection could be considered where conventional chlorination is unlikely to be reliable and hence appropriate:

* UV Radiation
* MOGGOD
* On-site hypochlorite production

All of these do require an electrical energy supply, which may also not be readily available in many small settlements. However, remote electrical power can be supplied relatively simply by means of solar photo-voltaic systems, and hence are considerably more suited to remote communities than the ongoing supply of a chemical.

Each system is briefly described below, and then criteria for their selection presented. Operation and maintenance guidelines of each system are also presented.

2. UV RADIATION

Ultraviolet radiation is a relatively old technology which was first used for disinfection purposes in 1910. Nevertheless it was, until recently, never considered to be a reliable means of disinfection. The main reason for this was that the core of the technology - the lamps - presented many problems. These lamps often failed, or were inconsistent in their emission (intensity and/or wavelength).

It was not until the early eighties that the technology of UV lamp manufacturing improved to the extent that lamps of high reliability are now readily available. Today, lamps with a life expectancy of up to 8000 hours and an emission decay of not more than 20 % over this period can be readily obtained commercially.

2.1 Description of UV Disinfection

Ultraviolet light is the term given to the electromagnetic radiation in the wavelength band between visible light and X-rays. The spectral range of ultraviolet radiation is between 100 and 400 nm (1 nm = 10^{-9} m) and is thus invisible. The UV spectrum is arbitrarily subdivided into three bands, as follows:

- UV-A (long wave) 315 - 400 nm
- UV-B (medium wave) 280 - 315 nm
- UV-C (short wave) 100 - 280 nm

The strongest germicidal effect is provided by the radiation in the UV-C (short wave) band. However, most bacteria are also highly susceptible to radiation at the 254 to 255 nm wavelengths, which is related to the carbon-oxygen double bond of organic molecules. Hence UV-B lamps which generate electromagnetic waves around the 254nm wavelength are generally highly efficient in terms of their germicidal effects.

The most efficient source for the artificial generation of focused UV-B radiation is the low-pressure mercury discharge lamp. Lamps of this nature are commercially available where the primary radiation generated consists almost exclusively of a spectral line at 254 nm, which is close to the maximum germicidal effect.

The lamps are similar to the familiar tubular fluorescent lamps and are operated similarly, i.e. by means of stabilizing ballast and a starter.

The simplest UV disinfection device is a container (normally a portion of pipe) where the water passes through in a controlled way (i.e. no short-circuiting and a limited flow rate). The lamps are contained in quartz tubes within the pipe, and result in a fixed average UV dose to the water passing through. Another type of UV system is where the lamps are mounted above a shallow tank through which the water passes.

A UV system is a very simple disinfection device, and among its many advantages are the following:

- no chemicals needed;
- the installation is very simple;
- operation and maintenance are extremely simple;
- there are no mobile parts;
- it is very quick in killing microorganisms;
- it does not form toxic compounds;
- there is no risk of overdosage;
- there is no oxidising chemical, and hence minimum corrosion to installations can be expected;

2.2 Effectiveness of UV Disinfection

There are certain disadvantages to the use of UV for disinfection. The first of these is related to the difficulty in determining the effective dose for a certain type of water. Only if the dose is adequate will microorganism destruction be complete.

The radiation dose required to achieve disinfection differs for different microorganisms as can be seen in the comparative sensitivity of a number of microorganisms to UV disinfection as listed in table 1 below. The dose is given in mWatt.sec/cm^2 for 99% reduction in their counts.

TABLE 1. Sensitivity of microorganisms to UV radiation
(source: various authors)

MICROORGANISM	GENUS	UV DOSE TO ACHIEVE 99% DESTRUCTION mW.s/cm^2
Bacteria:	Bacillus anthraces	4.5
	Bacillus anthraces spore	54.5
	Bacillus subtilus spores	12.0
	Clostridium tetani	12.0
	Corynebacterium diptheriae	3.4
	Escherichia coli	3.2
	Legionella pneumophila	1.0
	Micrococcus radiodurans	20.5
	Mycobacterium tuberculosis	6.0
	Pseudomona aeruginosa	5.5
	Salmonella enteritidis	4.0
	Salmonella paratyphi	3.2
	Salmonella typhi	2.1
	Salmonella typhimurium	8.0
	Shigella dysenteriae	2.2
	Staphilococcus aureus	5.0
	Streptococcus faecalis	4.4
	Streptococcus pyogenes	2.2
	Vibrio comma	6.5
Viruses:	F-specific bacteriophage	6.9
	Influenza virus	3.6
	Poliovirus	7.5
	Rotavirus (Reovirus)	11.3
Yeasts:	Saccharomyces cerevisiae	7.3
Moulds:	Penicillium roqueforti	14.5
	Aspergillus niger	180.0
Protozoa:	Various	60 - 200

From the above table it is clear that depending on the type of contamination the water may have, the dose should be properly and carefully chosen. As a general rule, UV disinfection systems are usually designed to provide a minimum dose of 30 $mW.s.cm^{-2}$, although a dose of 20 $mW.s.cm^{-2}$ is usually sufficient for disinfection of waters from protected natural resources.

UV disinfection efficiency is not only dependent on the individual resistance to the radiation that different organisms present. Beyond that, there are a number of other parameters that should be taken into account when determining the appropriate dose.

UV energy radiation is rapidly reduced the deeper the radiation must penetrate into the liquid in which the microorganisms are present. The degree of radiation reduction depends on the kind of liquid. In the case of water, it will depend on the transparency, which is related to the turbidity it may have. In addition to turbidity, iron salts and organic matter dissolved in the water will also decrease the penetration of germicidal radiation through the liquid. On the other hand alkali salts, such as those of aluminium sulphate, calcium, magnesium and sodium, will generally increase the effectiveness of penetration.

Temperature of the water is another factor that will modify the disinfection power of UV radiation.

However, it should be noted that water chemistry and temperature have less of an effect on UV dose requirements than on chemical dose requirements.

If the device has been properly designed, the retention time will be such that the exposure of the water to radiation will be sufficient to kill the microorganisms. However if the flux or flow pattern in the vessel where the lamp is acting is not homogeneous, there could be short-circuiting and some portions of the water passing through would not receive the necessary dose. Commercially available devices are designed to minimise short circuiting.

UV radiation results in instantaneous disinfection. There is therefore no disinfection residual. In certain cases the residual is not required, whereas in others it may be very important to have. In rural areas where water could be subject to recontamination, such as where reticulation is improperly done or where the water is likely to be contaminated after it is obtained from a tap or a standpipe (e.g. from the container in which it is collected and stored), a residual to cope with secondary contamination may be essential.

A final problem is the difficulty of knowing whether the lamp is functioning properly.

Most manufacturers provide in their equipment some type of "lamp on" indicator. But this is not the same as an indicator of "lamp failure". Most "lamp on" indicators will remain lighted even if the lamp burns out, provided the power supply to the lamp remains on. An important future requirement of all such devices is that a "lamp failure" indicator should clearly point out (visually or audibly) that the lamp has stopped its emission. In addition, it would be very important for such a device to be linked to another control that whenever the lamp burns out, the system should stop the water flow by means for example of a solenoid valve. However, as already mentioned, the improved reliability of the modern UV lamps means that in general life expectancies of 6000 hours can be expected with some degree of confidence.

Several companies in South Africa either manufacture or import UV systems. Typical systems are illustrated in figure 1. below.

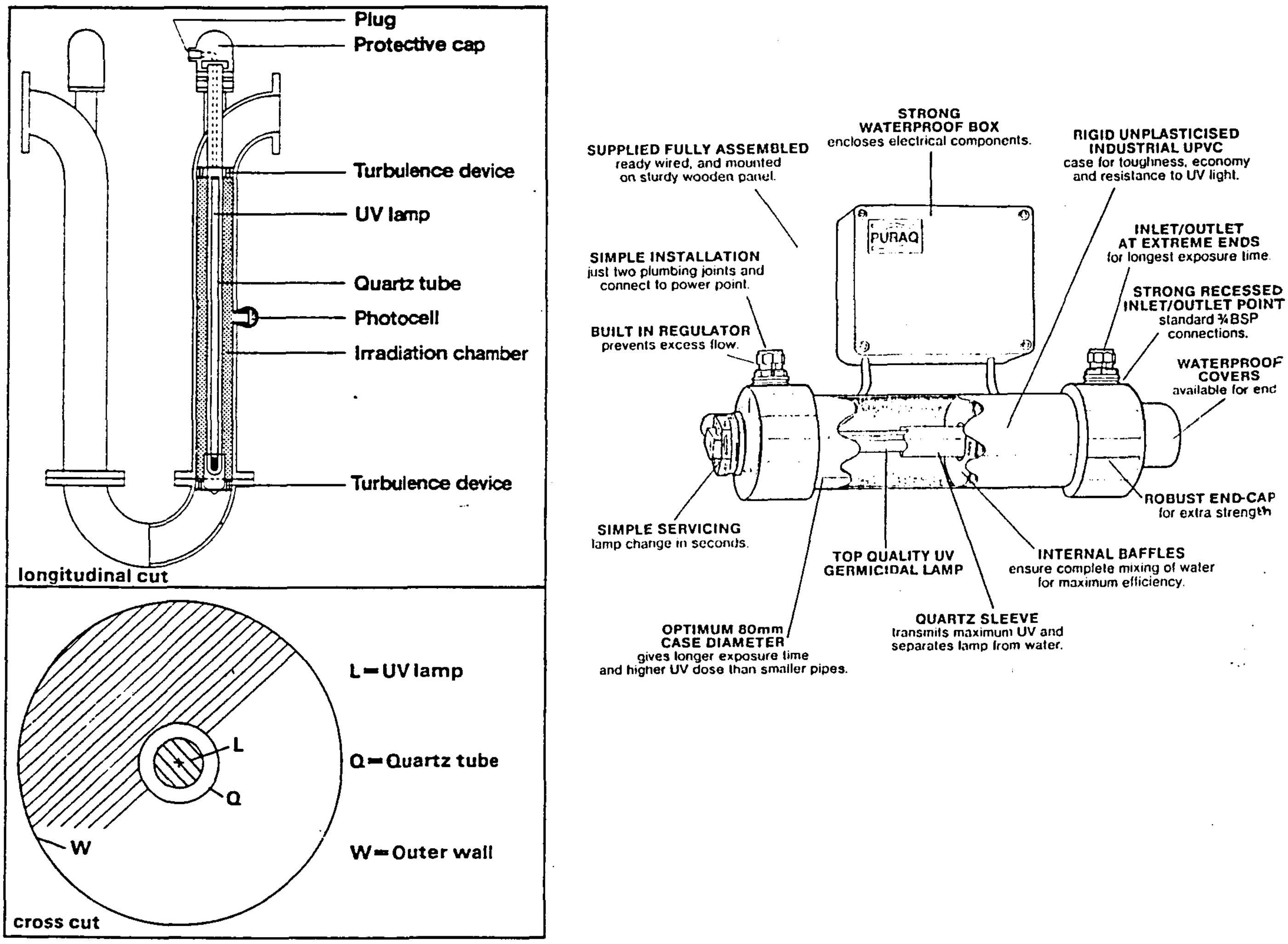

Figure 1. Different types of commercially available UV disinfection units

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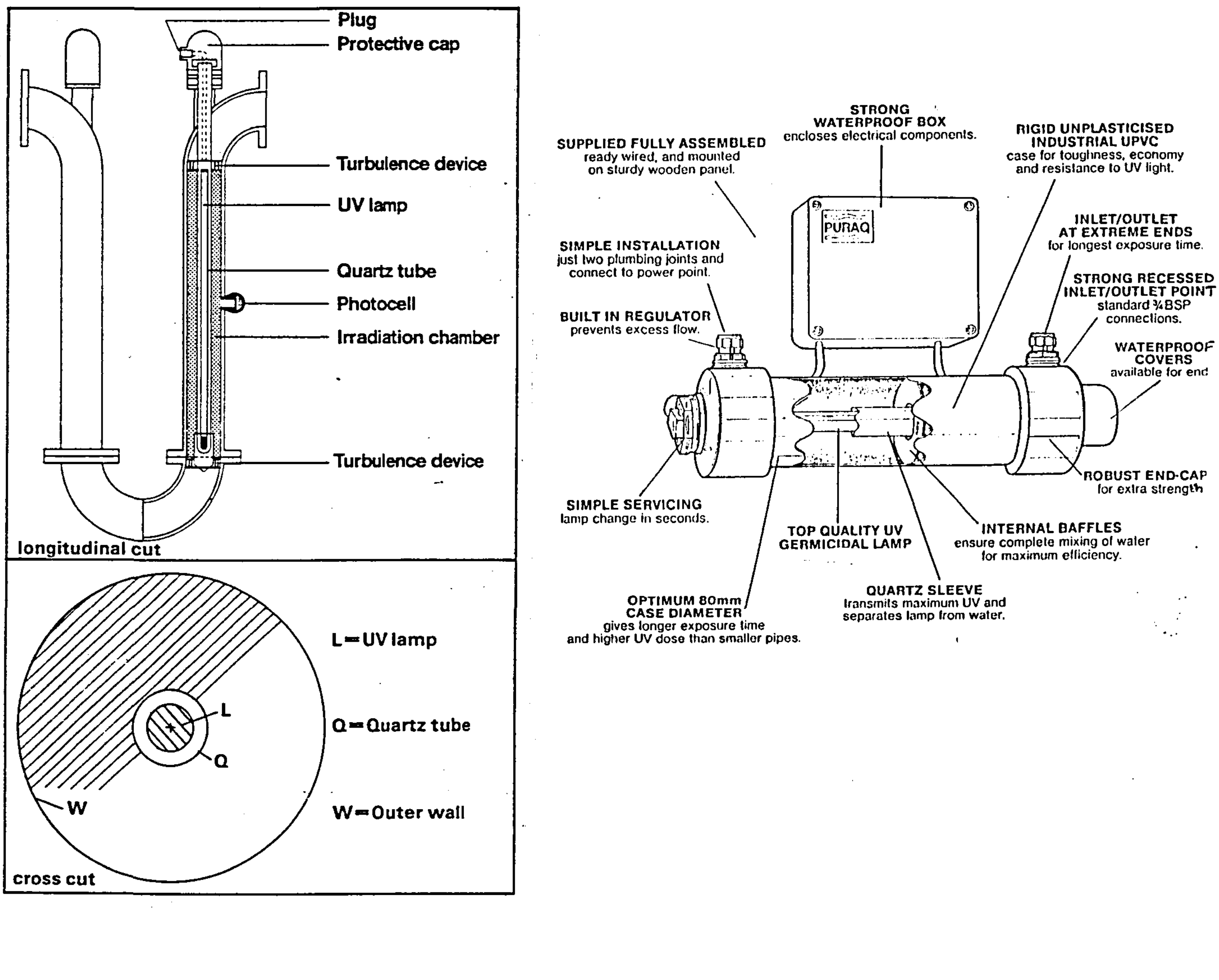


Figure 1. Different types of commercially available UV disinfection units

3. MOGGOD

This technology, based on the electrolysis of sodium chloride, has been developed only in the last ten years. Its development has been supported by the Pan American Health Organization in the Americas.

This electrolysis process makes use of any electrical power source, requiring approximately 4.5 kWh per kg of chlorine equivalent. The only feed chemical needed for the production of the disinfectant gases is common table salt, generally available in any village in the rural environment.

3.1 MOGGOD Electrolytic Process

The electrolysis of sodium chloride has been well documented since the middle of the nineteenth century. It means the electrolytic conversion of chloride ions (from a saturated or very concentrated solution of common table salt in water), forming chlorine, hydrogen and sodium hydroxide through the passage of an electric current.

This process is rather slow and inefficient when the electrodes are placed directly in the brine (concentrated salt solution), but if there is a separation of both compartments (cathodic and anodic) by means of a special membrane, the process is more efficient. When there is no separation between compartments, then the chlorine will react with the OH^- ions forming sodium hypochlorite which remains in solution together with the unreacted salts. When the cell is separated, chlorine gas is formed.

The cell for the electrolysis of sodium chloride in the MOGGOD cell is a typical one for this kind of process. In fact there is no special limitation to size or shape except for that related to certain logical reasons.

The production of gas is approximately that of:

0.6 kg of oxidant/kg of salt

3.2 MOGGOD Cells

Electrodes

The cathode is a standard piece of stainless steel from the series 400. However, it is the anode which is the important part of this system. The anode used in the MOGGOD cell is a DSA or "Dimensionally Stable Anode". The DSA is a technology developed in 1969 in the USA. These electrodes have been recognized as the single most significant improvement to chlor-alkali manufacturing techniques. The DSA offer substantial reductions in power consumption and allow the best efficiency in the process. Today, 90% of the chlorine production in the USA has been converted to DSA.

The DSA are based on inventions using metal oxide coatings, usually of the rare or transitional metal and platinum group metal oxides, applied to a rare metal - normally titanium substrate.

The MOGGOD technology is unique because there is an important innovation of the electrode geometry:

instead of a typical array:

cathode-membrane-anode

which has been historically used for the production of chlorine, the MOGGOD array makes use of an anode in several different planes parallel to the plane of the membrane and the cathode.

The different planes act as if the array would be:

cathode-membrane-anode-anode

And this simple fact allows the formation of chlorine (plus hydrogen and sodium hydroxide) plus several oxygen species including ozone. This is the reason for calling this technology "mixed oxidant gases generated on-site for disinfection" or MOGGOD. The effective disinfecting power of the mixture of oxidants is very high as all the additional species formed in the reaction display an extremely high oxidizing power.

Figure 2 illustrate the MOGGOD system and cells.

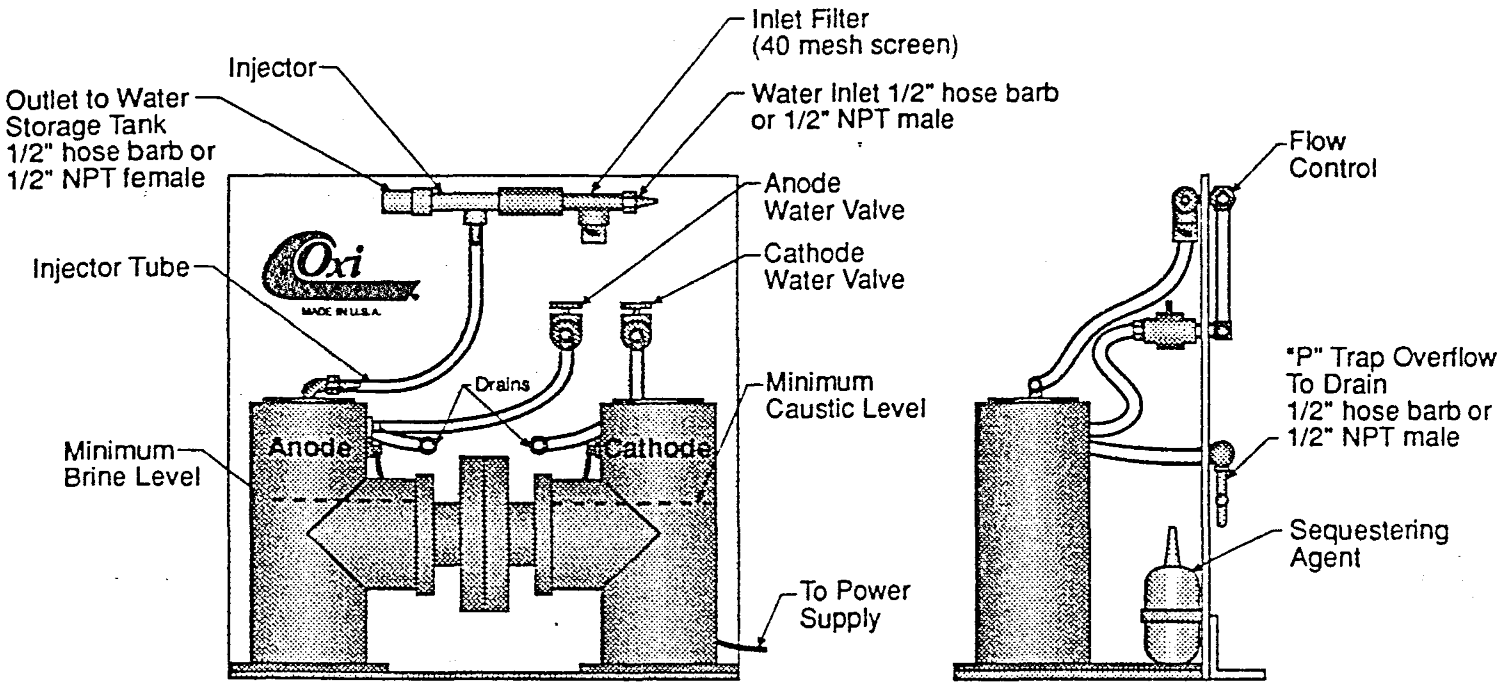
Operation requirements

The gas produced in the electrolytic cell is fed into the water to be treated by means of a venturi or injector. The operation of the system is to ensure that there is enough water and salt in the cell at all times, and to dilute the sodium hydroxide that is being continually produced as a by-product.

This operation requires attention only once every few days and the maintenance requirements are simply to clean the membrane which tends to clog with time.

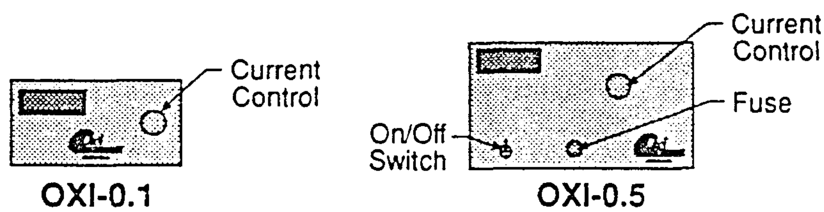
That fact - the clogging of the membrane - is perhaps the most important drawback of the technology. If common table salt is used; and this is the important advantage as salt is easily available in any rural location, then a number of unwanted by-product precipitates are formed. These precipitates, which are alien to the reaction of chlorine formation, are responsible for the clogging of the membrane.

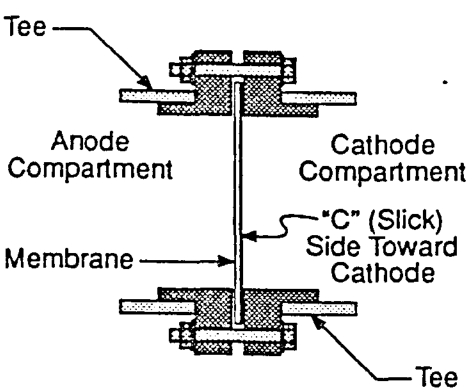
Oxi
Oxidant Generator
OXI-0.1 and OXI-0.5 Models
Manual Version



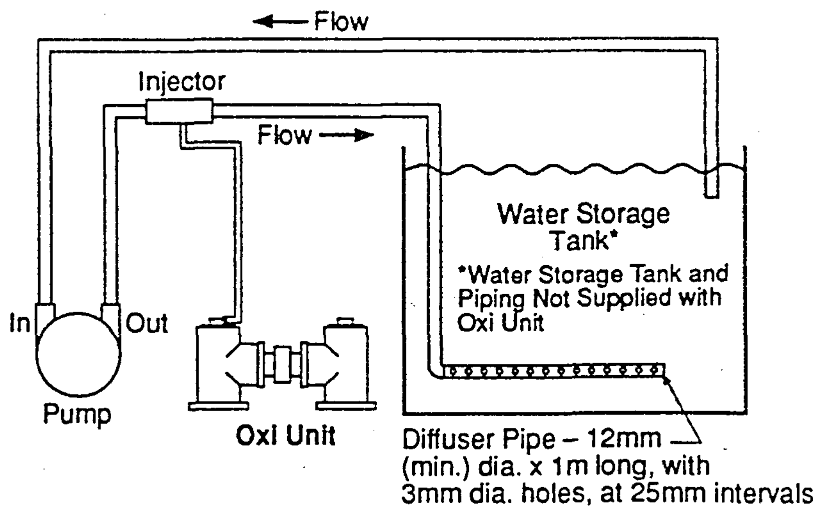
Installation Drawing

Power Supply





Cross Section of Membrane Assembly



Water System Schematic

A second drawback is the need to feed a gas into the flow of water. The dosing of substances into the water is best achieved when the substance is in the form of a solution, rather than a solid chemical. The dosing of a gas is the most difficult. However, if the system is designed to use all of the oxidant as it is produced, the venturi can be specified to ensure that all of the gas in the chamber is dosed into the water stream. The dose can then be controlled by controlling the electrical potential across the electrodes.

The disinfectant produced allows the treatment of even heavily contaminated water. The technology is rapidly developing and being used in Latin America where its applicability for developing areas has been confirmed.

There is one company producing a MOGGOD cell in the USA since 1985, and recently an agent in South Africa has been established.

4. ON-SITE HYPOCHLORITE PRODUCTION

This is a technology similar to that of MOGGOD where chlorine is produced within an electrolytic cell. However, the cell is not separated by a membrane, and is hence more simple to operate and maintain. The chlorine produced at the cathode will remain in solution and mix with the sodium hydroxide produced at the anode, giving sodium hypochlorite.

Although this is a less efficient system when compared to a membrane cell, it does not have the maintenance problems associated with the use of a membrane. In addition there is no need to feed a gas into the water to be treated, but instead a solution, which is much simpler and more reliable. What is more, as the efficiency is less and the chlorine stays in solution, the cell materials can be less stringent, while in the case of the MOGGOD cells there is a need to have special materials to prevent corrosion in the elements subject to the gas.

As in the case of the mixed oxidant gases, the on-site hypochlorite cells do not require any imported chemicals, but utilise common table salt.

There are several companies in the world producing this type of equipment. And at least one company in South Africa produces the cell.

5. INSTALLATION OF THE EQUIPMENT

5.1 Installation requirements

Installation of the specific disinfection units is fairly straightforward and can be accomplished by a person with basic plumbing skills. In the case of UV radiation, the whole stream must pass through the UV unit, whereas with MOGGOD and on-site hypochlorite generation the disinfectant is dosed into the pipeline or channel conveying the water flow. Table 1 lists the main aspects to be considered in the installation or selection of system.

TABLE 1: Installation Requirements and Options

Requirement/Option	UV Rad.	MOGGOD	ON-SITE CHLORINE
Can treat water in channel*	N	N	Y
Can treat water in a pipe*	Y	Y	Y
Can treat only a portion of flow#	N	Y	Y
Needs additional equipment$^{\alpha}$	N	Y	Y
Needs electric power source	Y	Y	Y
Installation needs only basic plumbing	Y	Y	Y
Needs special tools to install	N	N	N

\# In the case of MOGGOD and On-site hypochlorite generation it is possible to treat only a portion of the raw water from say a channel by abstracting this portion through a pipeline, adding the disinfectant at a high dose, and then returning this to the channel where the dose is well mixed and applied evenly throughout. This is not possible in the case of the UV Radiation where all the water must pass through the unit. Generally ancillary equipment will be needed in the secondary line to pump the water from the channel and return it after incorporating the oxidant, although this may not always be necessary if the pressure head is sufficient to divert this portion without the need for a pump.

$^{\alpha}$ Reference here is to ancillary equipment which is required to operate the unit. MOGGOD will need an injector and possibly a valve to control the difference in pressure around the injector. On-site hypochlorite generation will need some type of feeding equipment (anything from a sophisticated diaphragm pump to a simple constant level and restriction orifice device).

5.2 Design specifications

With respect to the different technologies, the installed equipment should be sized as follows:

For UV radiation, an emission that may produce a dose of not less than 30 mWs/cm^2 for the particular flows passing through the system. This is in contrast to the US EPA which only demands a dose of 16 mWs/cm_2. However, particularly in developing areas, the need for this extra margin of security is essential.

For MOGGOD and On-site hypochlorite generation it will be assumed that a demand of 1.4 mg Cl_2/l of raw water and a residual of 0.1 mg/l is required (total 1.5 mg/l or 1.5 $g/m^{3)}$. Here raw water means either the water coming directly from a natural source or water after any treatment but prior to disinfection.

5.3 Power requirements

TABLE 2: Power Requirements of the Systems

	UV Radiation	MOGGOD	On-site hypochlorite generation
Needs power source	Y	Y	Y
Can use battery/solar panels	Y	Y	Y
Are equipment/battery/solar systems customised for the technology and available in market	Y	N	N

The three devices require an electrical power source for their operation. However, the three devices can operate with a low level of current power. This means that a power source capable of providing 12 Volts - 6 Amps may be used to run the equipments.

Nevertheless to date only UV systems have been specifically customised for solar power.

5.4 Flows which can be treated

The flows which can be treated are in relation to the size of the community. In the case of the populations considered in this guide the flows for three sized communities will be considered as an example as follows: 500; 2 000 and 5 000 people.

Assuming the individual daily consumption suggested by the World Health Organization for rural population in the third world of 45 litres per capita and per day plus as 20 % for special needs or uses in the community (like a school, a clinic, etc) the figures for the three types of communities would be:

SMALL	27 000 litres	=	27 m^3
MEDIUM	108 000 litres	=	108 m^3
LARGE	270 000 litres	=	270 m^3

Hence the equipment must be suitable to treat flows within these ranges. In the case of the disinfection equipment described, this is possible in all cases either directly (with a single unit), or in modular form.

The disinfectant doses needed for the different plants in the three types of communities will be:

SMALL:	27 m^3/day * 1.5 g/m^3	= 40.5 g Cl_2/day
MEDIUM:	108 m^3/day * 1.5 g/m^3	= 162 g Cl_2/day
LARGE:	270 m^3/day * 1.5 g/m^3	= 405 g Cl_2/day

5.5 Quality of water which can be treated

In all cases turbidity will be a component to avoid, as the particles responsible for the turbidity could hinder the effect of any disinfectant. This is common to all three systems, but more pronounced with UV treatment.

Nevertheless, as the three technologies produce different disinfection products, the type of raw water to be treated would be particularly sensitive to each system in an individual way. Or alternatively, a certain water may be better disinfected by one technology than by another.

Of the most frequent parameters found in rural water supplies, the following table gives an idea of their influence on the disinfection action of the three technologies.

TABLE 3: **Effect of Water Quality on Disinfection Efficiency**

Quality parameter	UV Radiation	MOGGOD	On-site hypochlorite generation
Turbidity	H	M	M
Colour	M	L	L
Iron (as Fe^{3+})	H	L	M
Organic compounds (e.g. phenols)	H	L	M
Ammonia compounds	L	M	H
pH	L	M	M
Most inorganic ions	L	L	L
Biological components	L	L	L

Note : H = high influence (greatly reduced effect)
M = medium influence
L = low influence

It is very difficult to define the maximum microbiological count that a water should have in order that it can be disinfected by any of these methods. If other conditions (i.e. the parameters and their influence in the overall disinfection capabilities as expressed in the table above) are not important, then an increase in the microbiological contamination can be simply dealt with by a slight increase in the disinfectant dose. Final effectiveness should be evaluated by means of laboratory tests.

In practical terms, what this really means is that if the proper radiation is applied to a certain flow of water for the UV Radiation technology; or if the chlorine demand is satisfied and the MOGGOD and the On-site hypochlorite generation provide a measurable chlorine residual, then the technologies can be considered as appropriate for the particular situation.

5.6 Dose levels

In the case of the UV Radiation there is ample information on the radiation levels needed to destroy microorganisms (see Table 1). In the case of the oxidant producers (MOGGOD and On-site hypochlorite generation) the dose should be related to the chlorine demand and to a certain residual after a acceptable retention time. These two are estimated as 0.1 mg Cl_2/litre and 0.5 hour respectively. For shorter available contact times, the required residual should be proportionally increased (e.g. 0.3 mg/l and 10 minutes).

5.7 Standard unit sizes

The standard units of any equipment have been manufactured to meet the requirements of the majority of users. With each unit a number of models from different manufacturers are available.

In the case of UV equipment, the needed dose can be obtained giving relative importance either to the lamp power or to the retention time.

The market produces a wide range of models that can provide UV radiation levels sufficient to cope with contamination levels for flows up to 72 000 m^3/day. If in the cases of rural communities the maximum need would be the treatment for flows of up to 270 m^3/day, it is clear that the market offers UV equipment with the capacity of disinfection of systems almost 300 times bigger than that needed. So the availability of equipment is not a problem. It is only necessary to make a proper selection.

In the case of the MOGGOD systems there is an upper limit to production. Although in theory it is possible to make a unit as large as desired, for practical reasons (e.g. not to work with very high currents) there are limits posed for this equipment.

In the case of the Oxi-generator, commercially available from the USA, the limit for the largest unit is 3 000 g Cl_2/day, which is sufficient for the range of communities in the standard sizes given above (5.4).

The on-site hypochlorite production cells are also capable of producing up to many kg of chlorine per day, more than the needed amount of disinfectant.

If any particular model is too small with relatively low outputs, it is possible to install two or three in series.

5.8 Life expectancy of equipment

A lifespan of five years would be a good general assessment of all the equipment types. However, the following more detailed analysis may also be used.

UV Equipment

The UV system has three main components: the container, the electrical control and the lamp.

The UV lamps have a limited lifespan. A common low pressure mercury lamp between 15 and 40 Watts will have a life expectancy of 3 000 to 6 000 hours. In tests, consistent results were still obtained after 4 000 hours of use. Hence a safe estimate is to assume that 4 000 hours is the lifespan of the lamp. This means a life span of approximately six months.

MOGGOD

The MOGGOD system is composed of the cell, the electric control and the venturi or injector.

The electric control and the venturi will last five years without need for replacement.

The cell has three components. The container, the electrodes and the membrane. The container will present no problem as the material is suitable for the aggression of the oxidant gases. The electrode that is exposed to corrosion is the anode. A life expectancy of approximately 1000 days (or roughly two and a half years) should be used. This means one change during the equipment lifespan.

The membrane, should be renewed every 6 months.

On-site Hypochlorite Generator

Finally, the on-site hypochlorite production unit consists of a container and the cell.

The container may last five years without problems. As with the MOGGOD system, the anode should be replaced every 2½ years.

6. COST OF EQUIPMENT

For the cost analysis, the following approach has been made:

6.1 Capital Costs

In the case of the UV system, a South African manufacturer's unit is used for estimating costs. The cost figure given takes into consideration the type of water to be disinfected and the minimal dose adopted of 30 mWs/cm_2, plus the inclusion in the unit of a lamp failure alarm.

In the case of the MOGGOD unit, the complete unit with accessories (injector included) was considered. The price is that of the manufacturer from the USA and has a 20 % increase to cope with delivery charges.

With respect to the on-site hypochlorination unit, it was established that the lifespan of these cells is 2.5 years. For this reason the cost of the equipment includes the cost of only one cell (the second cell will be considered as maintenance). In the capital cost is also included the cost of a container and a small diaphragm pump to feed the solution.

The figures are in Rands, June 1993. (1 U$D = 3.2 Rands)
Prices include:

UV Radiation: Unit + Lamp failure alarm + control

MOGGOD: Cell + Injector + chemicals for start + hydrometer + control

On-site hypochlorite: Cell + Solution container + feeding pump + control

TABLE 4(a & b): Capital Cost of Equipment

a) Total Cost

	SMALL	MEDIUM	LARGE
UV Radiation	3 900	14 300	27 000
MOGGOD	5 400	7 300	7 300
On-site hypochlorite	3 700	4 900	6 100

If the lifespan is 5 years, then the yearly cost of equipment is:

b) Annual Cost

	SMALL	MEDIUM	LARGE
UV Radiation	780	2 860	5 400
MOGGOD	1 080	1 460	1 460
On-site hypochlorite	740	980	1 220

6.2 Cost of Operation

Three costs items can be identified in the operation: manpower, chemicals and power.

Manpower

The needed manpower is really very limited. The systems have proved to be very simple in their operation and maintenance. There is only a need of a few minutes on a daily basis to check the system. In the case of UV Radiation all that is required is to check if the system is in operation, i.e. if the lamp is burning. In the case of the MOGGOD the requirement is to verify if there is water and salt in one compartment, if there is a need to dilute the sodium hydroxide by adding a few millilitres of water to one of the semi-cells and finally to check that the injector is working properly. This will take a few minutes more than in the case of the UV Radiation. The On-site hypochlorite generation will also require a few minutes to see that there is still some solution in the container to be fed, to prepare a new batch of NaCl solution from time to time, and to rinse the used container.

Hence the time required for the operation of the systems studied is minimal, with no unit being significantly different from the others. Sometimes more time will be consumed in the trip to the plant than in the operation itself.

If there is a plant, the operator will have his duties, and the total time required for disinfection operations will not demand more than a small fraction of the time needed for the operation of the plant. With this very wide approach it can be very conservatively estimated that if in South Africa a rural plant operator would earn a salary of R 600./month, then his duties as disinfection operator would not mean more than R 200./ month.

Hence an annual figure for manpower of R 2 400.- can be considered for all the cases.

Chemicals

With respect to the analysis of the chemical cost:

The UV Radiation system does not require any chemicals.

In the case of the MOGGOD the consumption is 1.7 kg of salt/kg of equivalent chlorine. For the three cases of small, medium and large communities the values would be:

SMALL	-	69 g/d
MEDIUM	-	275 g/d
LARGE	-	689 g/d

For the On-site hypochlorite generation the output of 140 gCl_2/day will be produced by 10 litres of a 15% NaCl solution. That is the consumption of salt will be that of 140 g chlorine/1.5 kg of salt or approximately 100 g of chlorine are produced by 1 kg of salt. Hence the salt requirements are:

SMALL	-	405 g/d
MEDIUM	-	1620 g/d
LARGE	-	4050 g/d

The chemical cost/year for the different systems are:

TABLE 5: Annual Chemical Costs

	SMALL	**MEDIUM**	**MAJOR**
UV Radiation	-	-	-
MOGGOD	40	160	400
On-site hypochlorite	220	880	2 200

Power

Finally the cost of power is very difficult to evaluate. It depends in the way the particular unit is operating, in the amperage drawn by the particular system. Despite this it may be said that in all the systems values are very similar.

The power consumption for the different types of communities is approximately the same for the different equipment. It can be estimated in 2, 4 and 6 KWh/day for each equipment in a small, in a medium and in a major village. If the cost of the KWh is approximately 15c, then the yearly cost of the power for the three systems would be:

TABLE 6: Annual Power Costs

	SMALL	MEDIUM	LARGE
UV Radiation	100	200	300
MOGGOD	100	200	300
On-site hypochlorite	100	200	300

By adding all these operational costs together, the total annual operating cost may be estimated for each system.

TABLE 7: Total Annual Operation Costs:

	SMALL	MEDIUM	LARGE
UV Radiation	2 500	2 600	2 700
MOGGOD	2 540	2 760	3 100
On-site hypochlorite	2 770	3 480	4 900

6.3 Cost of Maintenance

The major costs of maintenance are the replacement of equipment or parts.

In the case of the UV systems it is the lamp replacement. In all cases the lamp to be replaced is a 75 Watt lamp. As the lifespan of each lamp was estimated at 6 months, there should be 10 changes in the equipment lifespan. The cost of each lamp is R 400. It will be seen that the lamp replacement cost in the bigger equipments is very high as these units run with 8 lamps.

In the case of the MOGGOD system the anodes should be changed once every two and a half years, and the membrane every six months.

In the case of the on-site chlorination cells, they will be totally replaced half way through the 5 year period.

TABLE 8(a & b): Total Estimated Maintenance Costs

a) Total costs

	SMALL	MEDIUM	LARGE
UV Radiation **MOGGOD** **On-site hypochlorite**	4 000 2 100 1 200	16 000 2 900 2 400	32 000 4 200 3 600

b) Annual costs

	SMALL	MEDIUM	LARGE
UV Radiation **MOGGOD** **On-site hypochlorite**	800 420 240	3 200 580 480	6 400 840 720

6.5 Estimated Total Costs per Unit

All of these costs may now be added together to give a total annual cost for each unit.

Total annual costs = (equipment + operation + maintenance)

TABLE 9: Total Annual Costs

	SMALL	MEDIUM	LARGE
UV Radiation **MOGGOD** **On-site hypochlorite**	4 280 4 240 3 950	8 860 5 000 5 140	14 700 5 600 7 040

The total cost may also be given as a cost per m^3, a measure often used in water supplies.

TABLE 10: Cost of Units expressed as R/m^3

	SMALL	MEDIUM	LARGE
UV Radiation	0.43	0.30	0.15
MOGGOD	0.43	0.17	0.06
On-site hypochlorite	0.40	0.17	0.07

7. OPERATIONAL ASPECTS

7.1 Key Points in the operation of the respective units

There are not many key points to be taken into consideration while performing operational activities with these technologies. Nevertheless it is important to highlight a few matters.

The UV system is practically free from any possible misuse. Nevertheless the operator should know that it is not possible to indicate that the disinfection is being carried out effectively, since there is no residual. So he must ensure that the lamp failure alarm is attended to immediately, or if there is no such alarm, that the lamp is continuously working. During maintenance cleaning of the quartz tube, great care should be taken with the UV lamp as it is very fragile. Spares should always be available in the community.

The MOGGOD equipment will operate if the solutions are in the right concentration and the salt and water levels between specified margins. Checking the sodium hydroxide solution density, diluting it, checking the chlorine residual and how to vary it by varying the amperage from the control unit, etc are simple operations, but may be a bit troubling for a rural operator that probably has never had contact with any electrical equipment. MOGGOD technology, while being very simple, is still the least simple of the three recommended systems. Special care should be placed on the instruction and training of the operators. Besides these points special care should be also placed on the operation of the venturi. This injector, if very small, may get clogged by particles, and its inner hole consequently very reduced. Sometimes it is better to place a filter before the venturi, and this filter then be cleaned with the appropriate frequency.

During the first change of the membrane, it would be important that a member of a technical support agency be present to aid or instruct the operator in the way of doing such a change.

The On-site hypochlorite generation is very simple and there are only a few points to be highlighted. Firstly when preparing the NaCl solution the operator has to be sure that all the salt has been dissolved. Failing to comply with this, will result in a less concentrated brine solution and in a weaker NaOCl solution concentration. Secondly, the cleaning of the electrodes is crucial as, if not properly done, the lifespan of the anodes will be drastically reduced. Checking of the feeding system (that may clog) is also important to the correct functioning of the disinfection procedure.

7.2 Level of Operator's Skills

From vast experience it can be said that the probability of contracting an operator with high level of skill, education or even awareness in the rural areas of third world countries, is definitely very low.

But fortunately it is not the level of his knowledge or education what matters, but rather his commitment, interest, and other factors. In many instances if there is a failure due to the operator, the reason lies beyond his level of education and training.

Lack of understanding what he is doing, what he has to do, and why he is doing what he is doing are typical with some of these operators, and this is the reason for many operator generated failures.

It is of the utmost importance to devote all the time that should be necessary to get the operator's support through the proper instruction, health care education and efficient training. As important to teach him what he is doing and why he is doing certain technical activities, is to convince an operator about the importance of his work and the responsibility he has towards his community.

If the process of interesting the operator is properly performed then this uneducated person that has accepted to work in a treatment plant only for money, may be transformed into a champion who will care for his system and even improve it, finding new alternatives to certain activities, and mostly through very simple but intelligent innovations. It is important that he may understand the system and take pride in it and in what he is doing. Such feelings will have to be implanted in him through the proper education performed by the support agency. If this social activity is not performed, then the technical issue will fail.

8. CONCLUSIONS AND RECOMMENDATIONS

Three appropriate disinfection technologies have been studied and understood. Either of them can be an important tool for improving the health of the water supplies to small and medium communities. Their use and their ongoing maintenance does not pose particular problems or difficulties.

Although not the perfect solution, they do have a number of advantages over alternative disinfection systems for use in such communities. This can be confirmed not only within the South African perspective, but from the actual state of the art of disinfection technology in the world today.

Their simplicity and their disinfection efficiency is high. Nevertheless, further field evaluations of the technologies should be carried out. Real problems will arise and will be seen when actual conditions are met.

PART II: BACKGROUND REPORT ON:

NON-CONVENTIONAL DISINFECTION TECHNOLOGIES FOR SMALL WATER SYSTEMS

by

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The steering committee responsible for this project consisted of the following persons:

Mr G Offringa	Water Research Commission (Chairman)
Mr HC Chapman	Water Research Commission
Mr D Huyser	Water Research Commission (Secretary)
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1. INTRODUCTION

Statistical analysis of the state of the world's health by the World Health Organisation indicate that every day approximately 150 000 people die in the world. One third of these die because of water related diseases, primarily through water-borne pathogens. It has further been noted that the main causes for the wide spread of water related diseases are as follows:

- poor quality of water used for drinking purposes, primarily due to the presence of pathogenic organisms;
- the lack of sufficient water for general hygiene;
- the lack of adequate sanitation facilities; and
- poor hygiene practises resulting from the lack of adequate hygiene education.

The first of these is related to the protection and disinfection of water used for domestic purposes. This technical guide is primarily concerned with the disinfection of water for small communities where conventional disinfection techniques may not be appropriate. Clearly, however, the protection of water supplies and attention to the other causes of water related diseases (provision of sufficient water, sanitation, and health education) should also be viewed as being of vital importance in any integrated water supply programme for small or larger communities.

The practice of disinfection of water supplies has been in general use since the beginning of the century in Europe and other developed countries, and has given rise to a substantial reduction in the occurrence of water related diseases in these countries. The most often used technology to achieve disinfection has been chlorination. This has traditionally meant the addition of chlorine gas or other chlorine compounds to the water to be supplied to domestic users. This method of disinfection has proved to be reliable, appropriate and effective in most developed countries and now also in virtually every large town and city in the world.

Nevertheless, UN agencies like the World Health Organization, and the Pan American Health Organization, have found that the practise of chlorine disinfection in rural, small town and peri-urban areas of developing countries is at best problematic, and at times can be considered as having being a failure[70]. This has received particular attention in South America where the primary author (F. Solsona) has personally been involved.

The reason for this failure, according to the WHO, is related to the problem of obtaining the chlorine chemicals in these small rural and informal urban settlements. In many cases the chemicals involved (chlorine gas, sodium hypochlorite, or calcium hypochlorite) are not readily obtainable by the community in the form and quantity required. Problems of cost, purchasing, transport, and of importation when the products are not produced in the country, are responsible for the above mentioned failures. The related problems of accurate dosing and residual monitoring without the necessary level of skills, equipment and instrumentation have also been significant in the lack of reliability of chlorination disinfection in small water systems. Institutional problems including lack of community education, inadequate operator training, and inadequate institutional capacity for the purchase, transport and storage of chemicals have also been cited[70].

Consequently, although conventional chlorination practices are one of the most suitable for water supply systems where the chemicals can be obtained in close proximity of the treatment plant at an affordable cost and where the necessary skills and equipment are accessible, alternative methods of disinfection should be assessed for settlements where this is not possible in the short to medium term at least. To address the present shortcomings, disinfection technologies which have the following characteristics should be further investigated and assessed:

- they must be affordable by the community from both a capital cost and the ongoing operation and maintenance costs points of view;
- they must be simple to operate and maintain, yet also give reasonably accurate doses of the disinfectant;
- the materials or chemicals which are regularly required for ongoing operation should be readily available at close proximity to the place of usage.

Although there is a good understanding of chlorination technology and there are many technical devices that can be used for feeding the chlorine gas or solutions to the water to be treated, the measure is often not being implemented, or it is implemented only for an initial short period whereafter it is discontinued.

The reason for this failure, according to the WHO, is related to the problem of obtaining the chlorine chemicals in these small rural and informal settlements. In almost all cases the chemicals involved (chlorine gas, sodium hypochlorite, calcium hypochlorite, etc) are not readily available to the community in the form and quantity required. Problems of purchasing, transport, and of importation when the products are not produced in the country, are responsible for the above mentioned failures.

Consequently there have been concerted efforts to research and develop alternative methods of disinfection. The aim of this research has not been focused on the more "scientific" developments around disinfection byproducts, but rather on finding methods which can be used safely and reliably in the more remote or less well serviced sections of the population.

The main objectives of this research and development have been to produce disinfection technologies which have the following characteristics:

- affordability to small communities (capital & O&M);
- technically simple yet accurate dosing;
- easy to operate and maintain;
- if any material or chemical should be needed, it should be readily available close to the place where it will be used.

The aim of this research project then has been to assess the available technologies in this context which have been developed to date, and to recommend those technologies which would be most suitable for the conditions prevalent in the small water systems as found in most developing communities, particularly in rural South Africa.

2. AIM OF THIS DOCUMENT

As stated above, the present research, supported by the Water Research Commission, intended to assess which alternative disinfection technologies could be regarded as potentially suitable for the conditions prevalent in the rural developing communities. These were to be tested and then their potential for use as reliable disinfection systems for small water projects in the South African rural environment be promoted.

It is felt important that the document should also highlight the advantages and disadvantages of the chosen technologies. Decisions on the technology to be used in a particular situation need to be based on a good understanding of the pros and cons of each particular technology.

With these important goals, the document should provide sound recommendations on what technologies can be used in the future for the provision of safe water for the rural communities of South Africa.

3. RELEVANT CHARACTERISTICS OF RURAL COMMUNITIES

One of the primary aims of this research project was to find appropriate disinfection systems for water supply schemes in rural communities. The selection of technology relevant to this aim requires firstly an understanding of the characteristics and circumstances prevailing in typical rural communities. Similar circumstances and characteristics may also be found in some informal and semi-formal urban communities.

There are many different definitions of "rural communities" around the world. There is furthermore no fixed number of people in a village/town that may define the limit between rural and urban. Limiting numbers have been set at 100; 500; 1 000; 5 000; 8 000; 10 000 and even 20 000 people, and in South Africa some "rural" villages are even larger than 20 000 people.

Since a simple number count is not a sufficient measure of the distinction between rural and urban, other characteristics which may describe the status of rural or urban must be used. To illustrate this dilemma, a small neighbourhood of perhaps 100 or 200 houses located around a big factory (like the paper mill in the Eastern Transvaal) and lodging employees of that firm, may be in a rural environment. However the overall conditions (services, roads, communications, etc) would place this community more on the side of "urban" than "rural". On the other hand elsewhere in South Africa the slum areas around the larger towns and cities may be considered to be "rural" in characteristic and not urban.

This illustrates that the primary distinction between settlements where alternative disinfection techniques may be required are related to the existing levels of service, the economic status of the community, and the level of the existing technical and institutional skills of the residents.

South Africa does not have a fixed norm for what is rural and what is urban. However, related to the aims of this project and the distinction above, this study has adopted the following criteria:

"Rural" means a community of people living in a country side environment which lacks access to major services. The homes may be located relatively close to each-other, but usually not as close as in the cities. There is a degree of isolation from important towns and cities where goods and services are more readily available. The residents are generally of low income, low education and having a low level of technical skills.

Concerning the number of people, three types of communities as defined by the Steering Committee for this project have been adopted. There may be situations where the size of the community has an impact of the choice of technology.

SMALL	1 to 500	inhabitants
MEDIUM	500 to 2 000	inhabitants
MAJOR	2 000 to 20 000	inhabitants

In the rural areas there is generally a lack of resources, skilled personnel, and education. The choice of technologies applicable to these conditions make take cognisance of the limitations that act as barriers to the use of technologies which are successful in the more developed areas.

In the search for appropriate technologies, the designer must gain an understanding of the conditions that prevail in the particular areas he is working in. In particular, the social aspect is something which is of vital importance in the rural communities, and aspects relevant to this must be taken into consideration.

From the point of view of disinfection of the water supplies, the approach is also quite different. In the case of a big town or city, the water supplier may worry about the risk of disinfection by-products, corrosion and water stability. In the rural areas the supplier will be concerned with the risk of having major outbreaks of diarrhoea in his village or town.

Designing water supply and disinfection systems for the rural areas generally requires a multidisciplinary approach, or holistic view, which incorporates not only the technical considerations, but also the institutional situation and development needs. The use of the technology in the actual situation which can be expected to exist in practice must be considered, as opposed to only considering the ideal. An important question the designer must continually ask himself is "will this technology actually result in an improvement in the health status of the users in the longer term?". This is particularly relevant since an unreliable disinfection system could result in a reduction in the resistance of the users when the system operates properly, and then a substantial increase in the incidence of infection when it breaks down due to the loss of existing built up immunity to water related infections.

Hence the approach of this research project was to assess those disinfection technologies best suited to the developing rural community environment, particularly with respect to small water systems in these situations.

4. WORK PROGRAMME

The work plan for this project consisted of three phases.

4.1 Phase 1: Literature survey

The first phase was a literature survey. It was necessary to assess the state of the art in rural water disinfection and what recent achievements in new "non-conventional" technologies had been attained in the world. The literature survey had to be sufficiently thorough to make it possible to identify potential technologies for further evaluation.

4.2 Phase 2: Evaluation of promising equipment

The second phase would consist in the testing of the identified most promising technologies in simulated conditions. Equipment for three types of systems was purchased, installed and tested to evaluate their main characteristics and their performance over a period of continuous use.

4.3 Phase 3: Write-up and final report

Finally, the last phase would be the analysis of the information obtained and the identification of relevant characteristics with regard to the use of these technologies in the rural environment. A document outlining all the information gathered during the study would be compiled as a final report. It should be noted however that in the final meeting of the steering committee of this project, the following documents were requested as a final report:

- executive summary and literature survey;
- technical guide on the selection and use of the alternative technologies.

5. LITERATURE SURVEY

A literature survey was carried out at the outset of this project. It was completed in May 1992, and made use of the Waterlit Service from the CSIR (supported by the WRC), as well as the experience of the researchers, and from reports and papers received from other studies around the globe.

About 80 documents from all parts of the world were scanned in order to assess the latest trends in water disinfection.

More than 20 different disinfection technologies were identified in the literature, and their respective characteristics were studied in further detail. Of these, three were finally selected for further evaluation.

5.1 DISINFECTION TECHNOLOGIES

Among the non-conventional disinfection technologies identified and studied in the literature survey, the following were considered:

- iodine and iodide mixtures
- ozone
- peroxone
- chlorine dioxide
- hydrogen peroxide
- peracetic acid
- bromine/bromine chloride
- electrical current or electrical fields
- ultrasonics
- methylene blue
- potassium permanganate
- metallic ions
- ultrafiltration
- MIOX
- UV radiation
- MOGGOD
- on-site hypochlorination

These technologies are used on their own, or in combination in order to achieve specific disinfection or oxidation objectives.

A particular consideration which had to be taken into account was whether it is absolutely necessary to provide a disinfectant residual for small rural water supplies. This has implications as to whether certain promising technologies, e.g. UV disinfection, can be considered or not. The decision was made that the need or not of a residual should be decided for each particular application, and this study would be based on the assumption that a residual may not always be required. Support for this viewpoint comes from the following considerations:

- Presently many rural water supply schemes are from boreholes where no disinfection is applied. The levels of diarrhoea in these communities are not abnormally high, and improved sanitation and health education result in a low level of water related sicknesses.

- Most rural women are fully aware of the need to store water in clean containers, and have adopted the practice of rinsing out containers before filling with water for drinking. Drinking water containers are, in general, used only for drinking water.

- In cases where a residual is deemed necessary, alternative disinfectants can still be used in conjunction with a low level disinfectant which will provide the residual.

- In cases where regrowth in the distribution system is of concern, periodic shock dosing of the system as opposed to continuous dosing can be practised.

From the literature survey the disinfection technologies could be grouped according to their potential for use in small water systems.

The first group was classified as "unapplicable". The technologies in this category are not suited to use as an alternative to conventional chlorination in small water systems due to one or more of the following:

- not yet truly commercialised - still at a laboratory level development stage;
- there is not sufficient information on the system to be able to assess its actual potential;
- they are very expensive, either in terms of capitol costs or operation and maintenance costs or both;
- they are intended for flows not typically found in small water treatment plants; or
- they require a high level of skill and knowledge to operate and maintain, beyond that which can reasonably be expected in a small community.

The second group was termed: "possible". This represents the technologies that show some merits for use as an alternative to conventional chlorination in small water systems, but either are not readily available or are not in a state that can be considered fully developed. That is:

- further equipment development still required;
- further research on the disinfection potential required; or
- further research on the operation and maintenance still required.

These technologies present a state of development that is not as yet suitable for the small water supply systems in the South African communities, typical of the rural environment. Nevertheless, they should not be totally discarded because improvements in their characteristics may allow them to be classified as "recommended" in the near future.

Finally, the third group was termed "recommended". This group contains those technologies which it is believed are suitable as alternatives to conventional chlorination in small water systems.

5.2 UNAPPLICABLE TECHNOLOGIES

As stated above, these technologies are considered to be unapplicable for use with small water supply systems, but are listed here for completeness, and to indicate their potential for use in other water treatment situations.

5.2.1 Iodine and iodide mixtures

Iodine is a strong disinfectant and is often used for medical applications in the sterilisation of wounds. In water treatment it can be used either by direct dosing into the water stream or, more commonly, by impregnation into a medium like a resin through which the water is passed[1,43]. Iodine disinfectants for potable water include the following[54]:

molecular iodine	I_2
hypoiodous acid	HOI
the iodine cation	H_2OI^+
3-iodide	I_3^-
penta-iodide	I_5^-

The latter two in particular have been used with some success on resins on the NASA space shuttles in the USA.

A number of studies have indicated that for contaminated water, complete disinfection is not always achieved when passing the water through an iodine impregnated resin[1,54].

Iodine does not react with ammonia compounds in water and hence retains its full oxidative power in the presence of these compounds[66]. However, an important disadvantage of iodine is its physiological thyroid activity[66], which necessitates its removal from water to be used for drinking purposes before consumption. This is usually achieved by passing the water through activated carbon.

Iodine is a costly option for disinfection, although it is being considered for emergency situations due to its property of impregnation into a resin giving rise to its ease and safety in transport and long shelf life. It has not been applied in South Africa to any extent to date for the disinfection of drinking water.

Iodine	unsuitable	acceptable	suitable
capital costs		x	
O&M costs	x		
skills for O&M			x
dosage accuracy	x		
local availability	x		

5.2.2 Ozone

Ozone came into use as a drinking water disinfectant as early as 1906 at the Bon-Voyage plant in Nice, France[39]. Since those early times, this technology has undergone further developments and today it is successfully used at many large water treatment plants for cities around the world. Ozone is a powerful disinfectant and some of these plants use it as a primary or even sole disinfectant. However others use it mainly as an oxidant for the control of flora, odour, and colour and to reduce the manganese and iron content of drinking water[39]. For effective disinfection of both bacteria and viruses, a standard treatment requires a dissolved residual ozone content of 0.4 mg/ℓ after a continuous reaction time of 4 minutes[20].

Ozone is commonly produced by the cold plasma discharge method in which ozone is formed by decomposition of diatomic oxygen. The feed gas is either air, air enriched with oxygen, or pure oxygen. The feed gas must be oil free and have a low dew point (-52 to -58 °C)[39]. Ozone generators are not very energy efficient and when operated with air about 17 Wh are necessary to produce 1g ozone, an energy yield of less than 5%[51]. Most of the energy is lost as heat, and hence it is essential to maintain a cooling water system when using ozonators[51]. The ozone enriched air must be piped to contact chambers where it is dispersed into the water by fine-bubble diffusers[62].

Ozone suffers from two major limitations as a disinfectant. Firstly it is unstable in water, it decomposes to oxygen at a rate proportional to the pH of the water (e.g. at pH 8, its half life is less than 1 hour), and secondly it reacts with natural organic substances to produce low molecular weight oxygenated substances that generally are more biodegradable than their precursors[39]. The result is that a residual disinfectant capacity will not be maintained in a distribution system, particularly where storage is a component of the distribution system, and furthermore the organic products of ozonation will promote biological growth in the distribution system. For these reasons ozone should be used in combination with other disinfectants that maintain an active residual[39].

Other drawbacks of ozone use is that despite efforts to clean the air, tiny amounts of contaminants eventually penetrate into the ozonators leaving microscopic deposits on the dielectric tubes and reducing efficiency[62]. Cleaning of the tubes is a complex process.

Ozone is used at a number of larger water purification plants in South Africa at present, and has proved effective in dealing with the specific oxidation needs at these plants.

Ozone	unsuitable	acceptable	suitable
capital costs	x		
O&M costs		x	
skills for O&M	x		
dosage accuracy		x	
local availability	x (spares)		x (air)

5.2.3 Hydrogen Peroxide

Hydrogen peroxide is an oxidant used in various industrial and medical processes, and is a common household antiseptic. However, it is considered more of a bacteriostat than a bactericide[30], and is used more to reduce bacterial populations than to eliminate them. It is also an important algicide and fungicide[30], and its harmless decomposition products of oxygen and water make it a choice disinfectant for certain applications in the food industry. Points in its favour for use in small water systems include[13]:

- ability to store large quantities under minimal storage regulations;
- not hazardous to the environment;
- effective over a wide pH range.

However, as already noted, hydrogen peroxide is not an effective disinfectant for the treatment of potable water on its own. To achieve adequate disinfection considerable higher dosages are required as compared to chlorine (1.5 to 5% for H_2O_2 vs 0.5 to 2mg/ℓ for chlorine), with extended contact times. In comparison to chlorine, the cost of the product is higher (up to 8 times more costly than chlorine for the same dose), and the availability at more remote areas is very poor. The measurement of a residual for monitoring purposes is also very difficult[36].

Hence in general hydrogen peroxide is unsuitable as a drinking water disinfectant even in the developed world, although it is being used for wastewater disinfection in certain circumstances, and could be considered for drinking water when used in conjunction with another oxidant or catalyst.

Hydrogen peroxide has not been applied in South Africa to any extent to date for the disinfection of drinking water.

Hydrogen Peroxide	unsuitable	acceptable	suitable
capital costs		x	
O&M costs	x		
skills for O&M		x	
dosage accuracy			x
local availability	x		

5.2.4 Peracetic acid

Peracetic acid is a relatively new product, with significantly higher disinfection power than hydrogen peroxide (10 to 100 times more effective[13]), but maintaining some of the useful properties of hydrogen peroxide. However, it also has a number of associated problems which discount its use as a disinfectant for small water systems. These problems include the following:

- high cost;
- hazardous to handle[13] due to its strong odour, its vapours can form explosive mixtures in air, and combustible materials (e.g. clothing) can easily ignite when contaminated with the chemical;
- self accelerating exothermal decomposition at high temperatures[13];
- reduced bactericidal effect as pH increases[30].

In its defence, however, it does have a number of advantages, particularly for use as a wastewater disinfectant. These include:

- can be used over a wide temperature range[30] (4-37°C);
- non-toxic decomposition products[30] (acetic acid, oxygen and water);
- strong fungicidal effect as compared to most other disinfectants[30];
- good sterilization of spores of sporulating microbes[30].

Peracetic acid has also not yet been extensively tested in practice, and the cost and other problems set out above make it unsuitable for use as a disinfectant for small water systems.

Peracetic acid has not been applied in South Africa to date for the disinfection of drinking water.

Peracetic acid	unsuitable	acceptable	suitable
capital costs		x	
O&M costs	x		
skills for O&M	x		
dosage accuracy		x	
local availability	x		

5.2.5 Peroxone

Peroxone is a relatively new disinfectant/oxidant which attempts to capitalise on the synergistic effect of combining ozone with hydrogen peroxide. It has been found that by combining these two oxidants, the oxidation strength is greater than with either of these on their own for certain applications[33]. Peroxone is formed by passing a hydrogen peroxide solution through ozone contactors while maintaining the ratio of hydrogen peroxide to ozone in the range of 0,1 - 0,3. This results in the production of the OH radical which is one of the most powerful oxidizing agents that can exist in water. Peroxone then results in a reduced ozone requirement when compared to ozone on its own[33].

However, the production of ozone is still a necessary component of the disinfection system, and hence the same drawbacks for its application in small community water supply systems as for ozone apply. The addition of hydrogen peroxide at a specific ratio to the ozone further complicates the system, including requirements for chemical purchasing, handling and storage, operating and maintaining the chemical dosage equipment, and increased capital costs. Hydrogen peroxide is less readily available than chlorine, particularly in the more remote areas.

Peroxone has only been used in laboratory scale tests in South Africa to date.

Peroxone	unsuitable	acceptable	suitable
capital costs	x		
O&M costs	x		
skills for O&M	x		
dosage accuracy	x		
local availability	x		

5.2.6 Bromine

Bromine, being a halogen similar to chlorine, acts in much the same way as chlorine. It can be supplied either as liquid bromine (but is highly corrosive), as bromine chloride (less corrosive), in a slow releasing organic complex (easy to handle but costly), or as NaBr salt which must then be oxidised to bromine on site (e.g. by addition to a chlorine solution). Bromine does have a number of advantages which make it an appropriate choice of disinfectant under specific circumstances. These advantages include the following:

- more reactive than chlorine for inactivating enteric viruses[2];
- bromamines which form when ammonia is present (e.g. wastewater) are significantly more effective than chloramines[2];
- bromine is effective over a wider pH range than chlorine;
- bromine and bromamines are less stable than their chlorine equivalents, and hence are less hazardous to aquatic life when wastewaters are discharged[11];
- being a liquid at ambient temperatures, bromine is less volatile than chlorine[11], and hence can be stored and handled more easily than chlorine gas.

Despite these advantages over chlorine, however, bromine is not commonly used for disinfection. Bromine has a significantly greater cost than chlorine and is not readily available. It can be easily generated from the salt (NaBr) by the addition of chlorine, but this then further complicates its use for small water supply systems.

Bromine is used in South Africa at present for the disinfection of recirculated mine service waters where ammonia levels are high, and in warm water spas where its lower volatility and the higher effectiveness of bromamines make it an attractive alternative to chlorine.

Bromine	unsuitable	acceptable	suitable
capital costs			x
O&M costs	x		
skills for O&M		x	
dosage accuracy			x
local availability	x		

5.2.7 Chlorine dioxide

Chlorine dioxide (ClO_2) is a water disinfectant now being used fairly extensively throughout the world, but particularly in Europe and the United States. Its major advantages over chlorine include the following:

- generally more powerful bactericide, sporicide and virucide[2];
- does not react with ammonia or aromatic organics, and does not form carcinogenic trihalomethanes (THMs)[2];
- it is less likely to form chlorinated organics[2];
- is capable of destroying certain precursors of THMs[51];
- in general produces less tastes and odours, and more effectively oxidizes organic tastes and odours;
- some studies indicate that the residual in the distribution system is better maintained than with free chlorine[34];
- chlorine dioxide is not as affected by variations in pH as is chlorine[34];
- more effective removal of iron and manganese[28].

Hence, although used extensively in some countries, chlorine dioxide does present a number of limitations for its use in small water systems. ClO_2 is an unstable gas and must be generated on site. It can be produced from sodium chlorite in combination with chlorine and/or a strong acid (HCl or H_2SO_4). The production process must be carefully monitored and controlled to produce high levels of chlorine dioxide. Other limitations to its use for small water systems include the following:

- high cost of precursor ($NaClO_2$);
- sensitive to light and hence should not be used where water is contained in open tanks[34];
- the byproducts of ClO_2 disinfection include chlorite and chlorate which may have health implications for consumers (still under research).

Chlorine dioxide has been used in South Africa for the disinfection of recirculated mine service water where ammonia levels are high, and for drinking water treatment where algal problems occur. It has also been used experimentally for drinking water treatment where iron and manganese problems occur.

Chlorine dioxide	unsuitable	acceptable	suitable
capital costs		x	
O&M costs	x		
skills for O&M	x		
dosage accuracy		x	
local availability	x		

5.2.8 Methylene blue

It has been found that methylene blue can be an effective disinfectant when combined with photo-oxidation methods[67], particularly for wastewater treatment. The methylene blue is covalently linked to polystyrene beads or coated on activated carbon, silica gel, or a polystyrene resin (XAD-2)[67]. These techniques have not yet been implemented to any extent internationally, and hence can at this stage be discounted for use in small water supply systems until further evaluations have been carried out.

Methylene blue	unsuitable	acceptable	suitable
capital costs	x		
O&M costs	x		
skills for O&M		x	
dosage accuracy			x
local availability	x		

5.2.9 Potassium permanganate

Potassium permanganate is primarily used as an oxidant in water treatment processes, and not as a disinfectant[18]. However, it does demonstrate some disinfection properties, although die-off rates are lower than for chlorine. However, potassium permanganate does decompose to manganese dioxide, which is a precipitate which can cause colouring of washing, household utensils, etc., and hence potassium permanganate is usually added before a coagulation/ flocculation step in water treatment.

As an oxidizing agent, potassium permanganate is effective in controlling tastes and odours, as well as removing hydrogen sulphide, iron and manganese[18]. It is simple to store, handle and dose to water.

The primary disadvantages to its use as a disinfectant in small water systems are its high cost, and the resulting residual which gives rise to discolourisation of washing, etc. unless removed in a coagulation/flocculation step. It is also not readily available in the more remote areas.

Potassium permanganate has been used in South Africa as an oxidant for the removal of iron and manganese at certain water treatment plants. It has not been used as a disinfectant on its own.

Potassium permanganate	unsuitable	acceptable	suitable
capital costs			x
O&M costs	x		
skills for O&M		x	
dosage accuracy			x
local availability	x		

5.2.11 Electric current or fields

It has been found that electric currents or fields with a field strength of 500 to 2500 V/m display disinfection properties[42]. Direct current is more effective than alternating current, but poor inactivation of certain bacterial species has been observed[40]. These processes involve passing the flow through an electrostatic or electromagnetic field. However, there has been much controversy over these processes, with mixed reports in the literature as to their effectiveness[2]. More recent research has found electrostatics to be a viable process for the reduction of bacteria and viruses in water treatment[2]. An increase in the effectiveness of the electrical field is accomplished by adding salts of polyvalent cations, particularly aluminium and lanthanum[47]. However, with respect to virus inactivation, an electric field, even in combination with polyvalent cations, does not result in a significant decrease in levels, although it does make viruses more sensitive to downstream chlorine treatment[47].

Disadvantages related to its use for small water systems include the following:

- high capital costs;
- high ongoing electrical costs;
- high level of technology for maintenance;
- not completely effective as a disinfectant on its own.

In South Africa the use of electrical currents in water treatment has been a matter of some controversy, and some testing has been undertaken on its use for scale control, particularly on the mines. Its use as a disinfectant has not been given much attention to date.

Electrical fields	unsuitable	acceptable	suitable
capital costs	x		
O&M costs	x		
skills for O&M	x		
dosage accuracy			x
local availability		x	

5.2.12 Ultrasonics

Ultrasonics or ultrasound is effective in destroying a wide range of bacteria, yeasts, and Ascaria[2]. However, as with electrical currents and fields, it is generally agreed that it should not be used as the sole disinfectant for drinking water treatment[42]. Problems associated with the use of ultrasound include the following:

- thick films of water attenuate the sound waves and thereby reduce effectiveness;
- high capital costs;
- not yet fully developed for commercial use;
- requires combination treatment, e.g. chlorine.

Ultrasound has not been used in South Africa for disinfection purposes.

Ultrasound	unsuitable	acceptable	suitable
capital costs	x		
O&M costs		x	
skills for O&M	x		
dosage accuracy			x
local availability	x		

5.3 POSSIBLE TECHNOLOGIES

As stated above, these technologies are considered to be possible for use with small water supply systems, but do require further development or a higher level of expertise than may be desirable for small systems. Hence these could be considered acceptable under certain circumstances, or with limited further development.

5.3.1 Microfiltration

One method of disinfecting water is to pass it through membranes with a pore size less than the size of the microorganisms. Microfiltration membranes generally have pore sizes in the range 0.1 to 5.0 μm, and the *E. Coli* bacteria have a size of 0.5 by 1-3 μm[46]. Hence by selection of a membrane close to but less than the minimum size of the microorganism of concern, good disinfection can theoretically be achieved. Experiments with microfiltration membranes, however, tend to result in some breakthrough of bacteria after a period of time (e.g.[46]). If it possible to maintain an ongoing cleaning programme of the filters however, microbiological quality of the final water can be maintained[29]. The removal of the much smaller viruses seems to be possible with these membranes aswell since most viruses are attached to larger bacteria or other particles[29]. Ultrafiltration membranes with pore sizes less than 0.1 μm can also be used, but excessively fine-pored membranes have a very high hydraulic resistance, resulting in very high ongoing energy costs.

The advantages of microfiltration disinfection are that there is no need for chemicals, and water clarification can take place simultaneously. However, membranes do become clogged with time despite the ongoing cross-flow cleaning process. Hence pretreatment of the water by conventional means is advocated to lengthen the life of the costly membranes. Methods to reduce the problem of fouling include sponge-ball cleaning of tubular membranes, physical roller cleaning of flexible woven fibre membranes, and the use of ceramic membranes which can withstand severe physical and/or chemical cleaning[59]. In case of the latter, ceramic filter systems with impregnated silver are commercially available where the combination of methods ensures a long life and effectiveness of the filter[7].

Although promising, this technology is at present not ready for use with small water supply systems. Capital costs are high and operation is complex, requiring a high level of skills. Future developments may enable this to be considered as appropriate in the future.

In South Africa microfiltration has not been used specifically for disinfection, but has been applied with some success to the concentration of water treatment sludges. Other laboratory and pilot scale treatment sequences have been carried out experimentally.

Microfiltration	unsuitable	acceptable	suitable
capital costs	x		
O&M costs			x
skills for O&M		x	
dosage accuracy			x
local availability		x	

5.3.2 Metallic ions

Certain metallic ions in water display a bactericidal effect, particularly copper, silver, aluminium, thorium and zinc. Relatively low levels of the metallic ions are required (less than 1 mg/ℓ), and these can be electrolytically generated on site. However, the inactivation rate is slow as compared to chlorine[49], e.g. a 2 $\log_{10}$ decrease in cell numbers was achieved with a combined copper:silver ion dose of 0.44 mg/ℓ after 2 hours, whereas chlorine at 0.2 mg/ℓ achieved a 2 $\log_{10}$ reduction after only 2 minutes[49]. This may not be a problem in certain cases. Higher levels of aluminium and thorium are required than for copper and silver[48], and hence the most appropriate ions are those of copper and silver. The use of these in combination at a ratio of 10:1 copper to silver improves their inactivation rate[49]. However, to date these systems have mainly been confined to swimming pool use.

Disadvantages related to the use of metallic ions for disinfection in small water systems include the following:

- difficulty of measuring concentrations in water;
- does not significantly affect virus levels[47,28], except at very high concentrations;
- less effective against certain bacteria, e.g. staphylococci, and hence should not be used as sole disinfectant[72];
- high cost of electrodes for production on site;
- toxicity of residual metal ions in water (max silver concentration permitted = 0.05 mg/ℓ)[66];
- long contact period required.

Metal ions have been used successfully for swimming pool disinfection in combination with low levels of chlorine, in which circumstances low levels of both disinfectants can be maintained[72].

In South Africa only limited laboratory scale tests have been undertaken with metal ions for disinfection.

Metal ions	unsuitable	acceptable	suitable
capital costs		x	
O&M costs		x	
skills for O&M			x
dosage accuracy	x		
local availability	x		

5.3.3 MIOX Technology

MIOX is a new technology based on a hypochlorite generating cell. As yet there is no generally published literature on the system, and the following relates to the author's own personal contact with the original developers.

MIOX has been developed in the USA with initial work beginning in 1982, supported by the US Army. In 1985 the first units were employed on certain of the US Navy's ships. The units produce a mixture of oxidant gases in solution. These include chlorine and certain oxygen species including ozone, hydrogen peroxide and the hydroxyl radical in small quantities. There is no membrane in the generator, the production being related to the configuration of the electrodes and the electrical potential across the electrodes. The system is therefore easily maintained, and can be used with any type of brine solution, or even seawater. Present systems can treat up to 12 m^3/h on a 24 h/d basis. It is unfortunately not yet generally available due to final evaluation and testing by the company involved in the USA.

MIOX	unsuitable	acceptable	suitable
capital costs		x	
O&M costs			x
skills for O&M			x
dosage accuracy		x	
local availability	x		

5.4 RECOMMENDED DISINFECTION TECHNOLOGIES

These are the technologies that in opinion of the researchers are potentially the most appropriate for the rural environment of South Africa, or to small water systems where problems with availability of chemicals, costs, and operator skills make conventional chlorine disinfection inappropriate.

The characteristics of these alternative systems are:

- they are independent of the need for "imported" chemicals;

- they are simple to operate and maintain;

- they have low capital and low running costs.

The following technologies were selected under this category:

*** UV Radiation

*** MOGGOD

*** On-site hypochlorite production

In the following sections these recommended technologies are described according to their characteristics, qualities, advantages and disadvantages.

5.4.1 UV Radiation

Ultraviolet radiation is a relatively old technology which was first used for disinfection purposes in 1910. Nevertheless it was, until recently, never considered to be a reliable means of disinfection[26]. The main reasons for this were, inter alia, as follows[73]:

- the core of the technology - the lamps - often failed, or were inconsistent in their emission (intensity and/or wavelength);

- chlorine is a relatively inexpensive commodity in most developed countries;

- there was a lack of understanding of the technology by users, engineers and authorities;

- there was a lack of effective systems for treating high flow rates;

- there was a lack of standards and uniform criteria for its application[25].

It was not until the early eighties that the technology of UV lamp manufacturing improved to the extent that lamps of high reliability are now readily available. Today, lamps with a life expectancy of up to 8000 hours and an emission decay of not more than 20 % over this period can be obtained, e.g.[6]. In particular the advent of continuous monitoring systems and the medium pressure lamps have enabled reliable systems capable of treating high flow rates possible[73].

A UV system is a very simple disinfection device, and among its many advantages are the following[9,25,26,73]:
- no chemicals needed;
- the installation is very simple;
- operation and maintenance are extremely simple;
- there are no moving parts;
- it is efficient in killing microorganisms within a short time period;
- it does not form toxic compounds as a by-product;
- it does not modify the organoleptic characteristics of the water (i.e. no resulting increase or decrease in taste and odours);
- there is no risk of overdosage and hence negative environmental impacts;
- there is no oxidation, so no possible increase in the corrosion potential.

Although its advantages seem to indicate that UV is a highly desirable disinfection technology, there are some drawbacks. The first is related to the difficulty in determining the effective dose for a certain type of water. Only if the dose is adequate will microorganism destruction be complete.

The maximum microorganism sensitivity to UV radiation is at a wavelength of 255 nm. Low pressure germicidal lamps emit UV light at wavelengths of 254 nm where the peak energy almost matches the peak bacterial sensitivity value of 255 nm. Medium pressure lamps are unable to emit energy within a narrow waveband but cover a broader range between 240 and 300 nm. However the significantly greater energy emissions associated with these lamps ensure a high dose of UV energy at the desired wavelengths (255nm)[73].

The resistance of the different of microorganisms to ultraviolet radiation varies considerably, and it has now been suggested that *Micrococcus lutea*, which is considerably more resistant to UV radiation than *E. coli*, be used as a standard for the assessment of UV performance[25].

The following table demonstrates this variation in sensitivity of different microorganisms to UV radiation[65], where UV energy is given in $mW.s/cm^2$ for 99% reduction in the counts of the various microorganisms:

TABLE 1. Sensitivity of microorganisms to UV radiation[65]

MICROORGANISM	GENUS	UV DOSE TO ACHIEVE 99% DESTRUCTION $mW.s/cm^2$
Bacteria:	*Bacillus anthraces* *Bacillus anthraces spore* *Bacillus subtilus spores* *Clostridium tetani* *Corynebacterium diptheriae* *Escherichia coli* *Legionella pneumophila* *Micrococcus radiodurans* *Mycobacterium tuberculosis* *Pseudomona aeruginosa* *Salmonella enteritidis* *Salmonella paratyphi* *Salmonella typhi* *Salmonella typhimurium* *Shigella dysenteriae* *Staphilococcus aureus* *Streptococcus faecalis* *Streptococcus pyogenes* *Vibrio comma*	4.5 54.5 12.0 12.0 3.4 3.2 1.0 20.5 6.0 5.5 4.0 3.2 2.1 8.0 2.2 5.0 4.4 2.2 6.5
Viruses:	*F-specific bacteriophage* *Influenza virus* *Poliovirus* *Rotavirus (Reovirus)*	6.9 3.6 7.5 11.3
Yeasts:	*Saccharomyces cerevisiae*	7.3
Moulds:	*Penicillium roqueforti* *Aspergillus niger*	14.5 180.0
Protozoa:	Various	60 - 200

From the above table it is clear that depending on the type of contamination the water may have, the UV dose, or the flow rate through the UV sterilizer, should be properly and carefully chosen. Generally a dose of 25-35 $mW.s/cm^2$ is considered acceptable for most water sources.

Other factors which must be taken into consideration when designing for UV disinfection include the following[26]:

- UV transmission in the water being treated is reduced by the presence of dissolved iron and manganese, by humic acids, and by other forms of turbidity;

- lamp intensity decreases with time, assumed to be 10% every 10 000 h;

- the quartz or teflon sleeve around the lamp could become scaled or contaminated with other deposits, and hence must be kept clean.

All UV systems should be equipped with an individual monitor on each lamp system[26]. This will enable performance losses to be detected and corrected before reaching a point of loss of effectiveness.

One further consideration is that UV radiation results in instantaneous disinfection. There is therefore no disinfection residual[9]. In certain cases the residual is not required, whereas in others it may be very important to have. In rural areas where water could be subject to recontamination, either through the reticulation system or where the water is likely to be contaminated in containers used to collect water from a tap or a standpipe, a residual to cope with secondary contamination may be essential.

Several companies in South Africa either manufacture or import UV systems.

UV Radiation	unsuitable	acceptable	suitable
capital costs		x	
O&M costs			x
skills for O&M		x	
dosage accuracy			x
local availability			x

5.4.2 Mixed Oxidant Gases Generated On-site for Disinfection (MOGGOD)

MOGGOD technology is based on the small scale electrolysis of sodium chloride, having been developed only in the last ten years. Its development has been supported by the Pan American Health Organization (PAHO)[72].

This electrolysis process requires an electric power source and common table salt as the only chemical requirement. Common table salt is easily available in any village in the rural areas, and grid electricity coverage is increasing daily in rural areas. Remote area power supplies (RAPS) can be considered where grid electricity is not yet available[22].

The conventional electrolysis of sodium chloride means the electrolytic conversion of chloride ions (from a saturated or very concentrated solution of common table salt in water), to form chlorine, hydrogen and sodium hydroxide.

The equations governing the process are:

At the anode:

$$Cl^- - e^- \longrightarrow \tfrac{1}{2} Cl_2$$

At the cathode:

$$Na^+ + H_2O + e^- \longrightarrow NaOH + \tfrac{1}{2} H_2$$

This process is rather slow and inefficient when the electrodes are placed in the brine media, but if there is a separation of both compartments (cathodic and anodic) by means of a membrane, the process becomes more efficient. When there is no separation between compartments, then the chlorine will react with the OH^- ions forming sodium hypochlorite which remains in solution together with the unreacted salts. When the cell is separated by a membrane, chlorine gas can be drawn off the anodic compartment.

The production of gas is approximately that of:

0.6 kg of oxidant/kg of salt

Electrodes

The cathode is a standard piece of stainless steel from the series 400. The anode used in the MOGGOD cell is a DSA or "Dimensionally Stable Anode"[12]. The DSA is a new technology developed in 1969 in the USA, recognized as the single most significant improvement to chlor-alkali manufacturing techniques. The DSA electrodes offer substantial reductions in power consumption and enable a high conversion efficiency in the process. Today, 90% of the chlorine production in the USA has been converted to DSA electrode systems[12].

The MOGGOD technology uses these electrodes in a special configuration - instead of a typical array:

cathode-membrane-anode

which is conventionally used for the production of chlorine, the new array makes use of an anode in several different planes parallel to the plane of the membrane and the cathode[61].

The different planes act as if the array would be:

cathode-membrane-anode-anode

This simple variation results in the production of not only chlorine at the anode, but also several oxygen species including ozone[4]. The effective disinfecting power of the mixture is very high as all the additional species formed in the reaction, although a small percentage of the total, have an extremely high oxidizing power.

Disadvantages (or operational requirements) of the MOGGOD cells are as follows[61]:

- the membrane clogs with time from unwanted by-product precipitates formed when common table salt is used;

- the gases formed must be fed into the flow of water which is more difficult than dosing of a liquid solution;

The mixed oxidant gases produced allows the treatment of even heavily contaminated water. The technology is rapidly developing and being used in Latin America, particularly in the small rural communities[61].

The MOGGOD systems have not been used to any extent in South Africa to date, although they are now commercially available. Laboratory scale tests have been carried out to a limited extent.

MOGGOD	unsuitable	acceptable	suitable
capital costs		x	
O&M costs			x
skills for O&M			x
dosage accuracy		x	
local availability			x

5.4.3 On-site hypochlorite production

This is a technology similar to that of MOGGOD. The production of chlorine is by the conventional electrolytic cell with or without a membrane. Small production units are available for both types of systems, although the cell without the membrane does mean a more simple system for operation and maintenance.

Sodium hypochlorite production is based on the same cell reactions as described for the MOGGOD system described above. When the cell has no membrane the chlorine will mix with the sodium hydroxide producing sodium hypochlorite.

Although the cells without membranes are less efficient, they do not have the maintenance problems associated with the use of a membrane. In addition there is no need to feed a gas, but a rather a solution, which is a much simpler and more reliable dosing system. What is more, as the efficiency is less and the chlorine stays in solution, the materials used in the cell can be less stringent.

As in the case of the mixed oxidant gases, the on-site hypochlorite cells do not need any imported chemicals, but use common table salt as the feed. An electrical power source is required as with the MOGGOD systems.

In South Africa small systems have been commercially available for some time, mainly supplying the swimming pool market. Problems have occurred due to the unreliability of the electrodes, but newer systems in which DSA electrodes are used are more reliable.

Hypochlorite production	unsuitable	acceptable	suitable
capital costs		x	
O&M costs			x
skills for O&M			x
dosage accuracy		x	
local availability			x

6. TESTING PHASE

Using the facilities that the Division of Water Technology have at the sewage treatment plant in Daspoort, Pretoria, a test plant being fed by relatively contaminated water from the Apies river was set up.

The plant consisted in a specially protected intake in the Apies River. The water from the river was pumped to a 3.6 m_3 tank placed on top of a platform 4 m high. This reservoir acted as a header tank.

Several distribution lines descended from the header tank to simulate water supply systems to be treated by the different disinfection systems. These systems, (UV, MOGGOD and On-site hypochlorite generator) were connected in parallel.

With the UV system all the water to be disinfected had to pass through the cell. The first tests were carried out with the cell in an horizontal position and the results were discouraging.

There was no proper disinfection. It was found that the water was short-circuiting inside the cell (through a piece of PVC tubing). The cell position was changed to a vertical one, with the inlet at the bottom and the outlet at the top. This solved the problem.

With the MOGGOD system the gases produced by the cell were introduced into the raw water by means of a venturi.

Finally for the hypochlorite system the hypochlorite was produced in a batch mode in a 40 litre plastic container in which a 20 litre sodium chloride (common coarse salt) solution was prepared. The generator cell was put into operation for 48 hours during which a hypochlorite solution was formed in the tank. With the aid of a small reciprocating pump the hypochlorite solution was then injected into the water to be treated.

The testing phase commenced in November 1992 and was completed by June 1993.

7. TEST RESULTS

The main idea of the testing programme was to get valid information with regard to the technical applicability of the different systems for use in the rural communities, particularly with respect to their reliability, ease of operation and maintenance, and operational costs.

Equipment used and disinfectant output

The following equipment was purchased, installed and tested at Daspoort:

UV system:

UVAQ 15/3P from UV SYSTEMS, Cape Town, RSA.
Capacity for a flow of 480ℓ/h

MOGGOD:

OXI-0.1 from Oxi Generators Inc, Virginia Beach, USA.
Production of 0.1 kg of chlorine equivalent per hour.

On-site hypochlorination unit:

AUTOCHLOR BT-6 SOLAR SWIM cell from Solar Swim, Helderkruin, RSA.
Production 140 g of chlorine/day

With respect to the installation and operation of the equipment, each system when properly installed was able to function effectively, and the technologies proved to be totally reliable.

In the particular case of the three types of communities described previously, the needs would be:

<u>For UV radiation</u>, an emission that may produce a dose of not less than 30 $mW.s/cm^2$ for the particular flows passing through the system.

<u>For MOGGOD and Hypochlorite systems</u> it will be assumed that a demand of 1.0 mg Cl_2/l of raw water and a residual of 0.5 mg/l is required (total 1.5 mg/l or 1.5 $g/m^{3)}$. Here raw water means either the water coming directly from a natural source or water after any treatment but prior to disinfection.

The doses needed for the different plants in the three types of communities will be:

SMALL:	27 m^3/day * 1.5 g/m^3	= 40.5 g Cl_2/day
MEDIUM:	108 m^3/day * 1.5 g/m^3	= 162 g Cl_2/day
MAJOR:	270 m^3/day * 1.5 g/m^3	= 405 g Cl_2/day

Commercially a wide range of UV systems can provide UV radiation levels sufficient to cope with contamination levels for flows up to 72 000 m^3/day. If in the cases of rural communities the maximum need would be the treatment for flows of up to 270 m^3/day, such systems can be readily obtained.

In the case of our experiments and in all the cost analyses that will follow, it was assumed that a radiation level of not less than 30 $m.Ws/cm_2$ was required. Although this may seem somehow exaggerated (the US EPA only demands a dose of 16 $mW.s/cm_2$) many experiences have proved the need for this extra margin of security. The tests carried out at Daspoort confirmed that when changes in the raw water quality occurred, it was the extra margin which ensured complete disinfection.

In the case of the MOGGOD systems there is currently an upper limit to the size of units. Although in theory it is possible to make a unit as large as wanted, for practical reasons (e.g. not to work with very high currents) there are limits posed for this equipment.In the case of the Oxi-generator, commercially available from the USA, the limit for the largest unit is 3 000 g Cl_2/day, which is appropriate for the range of communities studied.

The on-site hypochlorite production cells are also capable of producing the needed amount of disinfectant. If using the local cell, with relative low output, it is possible to install two or three in series. Alternatively larger cells, e.g. the Process Chlorination cell manufactured in South Africa, can produce up to several kilograms of chlorine/hour.

During the tests, when the proper conditions were met, the disinfection properties, i.e. the bactericidal power, proved to be as expected, i.e. good disinfection was achieved by all systems.

It is necessary to stress the expression: "when the proper conditions were met". And this was very important in the case of the UV equipment. As said, the unit installed was supposed to disinfect a flow of 480 l/hour (this was according to the manufacturer's specifications). However, when this flow was passed through the tube, disinfection was not complete. A study of the chamber characteristics showed that system could not disinfect more than a flow of 160 l/hour at 30 $mW.s/cm^2$. When the actual flow was reduced to the new value, complete disinfection was achieved.

Material Performance of Equipment

A close examination of the equipment during and after the tests was carried out in order to detect eventual problems, possible break downs, material failure, or corrosion, and any other signs of a shortened lifetime.

The period of time during which the tests were performed however, was less than one year, and this could be considered a rather limited period.

The UV system performed well all the time. No signs of material deterioration could be detected from the continuous use of the equipment.

Similarly in the case of the MOGGOD system no problems were observed in the cell material during the testing phase. The only sign of decay was the production of some deposits in the membrane. These deposits were calcium carbonate and were expected to occur as the manufacturer had advised. The membrane should be changed every six months.

The on-site hypochlorination system presented a few problems. The cell used in fact was not intended for a concentrated production of NaOCl in a small container of 20 litres with a sodium chloride solution 15 % strong, but for a mild hypochlorite solution from a 0.35 % NaCl concentration. This lead to some attack of the cathodes and to corrosion at the connection between cathode and the base holders.

As it is expected that these units will be used extensively in the rural areas for drinking water disinfection, the local manufacturer of the hypochlorite generator accepted to study the problem and fix it according to the new demand for the cell. It is the opinion of the research team that this can be easily done.

Key Points for the Operation of the different systems

There are not many key points to be taken into consideration while performing operational activities with these technologies. Nevertheless it is important to highlight a few matters.

The UV system is practically free from any possible misuse. Nevertheless the operator should know that it is not possible to indicate that the disinfection is being carried out effectively, since there is no residual. So he must ensure that the lamp failure alarm is attended to immediately, or if there is no such alarm, that the lamp is continuously working. During maintenance cleaning of the quartz tube, great care should be taken with the UV lamp as it is very fragile. Spares should always be available in the community.

The MOGGOD equipment will operate if the solutions are in the right concentration and the salt and water levels between specified margins. Checking the sodium hydroxide solution density, diluting it, checking the chlorine residual and how to vary it by varying the amperage from the control unit, etc are simple operations, but may be a bit troubling for a rural operator that probably has never had contact with any electrical equipment. MOGGOD technology, while being very simple, is still the least simple of the three recommended systems. Special care should be placed on the instruction and training of the operators. Besides these points special care should be also placed on the operation of the venturi. This injector, if very small, may get clogged by particles, and its inner hole consequently very reduced. Sometimes it is better to place a filter before the venturi, and this filter then be cleaned with the appropriate frequency.

During the first change of the membrane, it would be important that a member of a technical support agency be present to aid or instruct the operator in the way of doing such a change.

The on-site hypochlorite generator is very simple and there are only a few points to be highlighted. Firstly when preparing the NaCl solution the operator has to be sure that all the salt has been dissolved. Failing to comply with this, will result in a less concentrated brine solution and in a weaker NaOCl solution. Secondly, the cleaning of the electrodes is crucial as, if not properly done, the lifespan of the anodes will be drastically reduced. Checking of the feeding system (that may clog) is also important to the correct functioning of the disinfection procedure.

8. CONCLUSIONS

The work done during the period of this project has resulted in the identification of technologies that can be regarded as very promising for water disinfection in the rural communities of South Africa. This is particularly relevant to communities where conventional disinfection with chlorine based chemicals is likely to lead to unreliable disinfection due to skills, finances and resource access problems associated with remote rural communities.

Three technologies have been selected and tested. The assessments and test results with respect to the disinfection potential, ease of operation and maintenance, costs and in their general performance, are clear indications that these technologies are highly favourable for use with small water systems in rural areas.

A bold approach to promote the implementation of these, at least on a pilot scale, should be undertaken in order to get further information on actual utilisation and community management aspects with regard to these technologies.

9. RECOMMENDATIONS

Three appropriate disinfection technologies have been studied and understood. It is believed that each of them can be an important tool for improving the health of the water supplies to small and medium communities. Their use and their ongoing maintenance does not pose particular problems or difficulties.

Although not the perfect solution, they do have a number of advantages over alternative disinfection systems for use in such communities. This can be confirmed not only within the South African perspective, but from the actual state of the art of disinfection technology in the world today.

Their simplicity and their disinfection efficiency is high. Nevertheless, further field evaluations of the technologies should be carried out. Real problems will arise and will be seen when actual conditions are met.

The recommendation from this research is that, having assessed that these three technologies can be highly recommended for implementation in the rural areas of South Africa, a number of water systems using these systems should be set into operation to test the technical aspects and the institutional related activities in extended operational circumstances.

The suggested follow-up is then to implement the three technologies in at least five to ten systems, and monitor all the relevant aspects of their performance.

10. REFERENCES

1. **Aksenenko NV, Maslyukov KAV, Matyushin GA, Rakitskaya GA, Sladadze GK, and Solntseva DP, 1989.** Use of ion-exchange resins to disinfect water. Khimiya i Tekhnologiya Vody, Vol 11, 2, pp 181-182.

2. **Anderson AC, Reimers RS, and Dekernion P, 1982.** A brief review of the current status of alternatives to chlorine disinfection of water. Am. Journ. Public Health, vol 72, 11, pp 1290-1293.

3. **Anonomous, 1990.** Electrochlorination in action. European Water and Sewage, vol 94, 1130.

4. **Anonomous.** MOGGOD Water treatment. Trade brochure of Oxi-generators Inc.

5. **Anonomous.** The Dip-cell, Hypochlorite for disinfection. Trade brochure of Magneto-chemie.

6. **Anonomous.** Germicidal lamps and applications. Trade brochure of Philips.

7. **Anonomous.** Water disinfection by microfiltration with Katadyn ceramic filters. Trade brochure of Katadyn Products Inc.

8. **Anonomous.** Disinfection of water by ultraviolet light. Trade brochure of Katadyn Products Inc.

9. **Anonomous, 1988.** The town of upset tummies turns to ultraviolet. Asian water and Sewage, June 1988.

10. **Anonomous, 1991.** Industrial Applications of UV light. Trade brochure of UV Water Systems (Pty) Ltd.

11. **Anonomous, 1984.** Disinfection , odor prevention and control. Public Works, Public Works Manual, pp D48-D51.

12. **Anonomous.** Dimensionally stable anodes. Trade brochure of Eltech.

13. **Anonomous, 1990.** The alternatives to chlorine treatment. World Water, April, pp 47-49.

14. **Anonomous.** UV water systems sheds new light on water disinfection. Trade brochure of UV Water Systems (Pty) Ltd.

15. **Anonomous, 1990.** Disinfection By-products - Theme Introduction. Journal AWWA, vol 82, April, p 159.

16. **Anonomous.** Porpoise chlorine machine. Trade brochure of Sophisticated Systems Inc.

17. **Anonomous, 1991.** Isn't it time your bugs saw the light? Asian Water and Sewage, June.

18. **Anonomous, 1984.** Disinfection, taste, and odor control. Public Works, Public Works Manual, pp C21-C26.

19. **Anonomous.** Electrolytic Systems. Trade brochure of Pepcon.

20. **Aquazur, 1991.** The use of ozone in drinking water treatment. Technology SA, September, pp 3-8.

21. **Bancroft K, Chrostowski P, Wright RL, and Suffet, 1984.** Ozonation and oxidation competition values. Wat. Res., vol 18, 4, pp 473-478.

22. **Barrot LP, Lloyd BJ, and Graham NJD, 1990.** Comparative evaluation of two novel disinfection methods for small community water treatment in developing countries. Journ. Water SRT-Aqua, vol 39, 6, pp 396-404.

23. **Carlson S, 1991.** Fundamentals of water disinfection. Journ. Water-Aqua, vol 40, 6, pp 346-356.

24. **Cartwright P, 1990.** Designing pure water systems. Plumbing Engineer, vol 18, 8, pp 47-55.

25. **Comar D, 1989.** New developments in water disinfection by ultraviolet light. Water, April, pp 46-48.

26. **Conacher J, 1988.** EEC regulations spur interest in UV systems. Water and Wastewater International, August, pp 13-15.

27. **Cotti.** Water sterilizers by UV radiation. Trade brochure of Cotti Inc.

28. **CSIR, 1988.** Disinfection. Chapter 7 in: Manual on Water Purification Technology, Technical Report K73, Division of Water Technology, Pretoria, South Africa, pp 114-129.

29. **Day AW, Tsatsaronis S, Pederson F, and Fane AG, 1990.** Membrane microfiltration system for cost-effective clarification and disinfection of drinking water. In Proceedings: 15th Conference on Water Pollution RCS and Control,

30. **De Burggrave A, 1979.** Sterilisation and disinfection with peroxygen compounds. Effluent and Water Treatment Journal, pp 23-29.

31. **Dyer-Smith P, Brown BBC, and Boveri & Co. 1985.** Ultraviolet steriliser packages for large water flows. Water Sewage and Effluent.

32. **Electro-Katadyn.** The electro-katadyn method. Water purification with silver ions. Trade brochure of Katadyn Products Inc.

33. **Ferguson DW, McGuire MJ, Koch B, Wolfe RL, and Aieta EM, 1990.** Comparing peroxone and ozone for controlling taste and odor compounds, disinfection by-products, and microorganisms. Journal AWWA, vol 82, April, pp 181-191.

34. **Fiessinger F, Richard Y, Montiel A, and Musquere P, 1981.** Advantages and disadvantages of chemical oxidation and disinfection by ozone and chlorine dioxide. The Science of the Total Environment, vol 18, pp 245-261.

35. **Gardiner ER, 1986.** An analysis of OSEC in operation. European Water and Sewage, vol 90, 1085.

36. **Gardiner ER, Hobbs NJ, and Jeffrey J, 1981.** Hydrogen Peroxide - a real alternative to chlorine in water treatment? In 4th Conference on Water Chlorination: Environmental Impacts and Health effects, Ed. RJ Jolley, vol 4, book 1, pp 405-412.

37. **Gerba CP, 1990.** Disinfection of bacteria in water systems by using electrolytically generated copper:silver and reduced levels of free chlorine. Can. Journ. Microbiology, vol 36, pp 109-116.

38. **Gioia M.** New light on water disinfection for large and small water supplies. Trade brochure of UV Water Systems (Pty) Ltd.

39. **Glaze WH, 1987.** Drinking water treatment with ozone. Environ. Science & Technol., vol 21, 3, pp 224-230.

40. **Gould JP, and Haas CN, 1978.** Disinfection - literature review. Journ. Wat. Pol. Control Fed., vol 50, 6, pp 1134-1139.

41. **Groocock NH, 1984.** Disinfection of drinking water by ultraviolet light. Journ. Inst. Wat. Eng. & Scientists, vol , pp

42. **Haas CN, and Gould JP, 1980.** Disinfection - literature review. Journ. Wat. Pol. Control Fed., vol 52, 6, pp 1224-1232.

43. **Hatch GL, 1981.** Preparation of iodinated anion-exchange resins for the controlled release of disinfecting levels of iodine and hypoiodous acid. Ind. Eng. Chem. Prod. Res. Dev., vol 20, 2, pp 382-385.

44. **Hoppe RK, 1991.** Lata's mixed oxidant system, Trade brochure of Lata Inc.

45. **Hoppe RK and Bradford WL, 1991.** Personal communication.

46. **Krivobok SM, Volgin VD, Sinyak YE, Kanarskii AV and Smirnov DV, 1986.** Disinfecting water by means of microfiltration membranes. Soviet Journal of Water Chemistry and Technology.

47. **Kulskii LA, Vorobeva AM and Matskevich ES, 1982.** Ways of intensifying methods of removing viruses from water. Khimiya i Tekhnologiya Vody, Vol 4, 1, pp 82-86.

48. **Kulskii LA, Deinega YF, Savluk OS, Ulberg ZR, and Marochko LG, 1982.** Electrical surface properties of microbial cells during the sterilisation of water by metal ions. Khimiya i Tekhnologiya Vody, Vol 6, 4, pp 364-366.

49. **Landeen LK, Yahya MT, Kutz SM, and Gerba CP, 1989.** Microbiological evaluation of copper:silver disinfection units for use in swimming pools. Wat. Sci. Tech., vol 21, 3, pp 267-270.

50. **Lloyd BJ, 1990.** Comparative evaluation of two novel disinfection methods for small community water treatment in developing countries. Journ. Wat. SRT-Aqua, vol 39, 6, pp 396-404.

51. **Masschelein WJ, 1980.** The state of the art in the use of chlorine dioxide and ozone in the treatment of water. Water SA, vol 6, 3, pp 116-129.

52. **Mechsner KI, Fleischmann T, Mason CA and Hamer G, 1991.** UV disinfection: short term inactivation and revival. Wat. Sci. Tech., vol 24, 2, pp 339-342.

53. **Mechsner KI, 1987.** Theory and practice for the testing and operation of ultraviolet systems for water treatment. Aqua, vol 2, pp 73-79.

54. **Pyle BH and McFeters GA, 1989.** Iodine sensitivity of bacteria isolated from iodinated water systems. Canadian Journal of Microbiology, vol 53, pp 520-523.

55. **Ragab-Depere NJ, 1982.** Water disinfection with the hydrogen peroxide-ascorbic acid-copper(II) system. Applied and Environmental Microbiology, vol 44, 3, pp 555-560.

56. **Reiff FM, 1988.** Desinfeccion del aqua potable con una mezcla de gases oxidantes producidos in situ (MOGGOD). Boletin de la Oficina Sanitaria Pan Americana, vol 105, 4.

57. **Riley PA, 1989.** Wastewater dechlorination - a survey of alternatives. Public Works, June.

58. **Selleck RE and Colling HF, 1975.** The significance of wastewater disinfection. Progress in Water Technology, vol 7, 5/6, pp 843-855.

59. **Sharma RK, Kumar S, Ranteke PW and Ray PK, 1990.** Disinfection of drinking water by filtration through silver impregnated alumina. Journ. Environ. Sci. Health, vol A25, 5, pp 479-486.

60. **Solsona F, 1990.** Technical guide on: Disinfection for small water supplies. Division of water Technology, CSIR, 32p.

61. **Solsona F, 1991.** Evolucion del diseno en las celdas de ozono-cloracion. Paper presented at the Second International Conference on the Disinfection of Water with a Mixture of Oxidants Generated On-site. October.

62. **Soule BE and Medlar SJ, 1980.** O_3+Cl_2 produces taste-free, no THM, safe piped product. Water & Sewage Works, March, pp 44-45.

63. **Spink J.** An alternative to traditional methods of disinfection. Trade publication of Scientific Products Morton Salt Co., St. Louis, Missouri, 26p.

64. **Tan L and Amy GL, 1991.** Comparing ozonation and membrane separation for color removal and disinfection by-product control. Journ. AWWA, vol 83, May.

65. **Tobin RS, Smith DK, Horton A and Armstrong VC, 1983.** Methods of testing the efficacy of ultraviolet light disinfection devices for drinking water. Journ. AWWA, vol 75, September.

66. **Van der Merwe SW, 1979.** Disinfection: Lecture notes for Summer School, 24-26 January, Faculty of Chemical Engineering - water Utilization, University of Pretoria. 22p.

67. **Venosa AD and Isaac R, 1987.** Disinfection - literature review. Journ. Wat. Pol. Control Fed., vol 59, 6, pp 421-427.

68. **Vigneswaren S and Boonthanon S, 1989.** Application of cross-flow microfiltration in water works. Paper presented in the Conference: Water '89, Water Decade and Beyond. 3p.

69. **Warden JH, 1983.** Problems of small water supplies. Journ. Inst. Wat. Eng. Sci., pp 313-324.

70. **WASH, 1992.** Disinfection for rural community water supply systems in developing countries. WASH Technical Note, prepared by Dennis Harris, 8p.

71. **Wolfe RL, 1990.** Ultraviolet disinfection of potable water. Envir. Sci. Tech., vol 24, 6.

72. **Yahya MT, Landeen LK, Messina MC, Kutz SM, Schulze R and Gerba CP, 1990.** Disinfection of bacteria in water systems by using electrolytically generated copper:silver and reduced levels of free chlorine. Can. Journ. Microbiol., vol 36, pp 109-116.

73. **Zinnbauer FE, 1988.** US municipality opts for UV disinfection. Water and Wastewater International, Feb, pp 29-31.