Disinfection alternatives for rural applications

S D Freese, D J Nozaic and D L Trollip, S. Africa

CHLORINE GAS HAS long been used for potable water disinfection on account of its effectiveness and relative ease of use. However, it is usually not a suitable option for disinfection in rural applications. The gas is dangerous to handle, sophisticated dosing equipment is required and transport of the gas cylinders can be problematic. Umgeni Water together with the Water Research Commission of South Africa recently conducted a project to evaluate various disinfectants which could replace chlorine for wastewater disinfection and the suitability of some of these disinfectants for use in rural applications was realised. Disinfectants such as hypochlorite, electrolytic apparatuses, peracetic acid, bromine and ultra-violet (UV) irradiation were identified as potentially suitable for rural applications. Emphasis was placed on disinfectants that were safe to handle and either simple to dose and monitor or could be fitted with fail-safe dosing and/or monitoring devises.

Methodology

The various disinfectants were tested on secondary clarified wastewater effluent from a wastewater works treating predominantly domestic sewage. The quality of this effluent was fairly good in terms of water quality parameters such as turbidity (typically around 2 to 4 NTU) and COD (typically around 30 mg/L O_2), but contained high concentrations of bacterial indicator organisms and parasitic cysts and oocysts were often present. This effluent was therefore representative of a river water containing significant sewage contamination.

Tests were carried out in the laboratory and at pilot plant scale treating up to 10 m^3 per hour. UV and applied electric field tests were carried out on a batch, single and successive pass through, and continuous recycle basis. Disinfectants were added and tested in the laboratory and on the pilot plant for optimum contact time. In all cases a number of tests were conducted to establish the optimum dosage range for each method and to compare this to chlorine disinfection. The different methods were evaluated based on the reduction in mirco-organisms, including *Eschericia coli*, coliforms, faecal streptococci, total plate counts at 22°C and 37°C, coliphages, *Cryptosporidium* and *Giardia*. The effect of the various disinfectants on natural organic matter, DBP formation and various water quality parameters was also monitored by conducting a wide variety of analyses including total and dissolved organic carbon, biodegradable dissolved organic carbon, trihalomethane formation potential, UV extinction at 254 nm, COD, pH, turbidity,

conductivity, alkalinity, iron, manganese, calcium, magnesium, total hardness and total and dissolved solids. The disinfectant demand of the effluent was also measured. All analyses were conducted using accredited methods (South African National Accreditation Services) or methods from reputable sources (e.g. Standard Methods for the Examination of Water and Wastewater, 1998 and ISO Standards). Detailed descriptions of these methods can be found in Water Research Commission Report No. 1030/1/03, ISBN 1 86845 974 8.

Results

Chlorine and Hypochlorite: The chlorine demand of the secondary clarified wastewater effluent used in this investigation varied from as low as 4 mg/L to as much as 20 mg/L, the average for the two year duration of the project being 9 mg/L. Chlorine was obviously used throughout this investigation for comparative purposes and it was found that when used at the chlorine demand concentration with a 30 minute contact time, a 2 to 3 log reduction was obtained for most of the bacterial indicator organisms, although it was less effective for the removal of coliphages. This is in agreement with the findings of other researchers, who have reported 2 log reductions in bacterial organisms at chlorine concentrations of 1 to 2 mg/L above the demand value (Nagy et al, 1982). Chlorine was added in the form of liquid sodium hypochlorite for both the laboratory and the pilot scale tests, but whether adding chlorine as a gas or as liquid hypochlorite, the dissolved chlorine species formed are dependent on the pH of the water and not the form in which it is added. At the pH values commonly encountered in surface waters, namely 6,5 to 8,5, chlorine occurs as both hypochlorous acid (HOCl) and hypochlorite ion (OCl⁻), the ratio of HOCl to OCl⁻ decreasing as the pH rises. This is important since HOCl is a far more effective disinfectant than OCl⁻ (White, 1992). However, the ratio of the chlorine species present will be the same at a particular pH value regardless of the form of chlorine used.

Hypochlorite solutions offer significant advantages over chlorine gas in situations where the level of technology and maintenance is relatively low, such as is the case in rural applications. It is far safer to transport and the maintenance and dosing requirements are far less demanding than for chlorine gas. Simple constant head, drip-type dosing systems are available, which further simplify the use of this disinfectant. However, a serious disadvantage of hypochlorite solutions is their lack of stability. Heat, light,

pH and metal cations (e.g. iron, copper, nickel and cobalt) result in deterioration of hypochlorite solutions and a significant loss in available chlorine concentration can occur within a few days (White, 1992). For this reason it is important that hypochlorite solutions be properly stored and that storage periods be limited to preferably not more than two weeks. Solid forms of hypochlorite are far more stable than hypochlorite solutions. The most commonly available form of solid hypochlorite is the calcium salt, which is generally sold at around 65 to 70% available chlorine and which under normal conditions loses between 3 and 5% available chlorine per year. However, very careful storage of solid calcium hypochlorite is required since if exposed to heating or readily oxidisable organic matter, spontaneous combustion can occur. Another option if considering hypochlorination of rural water systems, is electrolytic hypochlorite production. A number of units are commercially available, but obviously these require a power source, maintenance, an operator with a basic level of technological knowledge and a supply of salt.

Electrode Systems: Two proprietary apparatuses were investigated, which, it was claimed by the suppliers, use an applied electric field to generate free radicals. It would appear that much of the disinfecting effect obtained with these apparatuses is in fact due to the dissolution of copper electrodes and to the generation of chlorine from dissolved chlorides in the water. Tests conducted using electrodes other than copper, gave very poor disinfection.

Units referred to as "Mixed Oxidant Generators" were also investigated. Although essentially the units electrolytically oxidised a brine solution to form hypochlorite, they were claimed to have disinfection capabilities superior to those of other hypochlorite generators, due to the formation of oxidants other than hypochlorite such as peroxide compounds and radicals, ozone, hydrogen peroxide and metal oxide hydrates. These units were found to be quite problematic to operate, suffering from a number of operational problems. Effluent samples were dosed with the anolyte at concentrations equivalent to chlorine concentrations and under these conditions, there were no significant differences in disinfection efficiency observed between the anolyte and sodium hypochlorite. Tests were conducted using sodium sulphate instead of sodium chloride to produce the anolyte, with a view to producing a higher ratio of "mixed oxidants" to hypochlorite. The concentration of the anolyte produced under these conditions was very low and no evidence of any "mixed oxidants" was evident. The lack of any obvious benefits in using these mixed oxidant generators, together with the operational problems experienced in operating the unit, do not make this an attractive option for rural applications.

Ultra-violet Irradiation: Two types of UV lamps are used in commercially available UV systems, low pressure and medium pressure mercury vapour lamps (Combs and McGuire, 1989). The low pressure lamps produce a narrow band of radiation at a wavelength of 253,7 nm, which is close to the maximum biocidal wavelength of 260 nm, but they only emit approximately 40% of the power input at that wavelength (Wolfe, 1991). The medium pressure lamps emit a much broader band of UV light, but at a significantly higher power output than the low pressure lamps.

Tests were conducted on a variety of systems, including both low pressure and medium pressure systems, but despite the differences in lamp type and design, the results obtained were similar at similar UV doses. Two low pressure systems were tested at both laboratory and pilot scale. The average transmittance of the effluent on which the tests were conducted, was approximately 70% and under these conditions, UV doses of approximately 60 mJ/cm^2 brought about 2 to 3 log reductions in most of the bacterial indicator organisms. At 140 mJ/cm^2 the reduction in the indicator organisms improved to between 3 and 4 log, but increasing the UV dose to over 300 mJ/cm^2 did not result in any significant improvement in disinfection. The one indicator organism against which UV was particularly effective, was coliphages, bacteria used as indicators of viruses. At UV doses of 60 mJ/cm^2, complete removal of coliphage organisms was achieved.

The medium pressure systems used could only be tested at pilot scale, since they required flow rates which made laboratory testing impractical (>1,4 m^3/h). Again, two systems were assessed, one an Hanovia Photon PMD 100A 1/2 medium pressure unit and the other a Berson In-Line HXFS (W) 1 Multiwave unit and here too, the results obtained with both systems were comparable at similar UV doses. Typical results obtained with the Hanovia system appear in **Table 1** and show that at lower UV doses (40 to 70 mJ/cm^2) 2 to 3 log removals were obtained for most of the bacterial indicator organisms, while higher doses brought about 3 to 4 log reductions in the same organisms. Increasing the UV dose from around 100 mJ/cm^2 to over 200 mJ/cm^2 did not significantly improve the disinfection. Removals of total count organisms were not as good as for the other indicator organisms, being between 1 and 2 log. Parasitic cysts and oocysts were not always present in the effluent and it was not economically feasible to spike such large quantities of effluent with these pathogens. During the 6 month period that the medium pressure UV tests were conducted, *Cryptosporidium* was never detected and *Giardia* cysts were only found in 5 of the effluent samples and then only in fairly low numbers (<30 cysts/10 L). After UV irradiation at doses of between 90 and 284 mJ/cm^2, the cysts were either completely removed or reduced to below 5 cysts/10 L. There is presently no explanation for the removal of these organisms, but the viability of the cysts detected in the effluent prior to irradiation averaged 94%, while that of the cysts present after irradiation was 23%.

The important aspect of these results is that using UV doses of around 40 to 70 mJ/cm^2, it was possible on a contaminated water source such as this to achieve

disinfection as good as, if not slightly better than, could be achieved at chlorine doses of around 1 to 2 mg/L above the chlorine demand value. These tests indicated that the UV dose is important in determining disinfection efficiency, regardless of the system used, but accurate measurement of the UV dose is essential. Among the many factors affecting UV disinfection efficiency are the depth of the water being irradiated and the transmissivity and turbidity of the water (Qualls et al., 1985) and these must be taken into account when quoting UV doses. UV provides good disinfection when used correctly and can offer additional advantages, since many pathogenic organisms are more susceptible to UV than they are to chlorine (Sobsey, 1989; Kaur et al, 1994).

UV systems have advanced significantly in the last 10 years and can now be purchased fitted with self-cleaning lamps, UV detectors and warning systems to alert the operator to lamp failure or poor transmissivity. Provided that a power supply is available, systems are suitable for low technology applications where an operator requires only a basic training in lamp maintenance and replacement. However, although fairly inexpensive units are now available, systems fitted with the UV detectors etc., which make them suitable for rural applications, are more costly. Another disadvantage with UV disinfection is that it provides no residual effect.

Peracetic Acid: Peracetic acid was found to be an effective disinfectant, in most cases providing disinfection comparable to that obtained using chlorine at equivalent mass concentrations. This is in agreement with the findings of Veschetti and co-workers (1998), who found that peracetic acid and sodium hypochlorite have similar bactericide efficiency against faecal and total coliforms, although they found it less effective than hypochlorite for the removal of faecal streptococci, while in this study peracetic acid was found to be at least as effective as chlorine in removing these organisms and in many cases slightly better. However, the disinfection efficiency of peracetic acid in terms of parasitic organisms was not quite as good as that achieved using chlorine at equivalent mass concentrations, but since chlorine residual restrictions do not apply to this disinfectant, as they do to chlorine, it is possible to use higher doses and therefore effect better removal of these pathogens. At present, peracetic acid is not readily available in Southern

Africa and so would not be an economically viable option at this point. However, prices could be expected to drop significantly if it became more widely used. Peracetic acid is fairly stable provided that it is properly stored, and although there are risks associated with handling, it poses far less dangers and hazards than a disinfectant such as chlorine gas.

Bromine: Bromine showed promise, providing disinfection similar to that obtained using chlorine on a mass equivalent basis. Hypobromite solutions are similar to hypochlorite solutions in terms of handling, but are far less stable, rapidly transforming into bromates, resulting in a significant loss in disinfection strength within a few days. Using ammonium bromide solution in conjunction with hypochlorite offers an alternative with good disinfection capabilities and fairly safe handling requirements. However, it is important when dosing to apply the ammonium bromide and hypochlorite solutions in the correct proportions and since the problems of hypochlorite stability are the same as when using hypochlorite alone, there are no obvious benefits to using a bromide/chlorine combination instead of a disinfectant such as hypochlorite, except for a reduction in the hypochlorite concentration when using bromide.

Cost Analysis: Based on the results of this investigation, the most promising disinfectants available for rural disinfection purposes have been selected and their cost effectiveness in South African cents per kL compared in **Table 2**. Chlorine gas capital costs for a 2 500 kL/d plant, amortised over 10 years at 12%, resulted in a cost of 1,33 c/kL. Allowing for maintenance costs, this is increased to 1,47 c/kL giving an overall cost of 4,47 c/kL. Capital costs for hypochlorite solution, peracetic acid, bromine solution and hypochlorite / ammonium bromide were considered negligible, since all of these disinfectants could be added to the water using a simple and inexpensive drip-type dosing system. The capital costs for a UV system were based on an open channel system requiring one 7 kW medium pressure unit to treat approximately 2 500 kL/d, which amounts to R100 000. This was amortised over a period of 10 years using an annual interest rate of 12%. The cost of lamp replacement and maintenance was calculated as approximately R1 500 per annum, while electricity costs, based on South African

Table 1: Average values for flow rate and UV dose of the medium pressure UV Hanovia lamp, together with the average log removals obtained for the various indicator organisms.

Flow Rate L/s	Average UV Dose mJ/cm^2	Log Removal *E. coli*	Log Removal Coliforms	Log Removal F. Strep.	Log Removal TC 37 °C	Log Removal TC 22 °C	Log Removal Coliphage
0,5	212	3,1	3,2	3,3	1,6	1,5	>2
1,0	98	3,0	3,0	3,0	1,5	1,5	>2
1,5	67	2,8	2,8	2,7	1,2	1,4	>2
2,0	47	2,1	2,3	2,2	1,2	1,5	>2

prices of 27c/kW, would add approximately 1,7 c/kL to give a total cost of 3,72 c/kL.

TABLE 2: Cost assessment for most promising alternative disinfectants for rural applications for treatment of polluted water sources.		
Disinfectant	**Dose**	**c/kL Costs (SA cents)**
Chlorine Gas	6 mg/L	4,47
Hypochlorite solution	6 mg/L	4,80
UV	40 mJ/cm^2	3,72
Peracetic acid	5 mg/L	40,0
Bromine solution	6 mg/L	50,0
HOCl and NH$_4$Br	3,2 mg/L and 2,56 mg/L	9,22

Conclusions

- In terms of dosing and operational ease, combined with cost effectiveness, hypochlorite would appear to offer the most advantages for rural applications.
- The situation could change were the cost of peracetic acid to drop drastically.
- UV offers potential benefits, but has no residual effect and is highly sensitive to water turbidity.

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S D FREESE, D J NOZAIC and D L TROLLIP UMGENI Water, P. O. Box 9, Pietermaritzburg, 3200 Tel. (033) 3968033 Fax. (033) 3968095 E-mail: sue.freese@umgeni.co.za