# **Executive Summary**

Wastewater effluents are routinely chlorinated prior to discharge to river or sea, but low concentrations of chlorine residuals are toxic to aquatic life and some chlorination by-products have been shown to be mutagenic. The chlorine residual concentration limit imposed on discharge of wastewater effluents in this country by the Department of Water Affairs and Forestry (DWAF) is already relatively low (general standard of 0,1 mg/L) and is set to become even more stringent, although the limit for bacterial indicator organisms will not change (general standard of 0 faecal coliforms per 100 mL).

The tests carried out by Umgeni Water for the purposes of this investigation, determined Eschericia coli specifically, rather than total faecal coliforms. Essentially, there is little difference between E. coli and faecal coliform counts as E. coli are the main subgroup of faecal coliforms and therefore total faecal coliform counts will be generally slightly higher than E. coli counts, but the test specific for E. coli is more accurate than that for faecal coliforms. In practice, the E. coli results can be considered representative of faecal coliforms and for the purposes of this report are used interchangeably. Internationally much controversy surrounds the faecal coliform grouping, as not all of them are in fact faecal, leading to some confusion.

Achieving the general faecal coliform standard while not exceeding the chlorine residual limit of 0,1 mg/L is often not possible without abnormally large contact tanks and lowering the chlorine residual limit still further will only aggravate this situation. A number of pathogenic micro-organisms, especially viruses and parasitic cysts, such as Cryptosporidium and Giardia, are far more resistant to chlorine than faecal coliform organisms and can be found in the absence of normal bacterial indicator organisms such as Eschericia coli, faecal streptococci and coliform bacteria, so it can be assumed that in many cases pathogenic organisms are entering receiving waters via wastewater effluent discharges. This has serious implications in a water scarce country such as South Africa where a significant proportion of the population do not have access to treated water or adequate sanitation and rely on untreated river water as their only source of drinking water. Inadequate water supply and sanitation is largely responsible for more than 800 million estimated cases of diarrhoeal disease and 4,5 million associated deaths in developing countries every year. In South Africa alone 12 million people do not have access to an adequate potable water supply and 21 million lack basic sanitation.

Obviously more effective disinfection of wastewater effluents is required and a number of alternative disinfectants warrant investigation, including ultraviolet irradiation (UV) and ozone, since many pathogenic organisms are more susceptible to these than they are to chlorine. It is suspected that ozone and/or UV may inactivate these organisms without actually rendering them unviable, but infectivity tests using animals such as mice would be required in order to confirm this and these tests were beyond the scope of this investigation. Another option which should be assessed, is that of combined treatments including UV/chlorine and UV/ozone. Membranes could also possibly be employed in removing these pathogens on account of their size, as they are fairly large in microbiological terms (>4 nm).

### 1.1. Objectives

This project had a number of objectives. The objectives were to:

- Adequately disinfect wastewater effluents in terms of parasitic (oo)cysts (Giardia and Cryptosporidium), viruses (coliphages) and bacterial indicator organisms (E. coli, faecal streptococci and coliforms) while not exceeding DWAF general standards for chlorine residual.
- Adequately disinfect wastewater effluents in terms of the above without producing a chlorine residual.
- Provide design and operational guidelines for simple and effective disinfection of wastewater effluents.
- Provide a disinfectant protocol suitable for use under low technology applications.
- Determine the potential for regeneration of micro-organisms, especially Giardia, Cryptosporidium and viruses after different methods of disinfection.

This project was expected to produce a number of research products, the most important being:

 A tetramethyl red (TMR) - fluorescein diacetate (FDA) viability stain test for Cryptosporidium and Giardia. This test would allow for more comprehensive screening for protozoan cysts and would reduce the risk of outbreaks of disease caused by these micro-organisms. This would be of benefit to all authorities involved. in the treatment of potable water as well as to water and wastewater treatment consultants. This stain also has potential for use with flow cytometry.

- The reduction or removal of chlorine residual from disinfected water, which would be ecologically beneficial.
- A simple method for adequately disinfecting wastewater, which would be especially beneficial to rural communities where advanced technology is inappropriate.
- Design and operational guidelines for effective wastewater disinfection, which would allow authorities involved in wastewater treatment to effectively disinfect wastewater without exceeding the general standards for chlorine residual concentration.
- A research report detailing alternative disinfectants for adequate disinfection of wastewater effluents while not exceeding general standards for chlorine residual concentration, which would also benefit all authorities involved in the treatment of wastewater.

These objectives have, for the most part, been achieved. It has been shown that it is possible to adequately disinfect wastewater, while keeping within the DWAF standards for chlorine and in some cases without even producing a chlorine residual at all.

#### 1.2. Results and Discussion

One of the primary aims of this project was to assess alternative disinfectants for use in wastewater applications, with special emphasis on minimising the chlorine residual produced while not compromising disinfection efficacy. Another important aspect considered was finding a disinfectant capable of inactivating parasitic organisms, such as *Cryptosporidium* and *Giardia*. For this reason a fairly wide range of disinfectants was investigated, both used independently and in conjunction with other disinfectants, in the hope that combinations might result in a synergistic effect capable of destroying these resistant organisms.

Both laboratory and pilot plant tests were conducted for this investigation. The wastewater effluent used in these tests came from the Darvill Wastewater Works (WWW) in Pietermaritzburg, which treats a predominantly domestic wastewater effluent and has a nominal design capacity of 75 ML/day. The process consists of primary sedimentation, at times augmented using primary enhanced treatment with ferric salts, an activated sludge plant

with aluminium sulphate and lime addition for phosphate removal, followed by secondary settling, chlorination and tertiary treatment through a series of oxidation ponds. The effluent used in both the laboratory and pilot plant tests was drawn out of the overflow channel from the secondary sedimentation tanks at a point well above the chlorination stage.

The effluent used in the laboratory tests was often, but not always, spiked with cultures of Cryptosporidium oocysts and Giardia cysts, although the effluent regularly contained these prior to spiking. The pilot plant tests were however conducted on unspiked effluent

A variety of disinfectants and combinations of disinfectants were assessed both in the laboratory and at pilot plant scale, these being:

- Chlorine
- 2 Ozone
- 3 Low pressure UV irradiation
- 4 Medium pressure UV irradiation
- 5 Multiwave UV irradiation
- 6 Peracetic acid
- 7 Hydrogen peroxide
- 8 Peracetic acid and hydrogen peroxide
- 9 Bromine
- 10 Klor-Free: a potassium persulphate and copper sulphate based disinfectant (laboratory testing only)
- 11 Mixed oxidant generator (only laboratory testing)
- 12 Ozone combinations:

ozone / chlorine

ozone / low pressure UV

ozone / medium pressure UV

ozone / peracetic acid

ozone / bromine

13 UV combinations:

UV / chlorine

UV / peracetic acid

UV / bromine

UV (multiwave only) / hydrogen peroxide

A number of tests were conducted on the secondary effluent before and after being exposed to these various disinfectants. The microbial testing protocol included all or some of the following:

- 1 E. coli
- 2 Coliform organisms
- 3 Faecal streptococci
- 4 Total colony counts at 37 and 22°C
- 5 Coliphages
- 6 Cryptosporidium
- 7 Giardia

The following analyses were also conducted on many of the samples:

- 1 Total Organic Carbon (TOC)
- 2 Dissolved Organi Carbon (DOC)
- 3 Biodegradable Dissolved Organic Carbon (BDOC)
- 4 Trihalomethane formation potential (THMFP)
- 5 Ultraviolet (UV) extinction (254 nm).
- 6 pH
- 7 Temperature
- 8 Turbidity
- 9 Conductivity
- 10 Alkalinity
- 11 Calcium, magnesium and total hardness
- 12 Iron
- 13 Manganese
- 14 Total dissolved solids
- 15 Suspended solids
- 16 Chemical Oxygen Demand (COD)

In all cases the chlorine demand of the water was determined and whenever ozone was used, the ozone requirement was also measured.

## 1.3. Summary of the Results

A number of conclusions were made from this investigation. These are:

The most promising disinfectants for use in wastewater, which show potential for meeting the DWAF standard for effluent discharge in terms of both chlorine residual and faecal coliforms are:

ozone

medium pressure UV irradiation bromine peracetic acid.

- 2. Combinations of ozone and UV with other disinfectants are difficult to justify in terms of the improvements obtained in disinfection. It is possible to achieve similar disinfection at lower doses of the combined disinfectants than can be achieved using each disinfectant alone, but the additional costs and operational difficulties that would be incurred by using disinfectant combinations is not warranted by the improvement in disinfection.
- The mixed oxidant generator for the most part produces hypochlorite and so does not
  offer any significant benefits over chlorine gas disinfection and Klor-Free did not
  prove to be a suitable alternative to chlorine for wastewater disinfection.
- Work conducted by Umgeni Water on membranes for the treatment of potable water sludges made it clear that the nature of the sludge is vitally important and that serious operational problems, such as membrane fouling, could be expected when using membranes for these applications. Therefore membranes were not investigated for the purposes of this investigation.

#### 1.4. Cost Assessment

Based on the results of this investigation, ozone, medium pressure UV irradiation, peracetic acid and bromine were selected as potential candidates for the disinfection of wastewater treatment. A cost assessment was conducted and appears below. Chlorine is included in the cost assessment in order to provide a benchmark. The cost assessment has taken into account the dosages that will be required in order to satisfy the DWAF relaxation standard for wastewater discharge of 500 faecal coliforms/100 mL (<500 E. coli CFU/100 mL has been used) as well as the higher doses that will be needed if the general effluent standard of 0 faecal coliform CFU/100 mL is to be met (<10 E. coli CFU/100 mL has been used).

Cost assessment for most promising alternative disinfectants for doses required to meet both the relaxed (<500 CFU/100 mL) and general (0 CFU/100 mL) DWAF effluent discharge standards.

	Relaxed Standard		General Standard	
Disinfectant	Dose for <500 E. coli	c/kL Costs for <500 E. coli	Dose for <10 E. coli	c/kL Costs for <10 E. coli

Ozone	2 mg/L	3,45	8 mg/L	9,45
UV	40 mW.s/cm <sup>2</sup>	3,72	150 mW.s/cm <sup>2</sup>	11,2
Peracetic acid	5 mg/L	40,0	9,5 mg/L	76,0
Bromine	6 mg/L	50,0	9,5 mg/L	79,2
Chlorine	6 mg/L	3,00	9.5 mg/L	4,75

Ozone satisfied the DWAF relaxed effluent discharge standard of faecal coliforms less than 500 CFU/100 mL at doses generally less than 2 mg/L, but in satisfying the general standard of 0 faecal coliforms the ozone dose needed to be increased significantly to between 6 and 8 mg/L. Although the capital costs of ozone are expensive, this is offset in some degree by relatively low running costs. However, ozone requires skilled personnel in order to run and maintain the ozone generation plant, so this will most probably pose a problem at most wastewater works.

Using medium pressure UV irradiation it was possible to achieve 98% compliance of the relaxed discharge standard, even using doses as low as 30 mW.s/cm<sup>2</sup>. However, to ensure better compliance of the relaxed discharge standard a slightly higher dose, between 40 and 50 mW.s/cm<sup>2</sup> would be recommended. In order to meet the general discharge standard it would be necessary to use higher UV doses and according to this investigation, doses of around 150 mW.s/cm<sup>2</sup> would be required to do this on a regular basis. Medium pressure UV has fairly high capital costs, but the running and maintenance costs are relatively low and in fact it compares very favourably with chlorine costs in achieving the special effluent discharge standard of 500 faecal coliform CFU/100 mL. It needs to be stressed that achievement of the general discharge standard of 0 faecal coliforms per 100 mL will be possible most of the time using doses much lower than 150 mW.s/cm<sup>2</sup>. Another advantage to using UV is that it is extremely simple to maintain and operate.

Peracetic acid was found to have 100% compliance with the special effluent discharge standard when used at a concentration of 5 mg/L or more. However, in meeting the general standard of 0 faceal coliforms it was necessary to almost double this dose. The current high price of peracetic acid would result in running costs which would be too high for this method of disinfection to be financially viable.

Bromine was found to be similar to chlorine for the disinfection of wastewater and in fact the bromine concentrations required to meet the special and general discharge standards were also similar. Bromine can be obtained in solution form as an 18 to 19% solution under the trade name of Aquatreat. However, at present the costs relative to chlorine are very high.

#### 1.5. Recommendations for Future Research

Both ozone and UV have been researched fairly intensively and apart from work on high intensity, low pressure systems, no further work appears to be necessary at this stage.

The tests conducted in this investigation revealed that bromine is an effective disinfectant for wastewater effluent. However, the bromine solution used in the pilot plant tests described in this report, was found to be unstable and as such, not suitable for these applications. Different methods of bromination, such as ammonium bromide used in conjunction with chlorine warrant further investigation.

Peracetic acid was produced in relatively small quantities for the experimental tests carried out for this investigation, but should full scale plant applications be considered, commercially available solutions would be required before this would be a feasible option. Peracetic acid is commercially available in Europe and this would need to be tested before implementation locally, but the cost would not be attractive under present conditions.

#### 1.6. Conclusions

The conclusions in terms of the objectives of this project are discussed:

- Adequately disinfect wastewater effluents in terms of parasitic (oo)cysts (Giardia and Cryptosporidium), viruses (coliphages) and bacterial indicator organisms (E. coli, faecal streptococci and coliforms) while not exceeding DWAF general standards for chlorine residual.
  - It was shown that there are a number of disinfectants capable of achieving this, such as ozone, UV, peracetic acid, bromine and combinations of chlorine with ozone or UV.
- Adequately disinfect wastewater effluents in terms of the above without producing a chlorine residual.
  - This was also achieved by using disinfectants such as ozone, UV, peracetic acid and bromine.
- Provide design and operational guidelines for simple and effective disinfection of wastewater effluents.

The basic operational parameters required when using the suitable options are listed in this report.

- 4. Provide a disinfectant protocol suitable for use under low technology applications. UV is a possibility for rural applications, provided that adequate instrumentation is installed to detect failure of lamps or poor transmissivity. Obviously a pre-requisite for UV disinfection would be an adequate power supply. Peracetic acid could also provide a method of wastewater disinfection suitable for rural areas. It is comparable to hypochlorite solutions in terms of required handling precautions, it is more stable than hypochlorite solutions, doesn't produce a chlorine residual and only requires a simple dosing pump. However, the cost would be prohibitive at this stage, and will remain so until peracetic acid is imported in bulk or is manufactured locally.
- Determine the potential for regeneration of micro-organisms, especially Giardia, Cryptosporidium and viruses after different methods of disinfection.
   For normal bacteriological indicator organisms and parasitic (oo)cysts, regrowth does not appear to be a problem within the limits of the indications of the tests.

### 1.7. Status in Terms of Cryptosporidium and Giardia

One of the problems experienced in carrying out the research for this project, was difficulty in establishing the viability of (oo)cysts once they had been detected. Future work into tests demonstrating the viability or infectivity of (oo)cysts is needed before definitive results on Cryptosporidium and Giardia inactivation can be reported for investigations of this nature. Measuring Cryptosporidium and Giardia recoveries tends to be generally low internationally (typically 30%) and improvement in detection and recovery techniques would be beneficial as regards accuracy of results.

The data generated during this project will be archived by Umgeni Water.