REPLACEMENT OF POWDERED ACTIVATED CARBON WITH OZONE AND BIOLOGICAL FILTRATION FOR TASTE, ODOUR AND CYANOTOXIN REMOVAL

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ABSTRACT

Malpas Dam is the source of water for the town of Armidale in the New England area of New South Wales, a community of 25,000 people. Since its commissioning, Malpas Dam has had a history of cyanobacterial (blue-green algae) events, with generally at least one bloom occurring per year. During the algal blooms, contamination of the raw water source with taste and odour compounds is common, and on occasions cyanotoxins have been detected. In the 1980s liver damage in the community was linked to a bloom of *Microcystis*. A robust barrier is therefore required to deliver safe and aesthetically pleasing drinking water to the Armidale community.

The 40 ML/d conventional treatment process at Armidale WTP (coagulation, flocculation, sedimentation, filtration and chlorination) was not capable of removing the organic contaminants to target levels. A powdered activated carbon (PAC) facility was installed and provided a barrier for the micropollutants however this approach was expensive, time consuming for operational staff and presented a number of health and safety issues. The PAC system was unreliable and customer complaints were still forthcoming.

This paper details the process of selecting, designing, building and operating an ozone and biological filtration process which has replaced the PAC dosing system and provided numerous water quality and operational benefits.

KEY WORDS

Ozone, Taste and Odour, Cyanotoxin, Intermediate Ozonation.

1.0 INTRODUCTION

Armidale Water Treatment Plant (WTP) has a treated water production capacity of 40 ML/d and comprises coagulation, flocculation, sedimentation, monosand open gravity filtration, fluoridation and chlorination. Raw water is sourced from Malpas Dam. Characteristics of the raw water are provided in Table 1. Cyanobacterial events in Malpas Dam are common, with generally at least one bloom occurring per year. Generally the events occur between November and March, however high levels of cyanobacteria have been recorded as early as August and persisted at times until July.

During the algal blooms, contamination of the raw water source with taste and odour compounds is common, and at times algal toxins have been detected. Recently the predominant genus is *Anabaena circinalis*, which is capable of releasing the neurotoxin *Saxitoxin*. Algal counts in the order of 1.75×10^6 cells/mL of *Microcystis aeruginosa* and 4×10^6 cells/mL of *Anabaena circinalis* have been recorded. High levels of *Microcystis aeruginosa* in Malpas Dam in the 1980s were linked to liver damage in the Armidale community [1]. The primary taste and odour compound of concern from Malpas Dam has been geosmin, with levels as high as 1000 ng/L measured.

These levels are extremely high considering that the odour threshold for geosmin is 4 ng/L. A robust barrier is required to deliver safe and aesthetically pleasing drinking water to the Armidale community.

Table 1: ***Armidale WTP raw water quality characteristics*.**

Parameter	Units	Average	Minimum	Maximum
Turbidity	NTU	1.3	0.2	12.5
True Colour	Hazen Units	15.2	1	96
pH		7.8	7.2	8.7
Temperature	^{O}C	16.1	7	25
Alkalinity	mg/L as $CaCO_3$	123.8	90	140
TOC	mg/L	6.33	4.3	15.9
DOC	mg/L	3.6	2.9	10.6

The conventional treatment process at Armidale WTP was not capable of removing the organic contaminants to target levels. A powdered activated carbon (PAC) facility was installed and provided a barrier for the micropollutants, however this approach was expensive, time consuming for operational staff, presented a number of health and safety issues and was unreliable. Historically, PAC has been dosed at Armidale WTP for periods of 4 to 6 months per year with doses ranging between 5 mg/L and 60 mg/L. The poor reliability of the PAC system meant customer complaints of unpalatable, "foul smelling" water were still reported on occasions. Operators worked on a rotating shift basis to maintain plant operations, which was most challenging during algal bloom events. Armidale Dumaresq Council (ADC) thus desired a continuous and reliable solution that also reduced the demands on operator resources.

2.0 INVESTIGATIONS

In September 1998, ADC engaged Hunter Water Australia (HWA) to investigate the suitability of an ozone and biological activated carbon (ozone/BAC) process to produce safe, palatable, odour-free drinking water for Armidale consumers. A technology review was first undertaken to identify suitable alternatives for the removal of taste and odours and cyanotoxins. A desktop feasibility study was then undertaken to determine how ozone could be applied and integrated at Armidale WTP and operational and cost implications. Intermediate and tertiary ozonation were considered potential options at this point.

Pilot testing was undertaken from December 1998 to April 2000. The complete pilot programme and results are too extensive to be completely detailed in this paper. The key findings were that ozone/BAC achieved excellent removal of MIB and geosmin levels up to the maximum tested of 2700 ng/L. Saxitoxin concentrations of 60 µg/L were removed with an ozone Ct of 4 mg.min/L, with biological filtration alone removing levels of 15 µg/L. Significant reductions in chlorine demand and trihalomethane (THM) formation potentials were also recorded. Bromate formation did not exceed the Australian Drinking Water Guideline limit of 0.020 mg/L.

Intermediate ozonation was selected as the most appropriate technique for application of ozone, as it minimised the amount of additional infrastructure as it makes use of the current filter structures, providing a significant cost advantage. The is also limited available space at Armidale WTP and therefore installation of supplementary filters for biological filtration in addition to ozone generation and contacting would be a major challenge and require significantly more site works.

While Armidale WTP has a hydraulic capacity of 40ML/day, the peak raw water usage in the 5 years prior to 2005 was only 21.9 ML/d; the 95-percentile flow was only 14.9 ML/d. This provided ADC a unique opportunity to use the existing plant filters to provide 10 minutes empty bed contact time (EBCT) at peak flows, while for most of the time greater than 15 minutes would be provided without the need for additional filter structures. ADC selected a maximum ozonation design flow of 22.5 ML/d for immediate production requirements. The system was designed however to be enable treatment of up to 29 ML/d if required in the future through addition of a third ozone generation train and modification to the existing filter structures to provide additional depth and hence EBCT. All piping and contacting infrastructure were designed and built for the ultimate 29 ML/d capacity.

3.0 UPGRADE PROCESS

The conversion of the sand filters to GAC/BAC was undertaken first. Installation of the new media commenced in January 2007, following detailed assessment of the filter structures, underdrains and nozzles to identify any potential rectification works. No issues were identified in these areas. All filters were converted to GAC by April 2007. GAC of the same size as the original sand media was used in the upgrade and garnet replaced gravel layers. The strong organic adsorption capability of the fresh GAC had immediate benefits on treated water quality. Once all filters were converted to GAC around a 1 to 2 mg/L reduction in chlorine dosing requirements was observed. This adsorption capacity diminished over time as the adsorption sites were exhausted, however removal capability was maintained by colonisation of the media by bacteria and subsequent biodegradation of organics.

During 2006, earlier conceptual designs for the ozone system were developed further to refine the design and finalise key process and design criteria. This included factors such as feed gas type, ozone injection techniques, ozone contactor configuration, hydraulics, power systems and control. Figure 1 is a schematic of the configuration selected for the upgrade. Table 2 presents the key design and operating criteria for the ozonation system.

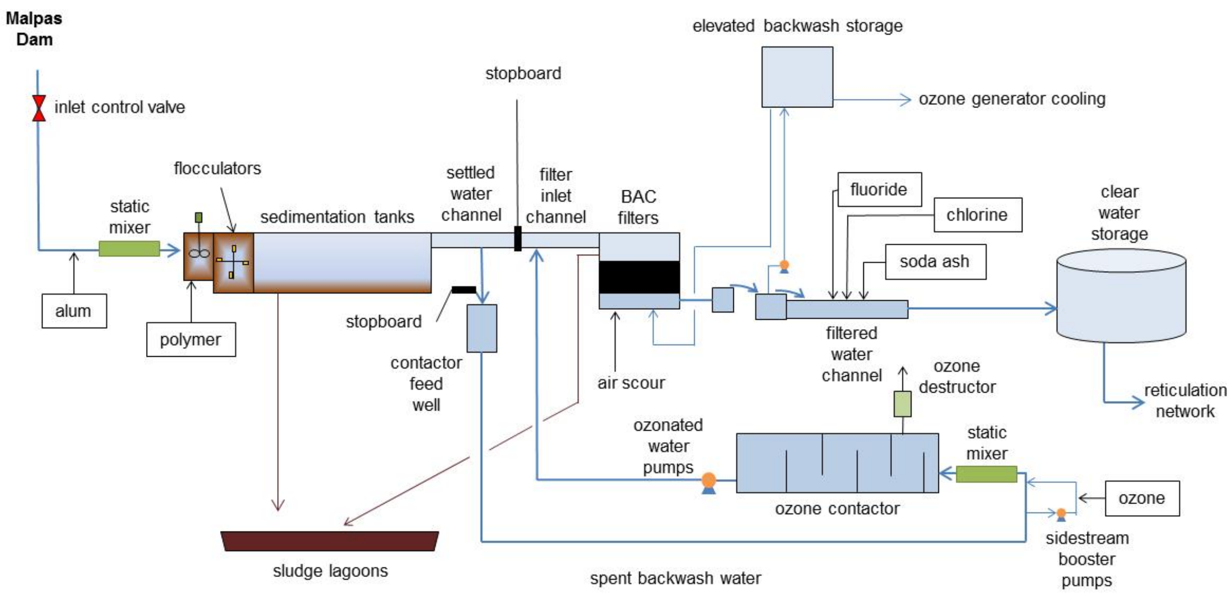

Figure 1: ***Upgraded Armidale WTP process schematic.***

Table 2: ***Ozonation system design and operating requirements.***

Requirement	Units	Criteria
Maximum settled water flow	ML/d	22.5
Ozone dose Maximum Typical	 mg/L mg/L	 6 2.5
Ozone generator feed gas	-	dry air
Generated ozone concentration	$g.Nm^3$	30 - 40
Minimum ozone generation capacity	kg/hour	5.6
No. of installed ozone generators	-	2
Maximum cooling water temperature	^{O}C	30
Contactor hydraulic residence time at maximum water flow	minutes	10
Minimum contactor water depth	m	4
Number of contacting compartments	-	4
Ozone contactor outlet stilling well residence time	minutes	5

One of the key challenges was integrating the plant additions to the site, which neighbours closely residential dwellings. Aesthetic amenity and noise were critical considerations. In order to reduce the visual impact and not to block afternoon winter sun to neighbouring properties, the contactor position, geometry and height required careful consideration. To reduce the height of the structure a number of features were incorporated:

- Static mixing was selected over bubble diffusion for ozone injection as the water depth in the contactor is less critical.
- The contactor was constructed at lower than the natural surface level.
- A pump station was designed to return ozonated water to the filters. Stainless pumps were required for this due to the corrosivity of the ozonated water.

A key objective of the design was to deliver an ozonation facility that met Council's expectations regarding access to equipment for operators and maintenance teams. Undertaking the design development process and incorporating these requirements gave tenderers a clear understanding of Council's vision and expectations.

In June 2007, three contractors were selected through an Expression of Interest process to tender for the design and construction of the ozonation plant. Bricon Pty Ltd was awarded the tender in November 2007 for a tender value of $3.45M. Preliminary design drawings were issued in January 2008 with construction commencing in April 2008. The commissioning process was completed in February 2009.

4.0 OZONE SYSTEM DESCRIPTION

Ozone is generated from air. Comparisons between oxygen and air sources indicated that for this scale plant an air fed system was more economical. The ozone system installed features two ozone generation trains. Each train consists of a rotary screw air compressor, desiccant dryer, aftercooler, air receiver and ITT Wedeco SMA600S ozone generator. Each ozone generator has a capacity of 2.8 kgO_3/hour at 40 gO_3/m^3 at a maximum gas flow of 70 Nm^3/hr, and alone can apply an ozone dose of 3.0 mg/L at 22.5 ML/d. Space has provided for addition of both a third air preparation and ozone system in the future if treated water demand increases.
Two Statiflo GDS (Gas Dispersion System) injection skids (duty/standby) featuring motive water pump and side stream static mixers were provided to mix ozone gas with the settled water feed. A sidestream of settled water is taken off the settled water main and is

pumped through the sidestream static mixers and then re-injected into the main immediately upstream of a Statiflo DN600 inline static mixer prior to the entry to the ozone contactor.

Ozonated water enters an inlet chamber in the ozone contactor and then passes through three over-under contacting compartments providing a combined 10 minute hydraulic detention time at a flow of 29 ML/d. Water flows over the last compartment outlet weir into a stilling chamber and is then pumped to the BAC filters. Ozone off-gas is treated by an ITT Wedeco COD200 ozone destructor installed in the ozone generation room.

5.0 RESULTS

The commissioning of the intermediate ozone system and biological filtration at Armidale WTP has enabled the mothballing of the PAC plant. The onerous and time consuming tasks associated with operating and maintaining the PAC dosing system and addressing breakdowns and failures are significantly reduced such that plant operators have moved to a 35-hour day-work week. The combination of ozone and BAC has mitigated numerous taste and odour events since commissioning. Cyanotoxins have not been detected in Malpas Dam since installation of the ozonation plant and therefore it has yet to be challenged in this regard.

In early February 2011, a significant bloom of *Anabaena circinalis* was detected, peaking at 660,000 cells/mL equating to a cyanobacterial biovolume of 165 mm^3/L. Operational staff observed that the algae had died on the 5th February and rainfall on 6th February had washed the dead bloom over the dam spillway. Raw water quality entering the plant was very poor, with dissolved oxygen around 1 mg/L, dissolved organic carbon (DOC) 10.6 mg/L and a combined geosmin and MIB concentration of 299 ng/L, most of which was intracellular. The combined settled water geosmin and MIB concentration was 41 ng/L, well above the human detection threshold. Table shows the quality of the raw, settled, ozonated and filtered water on the 9th February. It can be seen from Table that ozonation was removing around 83% of the settled water geosmin and MIB, with the biological filters providing approximately another 10% reduction. DOC removal by the ozonation and biological filtration process was 33% with ozone contributing 14% and biological filtration contributing 19%.

Table 3: ***Armidale WTP water quality 9th Feb 2011 during Anabaena circinalis event***

Parameter	**Units**	**Raw**	**Settled**	**Ozonated**	**Filtered**
Turbidity	NTU	4.9	1.2	0.7	0.3
True Colour	Hazen Units	40	15	<5	<5
pH		7.7	7.0	7.1	7.1
TOC	mg/L	13.2	5.9	5.1	4.2
DOC	mg/L	10.6	5.8	5.0	3.9
UVT	%	49.8	72.3	87.2	92.3
Geosmin	ng/L	282	27	4.7	2.8
MIB	ng/L	17	14	2.3	<1

The ozone generators were operating at maximum capacity to apply an ozone dose of 7.8 mg/L to a flow of 190 L/s.

The generators were operating in residual control mode, trying to achieve a 0.1 mg/L residual in the contactor outlet, however this could not be achieved due to the level of DOC. With the potential for cyanotoxin contamination and variation in ozone demand

Council considered this the safest mode of operation at these times. There are opportunities to reduce the ozone demand through reduction of DOC prior to ozonation. Work is to be undertaken to examine whether enhanced coagulation (low pH coagulation) can be employed for this purpose.

Since commissioning the ozone/BAC process has resulted in a reduction in organic carbon in filtered water, and a subsequent reduction in chlorine dose for final disinfection along with a more persistent residual throughout the distribution system.

6.0 CONCLUSION

The retrofit of the ozone/BAC process to Armidale WTP has provided a continuously operating barrier to taste and odours and cyanotoxins. The new system has significantly reduced operating labour requirements for maintaining a taste and odour and cyanotoxin barrier, so much so that the plant is only attended during daylight hours and operators have moved to a 35-hour week from a rotating around-the-clock shift basis. Improved chlorine residual stability has also been achieved throughout the distribution system.

The overall approach taken for the project ultimately resulted in a value for money solution that addressed the water quality challenges and site specific constraints. A significant contributor to the outcome was the piloting process, which enabled key design and performance criteria to be incorporated and considered in the design development process. Undertaking of the design development prior to tendering removed the water quality objectives risk from the contractor, as ozone doses and contact times were pre-defined. The design development also allowed Armidale Dumaresq Council to effectively manage the associated onsite risks and aesthetic aspects of the plant by pre-selection of the ozone feed-gas and the ozone injection technique and configuration of the ozone contactor. The delivery of a highly functional and operator friendly system, integrated on a challenging site, for a tender price of $3.5M represents significant value for a plant of this capacity.

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