OZONE EXPERIENCES AT UMGENI WATER

M.J. Pryor, P.S. Naidoo, P. Bahrs, S.D. Freese

Umgeni Water: P.O. Box 9, Pietermaritzburg, 3200. Tel. (031) 203 3003
Fax. (031) 203 3005 E-mail: martin.pryor@umgeni.co.za

1. INTRODUCTION

The design of the Wiggins Treatment Plant commenced in September 1980 with a commitment to increase the supply of potable water in the Durban area by the summer of 1984. The other main source of treated water, Durban Heights Water Treatment Works, was at the time utilised at near full capacity. The design capacity of the new Wiggins Plant was set at 175 ML per day with allowance for future expansion to 350 ML per day as demand increased.

From the commissioning of the works in 1984 the raw water supplied to the works was pumped from the lower uMngeni River, passing water to a balancing reservoir from where it gravitated through a series of three tunnels to the Wiggins inlet shaft. The process was however designed to be capable of treating water from both the pumped river supply and subsequently a eutrophied impounded water fed from the future Inanda Dam. Allowances were made for the addition of process items (dissolved air flotation) should this prove necessary in the future. Ozone was chosen as a primary disinfection medium to cope with pollution problems and to reduce the amount of chlorine required. Provision was made to increase the number of ozone generators should pre-ozonation become necessary.

In order to secure a long-term supply of potable water to the city of Durban, the Inanda Dam was completed in 1989, aqueducts from the Inanda Dam were completed in 1994, and the treatment capacity of the Wiggins Waterworks was upgraded to a full design capacity of 350 Ml per day. It was anticipated that water from the Inanda Dam would be highly eutrophic and in 1992 an experimental pre-ozonation facility was constructed at the works. This was a “full scale” pilot plant and was designed for full-scale evaluation of pre-ozonation at the works.

This paper discusses the operation of the initial ozone facility at Wiggins, the problems experienced, the possible water quality changes due to the change in raw water supply from the Inanda Dam, and discusses aspects associated with the design and operation of the “New Ozone Facility” at Wiggins.

Paper presented at the Biennial Conference of the Water Institute of Southern Africa (WISA) 19 – 23 May 2002, Durban, South Africa
www.wisa.co.za ISBN Number: 1-86845-844-X
CD-ROM produced by: Water Research Commission (WRC), www.wrc.org.za Organised by: Conference Planners

2. BACKGROUND TO OZONE IN WATER TREATMENT

The use of ozone in water treatment has increased significantly since it was first used for disinfection in 1893 and is now used extensively, especially in Europe where pollution and subsequent eutrophication have complicated water treatment. Although ozone was initially used only for disinfection, the usefulness of ozone in other aspects of water treatment became more apparent.

Ozone reacts by one of two pathways; the first being oxidation which is a highly selective direct molecular reaction, while the second is indirect with radical species that are formed during the decomposition of ozone (Hoigne & Bader, 1978, 1983a, 1983b; McKnight et al., 1993). Hydroxyl radical formation has been found to increase with increasing pH (Hoigne & Bader, 1978, 1983a), while direct oxidation by ozone predominates at lower pH values (McKnight et al., 1993). Bicarbonate ions have also been found to affect the reactions of ozone, since they act as scavengers for hydroxyl radicals (Beltran et al., 1994a, 1994b; McKnight et al., 1993). The different reaction pathways become important when considering the treatment objectives. The radical pathway is preferable for the destruction of organic molecules and micro-pollutants.

Pre-ozonation is used to enhance coagulation and flocculation (Farvardin & Collins, 1989; Jekel, 1994; Langlais et al., 1991; Richard, 1992). However, it has also been reported that these processes may be impaired by pre-ozonation (Edwards et al., 1992; Rencken, 1992).

It has also been found that pre-ozonation affects total organic carbon (TOC) removal, the rate of head loss build-up during filtration and the final water quality. These effects were found to depend on the nature and concentration of natural organic matter (NOM) in the water (Edwards et al*.,* 1994; Jekel, 1994).

When water containing NOM is ozonated, the larger molecular weight compounds are partially oxidised into smaller, more polar organics (Edwards et al., 1994; Jekel, 1994; Reckhow & Singer, 1984). The decrease in molecular weight and increase in functional group density or polarity decreases the amount of NOM removed by both precipitation reactions and adsorption (Edwards et al., 1994; Jekel 1994) and may increase coagulant demand. It is therefore obvious that the nature of the NOM, the ozone dose and the pH will all affect the treatment process and final water quality.

The Disinfection byproducts formed as a result of ozonation increase the biodegradability of NOM and can therefore also contribute to regrowth in distribution systems (Bull & Kopfler, 1991; Miltner et al., 1992). The increase in biodegradability allows for biological treatment after ozonation, with subsequent increased removal of organics (Huck et al., 1990a; Miltner et al., 1992), especially when using GAC where the benefits of biological filtration and GAC adsorption are combined (AWWA, 1981; Servais et al., 1994). Ozonation when used prior to GAC filters is sometimes referred to as "intermediate ozonation" and generally follows conventional potable water treatment.

At Umgeni Water however, pre-ozonation is used to enhance coagulation and flocculation, oxidise soluble iron and manganese, reduce incidents of taste and odour, and oxidise specific micropollutants such as pesticides, geosmin and 2-methyl isoborneol. Other benefits such as the effectiveness of ozone to inactivate protozoa and immobilise bacteria and viruses are also recognised as a benefit for ozonation.

3. INITIAL TREATMENT PROCESS AT THE WIGGINS WATERWORKS

The process was designed with the aim to be capable of treating water both from the pumped river supply and an impounded water fed by gravity from the Inanda Dam. The capacity of the plant was 175 ML per day (8 000 m^3/h - 22 hour basis).

The original treatment process consisted of aeration, clarification, rapid gravity filtration and ozonation with lime being used for pH correction and a low dose of final chlorination to maintain disinfection in the reticulation system. The design included post-ozonation, principally for disinfection, but also to combat taste and odours in the water. The experimental pre-ozonation facility was commissioned in June 1992 and was designed as a "full-scale" pilot study of pre-ozonation at the works. (Figure 1)

The aeration tank (4 400 m^3) was designed to achieve 33 minutes contact time. Air blowers were provided to assist with the removal of iron and manganese from waters low in oxygen. A section of the aeration tank was modified to include 350 diffusers placed about 5m below the surface of the water, covering an area of 200m^2. A temporary roof structure was constructed over this section of the aeration tank to capture the off-gas, which was piped to the catalytic ozone destructor. A locally manufactured sintered disk type diffuser was used due to the trial nature of the pre-ozonation process.

Lime was used for pH adjustment ahead of clarifiers. Powdered activated carbon could be added if required. A maximum dose of 18mg/L was used but it was envisaged that should algae related problems increase, up to 30mg/L could be required (with greater coagulant doses) in future. Blended polymeric coagulants were used for effective charge neutralisation and coagulation.

Four Degremont pulsator clarifiers were installed (total surface area 4 000 m^2). Twelve rapid gravity filters of the Degremont "Aquazur V" type were provided (surface area 1 344 m^2) with a maximum filtration rate of 6 m/h.

The post-ozone contact tank consisted of 2 parallel chambers each containing 340 corundum diffusers. A contact time for disinfection was 15,6 minutes. Chlorine was added at the end of the treatment process to maintain a residual concentration of up to 1,2 mg/L in the water delivered to the city of Durban.

3.1 Air Preparation

Air was filtered twice before it entered the blowers; firstly through coarse filters on the air intakes to the blower room and secondly through filters attached to the inlet of each air blower. The air needed to be dried to an equivalent dew point between -80°C and -60°C. To achieve this air from the blowers (60-75kPa; 60-120°C) was passed through a water-cooled heat exchanger to 30°C, with further cooling through a refrigeration heat exchanger to about 6°C. Water was removed in a separation unit and finally residual moisture and organics were removed in an air drier using a molecular sieve material firstly in a drying cycle and then a regeneration cycle.

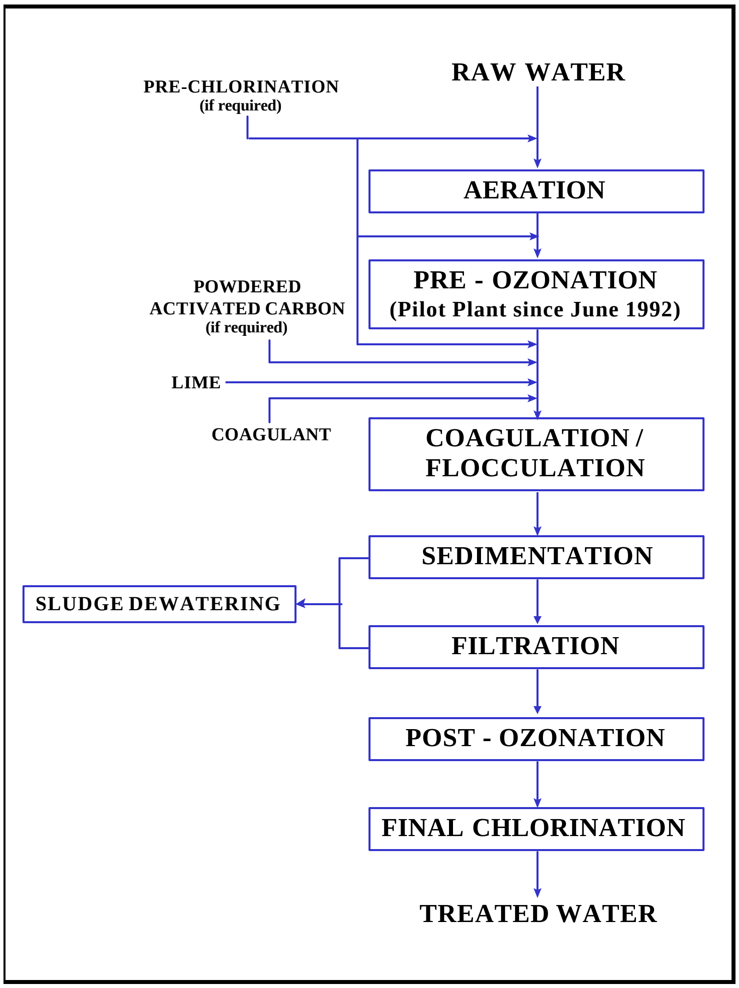

Figure 1 Schematic of Wiggins Waterworks treatment (prior to 1997)

3.2 Ozone generators and ozone destructor

Four Degremont low frequency ozonators (3 operational, 1 standby) were installed each capable of producing 6,6 kg O_3/h. Each ozonator consisted of 352 tubes operating at 16-19 kV, 50Hz. The energy requirement for ozone production was 16 kWh/kg O_3. Rotameters were used to measure the flowrates of air and cooling water to the ozone generators. A catalytic ozone destructor was installed to achieve 98-99% destruction of ozone.

3.3 Problems experienced

The ozonation plant experienced numerous problems between commissioning and 1993. The problems are summarized in Table 1. In hindsight air preparation was considered to be critical in the successful operation of the ozone generators.

Table 1 : Summary of main problems with old ozonation installation

Problem Area	Description
Air Blowers	• Calibration of temperature and vibration transmitters to monitor the performance of variable speed units was difficult and numerous false alarms were reported. • The flowrate of air delivered by the blowers to the ozone plant was not measured accurately. (faulty orifice plate) • The operating pressure of the blowers was set too low to effectively implement pre-ozonation.
Air Coolers	• Cooling water temperature in excess of the required 25°C maximum (30°C was achieved on some occasions). • Dedicated cooling water pumps were not installed resulting in the coolers being unable to cool the air sufficiently (60% reliability)
Air Refrigeration	• Ambient cooling water used in condenser • The humidity of the ambient air in Durban also placed an additional burden on the removal of moisture • Outlet from water separator and filters problematic. A filter in the outlet from the separator regularly became blocked
Air Driers	• The additional load on the drier units became critical in providing a dry air to the ozone generators • Modifications made to electrical control. Often operated in manual • Lack of interlocks when power failure • Mechanical type timers problematic • General control of air preparation plant poor
Ozone Generators	• Generators opened every 6 months for cleaning and inspection. Reports of dusty tubes in ozonators • Considerable arcing across tubes (dust / moisture) • Tube and fuse replacement high • No dedicated cooling water system for ozonators • General control of system and co-ordination with air preparation plant poor
Ozone Destructor	• Poisoning of catalyst due to pre-chlorination • Suction fan undersized for pre-ozonation
Post Ozonation	• Low transfer efficiency reported (estimated 65%) • Accuracy of gas flowmeters doubtful
Pre Ozonation	• Installed as a "full-scale" experimental plant • Low transfer efficiency reported • Leaks from temporary roof structure • Clogging of diffuser disks • Backflow into air distribution pipework when air blowers off-line • Leaks in the uPVC line supplying ozone to pre-ozonation

Table 2 Description of expected water quality related problems

Problem	Description
Anaerobic Water	• Strong stratification is evident with the bulk of the hypolimnion having <1mg/l dissolved oxygen. During this stratification high concentrations of dissolved iron and manganese may be present.
Dam Draw Down	• During periods of lower than average rainfall the dam may be drawn down. During these periods it will be impossible to eliminate algal scums by spilling.
Algae	• The study revealed that algae numbers decreased from the inlet to the wall, but the possibility existed for large numbers of algae to be transported from the main basin to the abstraction.
Dam Turnover	• This event is a predictable phenomenon. During such periods dissolved metals will be distributed over the entire water column.
Taste and Odour	• The extensive anaerobic hypolimnion which occupies most of the volume of the impoundment will give rise to taste and odour forming compounds.
Organic micro-pollutants	• A number of organic compounds might be encountered including algal metabolites, pesticides and herbicides and industrial chemicals.

4. PROPOSED UPGRADE OF THE OZONE FACILITY

When the decision was made to upgrade the treatment capacity of the Wiggins Waterworks the Inanda Dam had only recently been completed. A tunnel to transfer water from the dam to Wiggins was still under construction. The tunnel was completed during 1994.

Although some experience in the treatment of water using ozone had been obtained at Wiggins, the water quality was expected to be different once the supply from the Inanda dam was brought online. This is due to the uMsunduze river which joins the uMngeni river above the Inanda Dam. The catchment area of this river is associated with a large informal settlement. The effluent from the sewage works in Pietermaritzburg is also discharged into this river and high concentrations of nutrients were expected. A study of the raw water quality in the Inanda Dam identified certain problems for which ozonation would provide a treatment benefit (Table 2).

5. LABORATORY INVESTIGATIONS

A laboratory investigation was carried out on small-scale ozonation columns designed for batch treatment with ozone. As the water from the new Inanda Dam was expected to be highly eutrophic water was spiked with algal scums to produce algal cell concentrations of 10 000, 100 000 and 500 000 /mL. The effect of two algal genera, *Mycrocyctis* and *Anabaena*, which most often give rise to taste and odour problems in Southern Africa, were assessed. The waters were spiked with atrazine and geosmin as micro-pollutants to determine the effects of ozone in managing pesticides and taste and odour related problems.

On account of the difficulty in analysing NOM, a number of surrogate parameters are used for characterisation of the wide variety of organic compounds that occur in water. THMFP, TOC and DOC, BDOC, UV absorbance at 254 nm, chlorine demand and optimum coagulant dose are amongst the surrogate parameters used for NOM characterisation .

5.1 Trihalomethane Formation Potential (THMFP)

Pre-ozonation was not found to have a significant effect on THMFP, although a decrease in the THMFP after ozonation was often observed at applied ozone doses of between 0,01 to 0,15 mg O_3/mg DOC (between 0,25 and 1 mg/L applied ozone). (Figure 2). A decrease in coagulant demand appeared to coincide with this phenomenon. The decreases in the colloidal charge density at low ozone concentration reported by Farvadin and Collins (1989) may account for this effect, resulting in precipitation of a portion of the THM precursors.

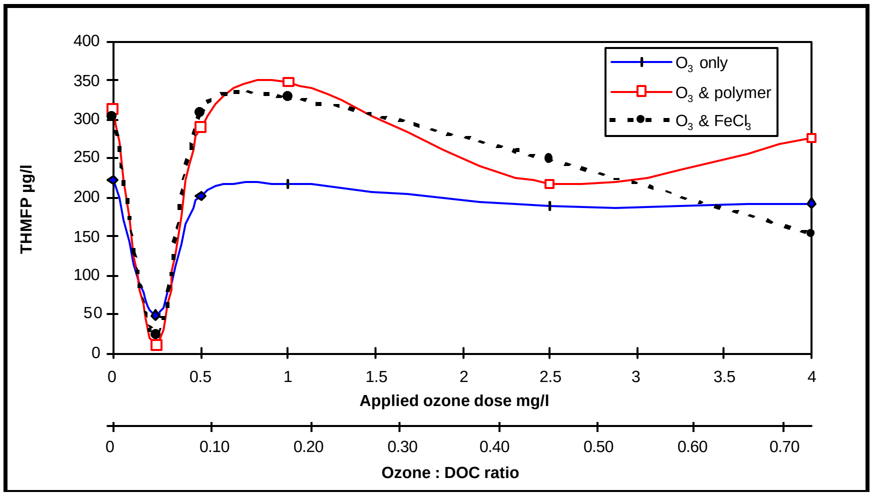

Figure 2: Effect of Pre-ozonation and conventional treatment on the THMFP of a eutrophic water (Inanda Dam water containing 100 000 *Microcystis* cells/ml).

5.2 Dissolved and total organic carbon (DOC and TOC)

Ozone was often found to have little or no effect on the TOC of water. In cases where the TOC concentrations were higher, such as in algal spiked water, a decrease of up to 25% was possible at applied ozone doses of 0,3 to 0,5 mg O_3/mg DOC (generally 2 to 4 mg/L O_3) (Figure 3). This correlates with literature reports of 20 to 30% removal of TOC after ozonation (Tuhkanen et al., 1994; Cipparone et al., 1997).

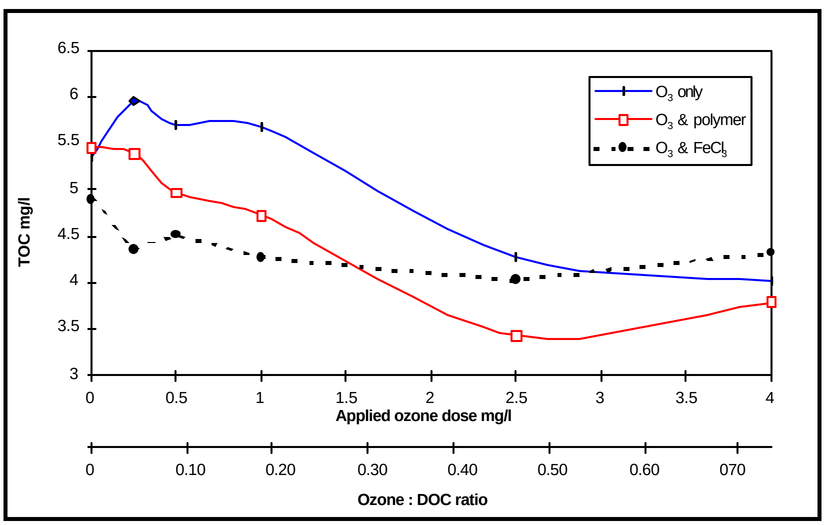

Figure 3 Effect of ozone on the TOC of an eutrophic water (Inanda Dam water containing 100 000 *Microcystis* cells/ml).

5.3 Biodegradable dissolved organic carbon (BDOC)

The BDOC was generally found to increase with increasing ozone concentration, stabilising at higher ozone concentrations, which is in agreement with the findings of other authors (Janssens et al., 1985; Somiya et al., 1986; Sontheimer, 1979). In waters which were fairly low in organic content, such as the Inanda Dam water and algal spiked water, stabilisation of the BDOC concentration was generally found to occur at an applied ozone dose above 1,5 to 2 mg/L O_3 (i.e. ozone to DOC ratios of approximately 0,3 to 0,5) (Figure 4).

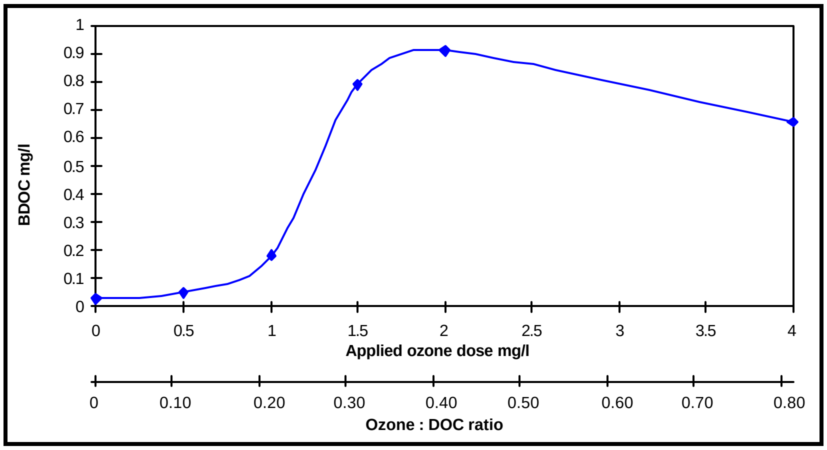

Figure 4 **Effect of ozone on the BDOC of a final filtered water.**

5.4 Effect of ozone on micropollutants and taste and odour compounds

Atrazine, geosmin and 2-MIB were found to decrease with increasing ozone concentration, with an applied ozone concentration of between 0,1 and 0,3 mg O_3/mg DOC generally being required in order to obtain a significant decrease in these compounds (i.e. between 0,5 and 1,5 mg/L applied ozone for the low DOC waters used in this investigation, but between 2,5 and 5,0 mg/L for the higher DOC waters). (Figure 5).

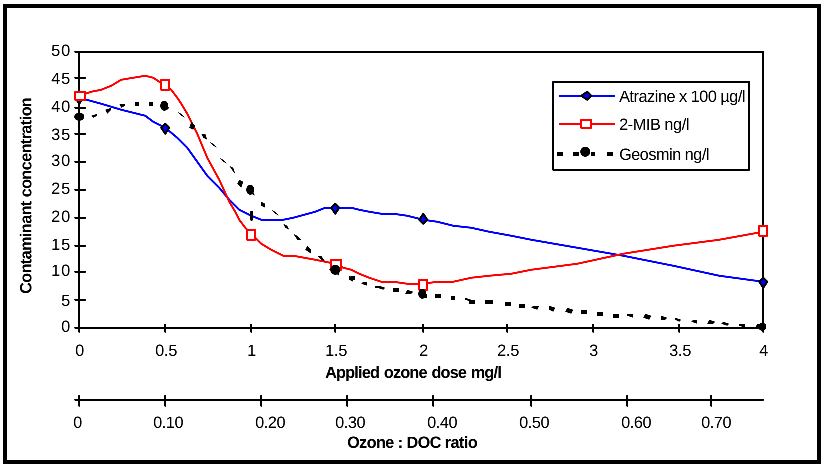

Figure 5: Effect of ozone on atrazine, geosmin and 2-MIB of a final filtered water.

6. DESIGN OF THE UPGRADED OZONE FACILITY

For design purposes the ozone dosage to be applied was considered in two sections, pre-ozonation and post/intermediate ozonation. Due to the unpredictable nature of the Inanda Dam water, the design dosage was based on experience at the works, and on values reported in the literature. These doses were confirmed by the laboratory studies for the typical water quality expected. Pre-ozonation should be between 0,5 and 1,5 mg O_3/mg DOC (DOC 3 to 5mg/L), and at least 2 mg/L ozone may be required for intermediate ozonation. (Table 3).

Table 3 Design Ozone Capacity (Q_{max})

	Upgrading Period	Pre-Ozonation	Post/Inter Ozone	Installed Ozone
Phase I	Prior to implementation of GAC	3 to 5 mg/l (80 kg/h max)	up to 2 mg/l	90 kg/h @ 10% >100 kg/h @ 13%
Phase II	After GAC implementation	3 mg/l (48 kg/h max)	2 to 4 mg/l (64 kg/h max)	

6.1 Oxygen Supply

Three possibilities were available at the time of design; air, pure oxygen produced by on-site cryogenic air separation or evaporating liquid oxygen (LOX) and 92 to 95% oxygen generated by non-cryogenic processes (pressure swing adsorption or vacuum swing adsorption). Electrical power demand of air preparation, oxygen separation processes as well as power for the production of ozone from air were considered (~10kWh/kg ozone from oxygen @ 10% concentration and ~20kWh/kg ozone from air @ 2%).

Previous problems associated with air preparation and the humid weather conditions strengthened the argument for an oxygen fed system. A LOX system was found to be most economical. Two 35m^3 storage tanks (80t LOX) providing a 12 day storage capacity were installed with provision made for a third tank should this be required.

6.2 Ozone Generator

In deciding the number of ozone generators most suitable to the works the following factors were considered

- It would be necessary to shut down each ozonator for maintenance (up to one week).
- The delivery time of essential spares in the case of an unexpected breakdown of power supply units.
- It is Umgeni Water's policy that all mechanical equipment should have a degree of redundancy.
- The capital cost of three units to produce 80 kg/h would be greater than two units of the same capacity.
- It was expected that during Phase II (intermediate ozonation and GAC) the ozonation capacity would have to be increased to 112 kg/h.

It was estimated that adopting a 3 x 30kg/hr system as opposed to a 2 x 40 kg/h system would increase the capital cost of power supply units and ozonators by 15 to 20 percent. However due to the additional flexibility and redundant capacity that this offered, the additional cost was warranted.

Other aspects also considered were the supply of cooling water to the ozone generators, the supply of cooling water to the power supply units, the temperature of the cooling water and whether a chiller was required for the cooling water system.

6.3 Destruction of residual and vent ozone

Two methods of ozone destruction are available (catalytic and thermal). Problems with poisoning of catalysts and the high cost of replacement had been experienced. The permanent installation of pre-ozonation in the new design warranted a dedicated ozone destructor for pre-ozonation. A second destructor being placed in the main ozone building to handle off-gas from the post/intermediate ozonation as well as any leak in the generator room itself. The thermal destructors were a thermal type, with heat recovery. Peak internal temperature is 350°C at which ozone rapidly decomposes back into oxygen. The hot gas is used to pre-heat the incoming gas thus economising in electrical power requirements.

6.4 Pre-Ozone contacting system

The choice of pre-ozonation contacting equipment was subject to several constraints. The equipment had to suit the existing plant layout, have a high efficiency of ozone transfer and a high flexibility to cope with the large range of flow through the works. Two contacting systems were seriously considered namely radial diffusers with injectors, and static mixer systems. The final design specified that a 10% side stream should be mixed with the ozone gas (through a side stream static mixer) and be injected into the main water flow ahead of a main stream static mixer. Due to a guarantee of >95% transfer efficiency from the equipment supplier the ozone is injected directly before the mainstream static mixer and the side stream injection and mixers were not installed.

6.5 Post Ozone Contacting System

Two existing post ozone contactors were retained providing a hydraulic retention time of 7 to 8 minutes. At this point the turbidity of the water should be <0,5 NTU and should not contain appreciable amounts of iron and manganese. Thus the conventional porous diffuser type system could be used. The contact chambers had to be modified to cater for lower gas flows at 10% concentration.

6.6 Control System

The operation and control of the ozone plant can be performed automatically (this is preferred) or manually either remotely from the control room or locally in the ozone room. There are numerous interlocks and safety checks that are performed by the control hardware to ensure a smooth operation. Based on the flow of water through the plant and the specified ozone dose for pre- and post/intermediate ozonation, the oxygen requirement is calculated. The number of ozone generators is selected to provide the ozone requirement. The running hours of each generator are monitored and the generator with the most hours is assigned the lowest priority level, thereby ensuring almost even wear on the plant. Power to each generator is controlled by a local PID controller, to achieve a desired ozone concentration. The flow of ozone is split automatically between pre- and intermediate contacting to maintain the required dose of ozone for each section of the plant.

6.7 Safety and Environmental Issues

Ozone is recognised as a hazardous gas. The occupational exposure limits are 0,1 ppm for 8 hour exposure (equivalent 0,2 mg per m^3 of air) and 0,3 ppm for 15 minutes exposure. An environmental impact assessment was performed prior to the final design where a worst-case accidental release of ozone was modelled. (1 000 L at 10% concentration (m/m) = 135 g ozone). The design of the ozone building was such that two fans (25 000m^3/h) would start and extract air through ducts located at one side of the building. It was assumed that the cloud of potentially hazardous gas would disperse under low wind conditions (1m/s). The model calculated ground concentrations of ozone at different distances from the source.

It was concluded that there would be a negative impact on residents living adjacent to the works. The impact was found to be an ozone concentration of 0,1 ppm reaching a distance of 3 250 m from the works. This was a sufficiently high risk that it was decided to alter the design that in the event of a serious gas leak the fans would not remove air to atmosphere but direct the gases through a thermal destructor.

7. OPERATING EXPERIENCE AT WIGGINS

7.1 Reduction in the coagulant dose

The use of ozone to treat water from the Inanda Dam has resulted in a reduction in coagulant dose. During a trial (December 2000) it was established that in order to achieve stable coagulation and sedimentation without ozone a coagulant dose of on average 2.5 mg/L had to be used as compared to 1.9 mg/L whilst ozone was in operation. The basis of the performance comparison was to obtain similar particle counts on the final filtered water.

7.2 Oxidation of Manganese

During periods of dam turnover, levels of manganese increase in the raw water supply to the works. Raw water was first received from the Inanda Dam in 1994, and on a seasonal basis problems with elevated levels of iron and manganese are likely to occur. During the construction of the new ozone plant there was a period at the works when no ozone was available. Although this was a concern and planning had been able to keep ozone available for as long as possible a manganese problem was experienced in 1996. The final water turbidity increased and it was found that manganese was passing through the plant (Figure 6). Whilst ozone was available no incidents of manganese breakthrough were experienced.

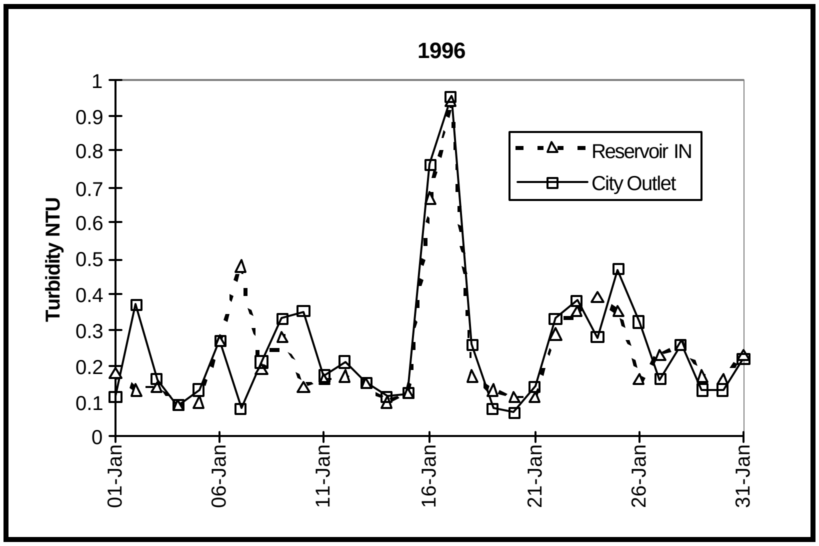

Figure 6: Turbidity entering and exiting the reservoir at Wiggins

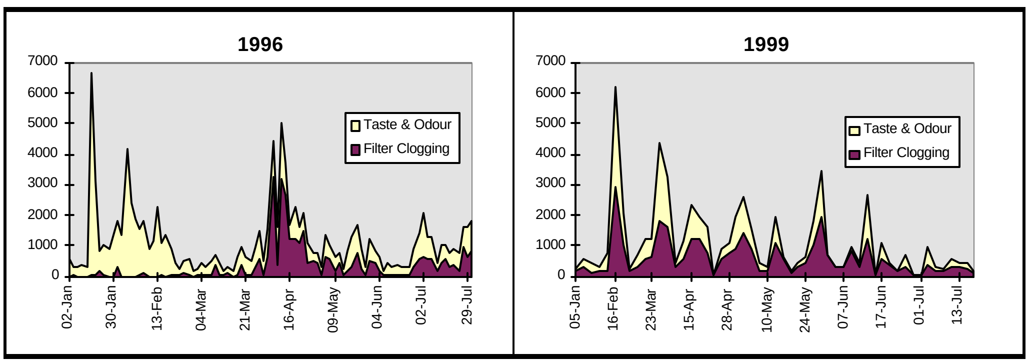

Figure 7 **Algae measured in the Wiggins Raw water during 1996 and 1999**

7.3 Treatment of Algae Related Problems

The main problems associated with algae in the raw water are related to taste and odour incidents arising from the release of intracellular matter into the water. These organics don't normally affect the DOC of the water, but geosmin or 2-methyl-isoborneol can be detected at levels as low as 15-20 ng/L. The normal treatment philosophy is to dose powdered activated carbon to prevent taste and odour compounds passing through the plant. During 1996 (Figure 7) whilst ozone was offline, algae levels in the raw water were high, resulting in the use of 22 tons of powdered activated carbon. Since the commissioning of the new ozone installation, the continuous use of ozone has been effective in reducing the need to use powdered activated carbon. During 1999, although the levels of algae and potential taste and odour problems were high, no carbon was dosed at the works.

7.4 **Operating and maintenance issues**

Having had the experience of struggling with an ozone plant, which appeared to be plagued with operating problems, the effort in the design and specification of the new plant has now eventually paid off. The commissioning and "learning" the operation of the new plant did not however go without hitch.

7.4.1 Commissioning

Each item of the new ozone plant had to be commissioned, not just to check mechanical and electrical functionality, but also to perform according to a performance specification stipulated by the design of each unit. The ozone generators themselves functioned well, but the thermal destruction units performed poorly. Although the temperature of the gas was being heated to 350°C, the ozone concentration on the outlet still remained above 0,1 ppm. The thermal destructor units were removed and newly designed units were manufactured and installed. These subsequently passed the performance testing.

7.4.2 Cooling water temperature

During summer months the ambient water temperature increases to an average of 26 degrees. Although it was stated in the specification that the ozone generators should be able to operate utilising higher cooling water temperatures, the units were designed and tested, during commissioning, under cooler conditions. During summer, too high a cooling water temperature prevented the start-up of the generators. The manufacturer re-programmed the ozonator controllers to allow for higher cooling water temperatures. Whilst this was being done the cooling water pumps were started manually so that once the ozonators had been cooled sufficiently, operation of the generator was allowed to proceed. Once operating satisfactorily the cooling water circuit can be switched onto automatic.

7.4.3 Cooling water to the power supply units

The power supply units (PSU) require very clean water, which is recirculated through the system for cooling. Insufficient flow of cooling water was observed after a number of months of operation. This had not been a problem previously. A flexible hose connection between the centrifugal pumps and the cooling piping to the PSU was found to have "kinked" over time and was thereby preventing flow. This section of pipe was replaced with a rigid pipe.

7.4.4 Interlocks in control software

At Wiggins a high degree of process automation has been employed. The level of operator supervision of the whole works has decreased in the last 10 years and a high level of automation is evident throughout the plant. This however, with a large ozone plant, has led to many "checks and balances" which at times result in operating problems (particularly during start-up).

Following commissioning there was a period during which a number of niggling power and instrumentation problems were experienced. The error messages, which were displayed on the SCADA system were not clear resulting in difficulty identifying the fault. These had to be re-written to enable easier fault identification and better operating control of the plant.

7.4.5 Training of operating & maintenance

Umgeni Water made a point of training all the operating and maintenance staff in the use of ozone, the control system, how the plant works and the benefits of ozonation. This has paid off especially for the maintenance staff. The operating staff now have a responsibility to maintain water production, and in most cases the maintenance personnel have the ability to identify any faults.

7.4.6 Operating philosophy of the plant

Since the commissioning of the plant the philosophy has been to operate the plant continuously, except during planned maintenance or plant shutdown, and should there be a problem it should be identified and be repaired within 24 hours. The ozone plant availability has been excellent at greater than 85%. There has only been a need to operate one ozone generator at a time, and on occasions two have been operated together.

8. CONCLUSIONS

Umgeni Water has over the past 15 years gained significant experience in the treatment of potable water using ozone. The benefits for ozone in water treatment, although these cannot be easily quantified, still however outweigh the drawbacks and can result in a more cost effective operation.

Specification of the design and performance criteria prior to tendering are also critical as this can impact on environmental and occupational safety practises. It is extremely important to go through a rigorous commissioning phase and test the equipment according to the design and not just check mechanical correctness and electrical connection. The main problems were identified as being instrumentation related, and attributed to short cuts taken by the suppliers during installation.

Experience has shown that operator training is definitely required to improve the handover from commissioning to plant operations. The effective training of maintenance personal was critical to the successful implementation and continued operation of the plant. After a period of intensive training and familiarisation with the plant, it has taken the operating and maintenance personnel 18 months to really sort out most of the niggling problems and it can now be said that the plant operates smoothly. The continuous and regular maintenance of the plant is now continuing. The extent of how this will impact on the performance of the plant with time is yet to be determined.

Umgeni Water is proud of the successful operation of the new ozone plant and will certainly consider the use of ozone at other treatment works where the raw water quality dictates that ozone should be required.

REFERENCES

1. AWWA Committee Report (1981) An assessment of microbial activity on GAC. J. AWWA 73(8) 447-454.
2. BELTRAN FJ, GARCIA-ARAYA J, and ACEDO B (1994a) Advanced oxidation of atrazine in water - I. Ozonation. Wat. Res. 28 (10) 2153-2164.
3. BELTRAN FJ, GARCIA-ARAYA J, and ACEDO B (1994b) Advanced oxidation of atrazine in water - II. Ozonation combined with ultraviolet radiation Wat. Res. 28(10), 2165-2174.
4. BULL RJ, and KOPFLER FC (1991) Health effects of disinfectants and disinfection by-products AWWA Research Foundation Report (Denver, CO: AWWA).
5. CIPPARONE LA, DIEHL AC, and SPEITEL Jr. GE (1997) Ozonation and BDOC removal: Effect on water quality. J. AWWA 89(2) 84-97.
6. EDWARDS M, and BENJAMIN MM (1992) The effect of preozonation on coagulant - Natural organic matter interactions. J. AWWA 84(8) 63-72.
7. EDWARDS M, BENJAMIN MM, and TOBIASON JE (1994) Effects of ozonation on coagulation of NOM using polymer alone and polymer/metal salt mixtures. J. AWWA 86(1) 105-116.
8. FARVADIN MR, and COLLINS AG (1989) Preozonation as an aid in the coagulation of humic substances - Optimum preozonation dose. Water Res. 23 307-316.
9. HOIGNE J, and BADER H (1978) Ozone initiated oxidations of solutes in wastewater: A reaction kinetic approach. Prog. Wat. Technol. 10 657-669.
10. HOIGNE J, and BADER H (1983a) Rate constants of reactions of ozone with organic and inorganic compounds - I Non-dissociating organic. Wat Res. 17 173-183.
11. HOIGNE J, and BADER H (1983b) Rate constants of reactions of ozone with organic and inorganic compounds - II Dissociating organic. Wat.Res. 17 185-194.
12. HUCK PM (1990) Measurement of biodegradable organic matter and bacterial growth potential in drinking water. J. AWWA 82(7) 78-86.
13. JANSSENS JG, MEHEUS J, and DIRICKZ J (1984) Ozone enhanced biological activated carbon filtration and its effect on organic matter removal and in particular on AOC reduction. Wat. Sci. Technol. 17(6/7) 1055-1068.
14. JEKEL MR (1994) Flocculation effects of ozone. Ozone Sci. & Eng. 16(1) 55-66.
15. LANGLAIS B, RECKHOW DA, and BRINK DR (1991) Ozone in water treatment: Application and engineering. Cooperative Research Report : American Water Works Association and Compagnie Generale des Eaux, (Michigan, USA : Lewis Publishers Inc).
16. MCKNIGHT KF, CARLSON M, FORTIN P, and ZIESEMER C (1993) Comparison of ozone efficiency for manganese oxidation between raw and settled water. Ozone Sci. & Eng. 15 331-341.
17. MILTNER J, SHUKIARY HM, and SUMMERS RS (1992) Disinfection by-product formation and control by ozonation and biotreatment. J. AWWA 84(11) 53-62.
18. RECKHOW DA, and SINGER PC (1984) The removal of organic halide precursors by preozonation and alum coagulation. J. AWWA 76(4) 151-157.
19. RENCKEN GE (1992) Ozonation at Wiggins Water Purification Works, Durban. Proceedings of the second Southern African Ozone Association Conference, Warmbaths, South Africa.

20. RICHARD M (1992) Preozonation related to algal removal. Proceedings of the Second International Ozone Association Conference, Warmbaths, South Africa.
21. SERVAIS P, BILLEN G, and BOUILLOT P (1994) Biological colonization of granular activated carbon filters in drinking water treatment. Journ. Environ. Eng. 120(4) 888-899.
22. SOMIYA I, YAMADA H, NOZAWA E, and MOHRI M (1986) Biodegradability and GAC adsorbability of micropollutants by preozonation. Ozone Sci. & Eng. 8(1) 11-26.
23. SONTHEIMER H (1979) Process engineering aspects in the combination of chemical and biological oxidation in Oxidation Techniques in Drinking Water Treatment, Edited by W. Kuhn and H. Sontheimer, EPA-590/9-79-020.
24. TUHKANEN TA, KAINULAINEN TK, VATIAINEN TK, and KALLIOKOSKI PJ (1994) The effect of preozonation, ozone/hydrogen peroxide treatment, and nanofiltration on the removal of organic matter from drinking water. Ozone Sci. & Eng. 16 367-383.