8 YEARS OF MEMBRANE OPERATIONS AT BENDIGO: MAINTENANCE, MONITORING AND MAPPING

Paper Presented by:

Kathy Northcott

Authors:

Kathy Northcott, *Process Operations Engineer,*
Colin Ellett, *Senior Water Operator,*

Veolia Bendigo Operations

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Kathy Northcott, *Process Operations Engineer,* Veolia Bendigo Operations.
Colin Ellett, *Senior Water Operator,* Veolia Bendigo Operations.

ABSTRACT

Veolia Water Australia (Veolia) operates three water treatment plants (WTPs) under the AQUA 2000 contract with Coliban Water, to supply safe and reliable drinking water to Bendigo, Castlemaine and Kyneton. All three WTPs are advanced microfiltration plants with a combined capacity of around 150 ML/d, making Veolia Bendigo Operations one of the largest microfiltration plant operators in Australia. The three microfiltration plants have been fully operational since 2002 and since then the Bendigo Operations team has collected a significant body of knowledge on membrane performance. The team uses a customized access data base for recording maintenance activities such as pinning, membrane change-out and damage to membranes. Membrane performance parameters such as flux, resistance, log removal value (LRV, pathogen reduction) are routinely monitored and reported. This is compared with data on raw water quality and membrane recovery after backwashing and chemical cleans. Finally, membranes are periodically sent for autopsy to assess the effectiveness of cleaning and evidence of fouling. The combined monitoring and maintenance information enables better understanding of membrane behaviour. This paper will present the results of the first 8 years of operation of microfiltration membranes at Bendigo WTP. In particular the lessons learned with regard to the interaction of raw water quality, backwashing and chemical cleaning and the importance of a good maintenance regime on maintaining performance.

KEY WORDS

Membranes, Microfiltration, Performance Monitoring

1.0 INTRODUCTION

1.1 Overview of the Bendigo treatment process

The Bendigo WTP is designed to deliver treated water with quality targets higher than Australian Drinking Water Guideline standards and supplies approximately 110,000 customers. When commissioned in mid 2002, the Bendigo WTP was the largest Submerged Continuous Micro Filtration Submerged (CMF-S) Plant in the world with a maximum capacity of 126ML/day. The Bendigo WTP is designed based upon a multi-barrier treatment approach, combining microfiltration, ozone, biological activated carbon filters (BAC), followed by chloramination for final disinfection throughout the network to the customer tap.

The microfiltration (CMF-S) plant consists of eight cells (typically 6 duty cells, 2 stand-by cells), each containing 576 submerged membrane modules. Water enters at the side of the cell and is drawn through the porous membranes by suction provided by a filtrate pump. The integrity of the CMF-S system is determined via a Pressure Decay Test (PDT) capable of validation to better than 99.99% removal of particles (4 LRV). At the Bendigo WTP, every CMF-S cell is monitored with on-line turbidity meters and particle counters, along with a daily Pressure Decay Test (PDT) to validate membrane integrity.

The specification for the treated water was designed to meet existing and any future drinking water regulations. Coliban Water can impose a toll (penalty) for failure to comply with any of the performance criteria. Table 1 shows the treatment specifications pertinent to the CMF-S system.

Table 1: ***Treated Water Quality Targets***

Parameter	Measure	Measurement Frequency	Pass Percentile
Colour at the Treatment Plant	<5 HU	Daily	95%
Turbidity at Each Filter	<0.1NTU or <0.3NTU change in 10 minutes	Continuous	95%
Particles in each Filter	<10counts /mL	Continuous	95%
Crypto/Giardia across each filter	>4 log removal by PDT	Daily	95%

1.2 Membrane Cleaning

Membrane cleaning comprises both regular backwashing and periodic chemical clean in place (CIP). The cells are backwashed at 20 to 30 minute intervals per cell with a robust, air/liquid backwash process, combining an air scour along the membrane fibres with an air scour / liquid backflow to achieve removal of solids from the membrane surface.

Chemical cleans are performed either when the maximum transmembrane pressure (TMP) is reached or the cells have run in filtration mode for a preset period of time. The CIP sequence for each cell is typically:

- Acid CIP with sulphuric acid-EDTA at pH 2 to remove inorganic foulants. EDTA is used to complex with metals present and to prevent degradation of the fibres in the presence of manganese.
- CIP rinse to remove traces of acid.
- Caustic CIP with sodium hydroxide to remove organic foulants and trace amounts of hydrogen peroxide or Memclean C to enhance cleaning.
- CIP rinse to remove traces of caustic.
- Return membrane cell to normal service.

1.3 Membrane Maintenance

Membrane testing and repair is conducted on a 6 month basis, earlier if the LRV drops close to the contract limit. The maintenance consists of conducting a leak test which pressurises the inside of the fibre at a low pressure so that only a broken or damaged fibre will allow the air to escape. This provides a visual stream of bubbles for the operator to mark the location of the faulty membrane on a map. Then the noted rack is removed and the offending membrane is removed and placed in a test unit. Air is applied to the outside of the fibre which then shows up a stream of bubbles coming from the faulty fibre. The fibre is then sealed with a dressmaking pin made from stainless steel. If the damage is in more than one fibre (i.e. a small area) then a patch can sometimes be fitted to save replacement of the membrane. All o-rings are then checked as well as end cups. The

o-rings are then lubricated and the membrane is reinstalled in the rack.
When all the damaged membranes have been serviced and the racks refitted to the cell another leak test is conducted to make sure that the right membrane was repaired and also that no o-rings have been damaged or pinched on reinstallation back into the cell.

2.0 DISCUSSION

2.1 Raw Water Quality and Membrane Performance

Table 2 outlines the original water quality design parameters set for the plant compared to actual water quality. From initial commissioning in 2001, the plant was receiving Coliban main channel water. This water supply was characterised by low turbidity and colour and high alkalinity. As a result of prolonged drought and the need for water supply security, the Goldfields Superpipe was brought online in September 2007. This new water supply has very different characteristics from the main channel, namely higher turbidity and colour. Lower alkalinity has also increased the lime and carbon dioxide pre-dose requirement, whilst high colour has necessitated higher coagulant dose at certain times. The higher turbidities have resulted in more frequent backwashing being required, down to 20 minute intervals from the original 30 minutes setpoint pre-2007.

<u>Table 2</u>: ***Water quality data for Sandhurst, Coliban channel and Waranga channel***

Parameter	Average (Maximum)		
	Design	Coliban Main Channel	Waranga Channel
Turbidity (NTU)	18.2 (27.0)	3.2 (11.6)	19.6 (45.8)
True Colour (HU)	34.9 (49.0)	17.2 (55.0)	50.5 (183)
Alkalinity (mg/L)	40 - 50	49.6 (96.2)	19.7 (22.4)

2.2 Process Monitoring and Optimisation

The integrity (LRV) has been closely monitored on all cells throughout the life of the membranes at Bendigo WTP. In the first three years of operation, LRV monitoring indicated that membrane integrity generally improved. This was attributed to the modules taking a substantial period of time for full wetting to occur, almost the entire first year of operation. As the membranes aged it was found that the modules have a tendency to dry out quickly and with age the membranes seem to be more sensitive to dryness. The Memcor proprietary chemical, Memclean C, was found to help reduce the number of membrane modules that dried out in each cell. In recent years, whilst the LRV has consistently remained above 4 log removal of bacteria and viruses for all cells, this has been mainly due to the rigorous maintenance routine performed by the operations team (see section 1.3).

In addition to LRV, the CMF-S system also has performance standards for particles and turbidity (see Table 1). There have been no genuine excursions from the performance criteria for particles and turbidity for the life of the membranes at Bendigo WTP. A fibre destruction study was performed on the CMF-S membranes used at Bendigo in 2009 to assess the sensitivity of LRV, particle count and turbidity as measures of membrane integrity. LRV was found to be the most sensitive measure of membrane integrity as it provided the earliest indication of compromise to membrane integrity. Particle count was the next most sensitive measure, followed by turbidity.

As a result of this study and work conducted elsewhere, Veolia is currently working on development of a new performance system where membrane integrity is predominantly based on LRV, with particles and turbidity providing supporting data. This will improve reporting and reduce the number of false reports of failed membrane integrity based on particle and turbidity data.

Membrane performance is also routinely monitored via membrane resistance (R). This parameter is vital for determining membrane fouling trends by plotting the change in membrane resistance relative to the volume of water filtered (DR/DV). Figure 1 shows the DR/DV trends for the Bendigo CMF-S cells between 2002 and 2010. DR/DV values were higher in the first few years of operation as membranes took time to wet and cleaning regimes were developed and optimised. From that period onwards the DR/DV values have generally remained below 0.02, with occasional increases due to changes in raw water quality. This was particularly noticeable with the introduction of the new Waranga channel water in 2007. Resistances returned to normal after cleaning regimes were optimised for this new source water. However in 2009 a high flow event where the plant was operated at full flow for a short period of time resulted in severe membrane fouling that took a period of months for the plant to recover from. At this point the membranes were around 8 years old and investigations determined that a combination of age and irreversible fouling on the membranes have impacted membrane performance (see section 2.4). Hence it becomes more and more difficult to recover membrane performance as membranes exceeded their design life and as foulants gradually build up on the fibres. Some benefits have been seen in changing CIP cleaning regimes. These have included increasing CIP frequency as the membranes age and implementing back-to-back caustic CIP cleaning for enhanced organics removal.

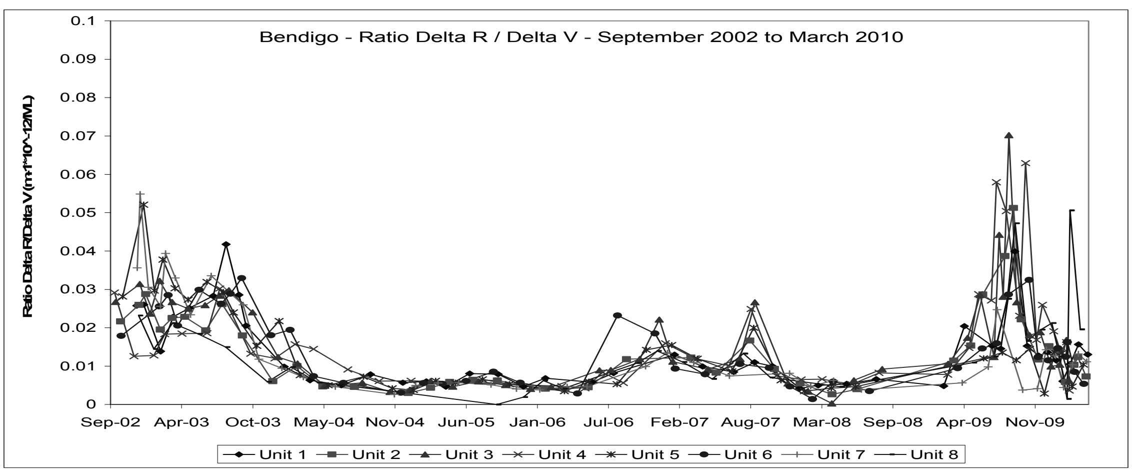

Figure 1: ***DR/DV plots used to characterise membrane fouling for Bendigo CMF-S cells***

2.3 Membrane Maintenance and Record Keeping

All membrane maintenance activities are recorded in an in-house database called the membrane "Module-Map". This database contains information on the frequency of membrane inspections, membrane pinning and patching, membrane replacement, dry membranes and damage to membranes. The database can also be used to generate reports to investigate trends in maintenance and membrane performance.

Whilst maintenance trends are impacted by changes in frequency of membrane maintenance and other plant and process activities, the general observations on membrane performance have shown that membranes older than 5 years have required:

- More pins and more patches with every year of operation
- Greater numbers of membrane discards and replacements (see Figure 2)
- More dry membranes (refer section 2.2).

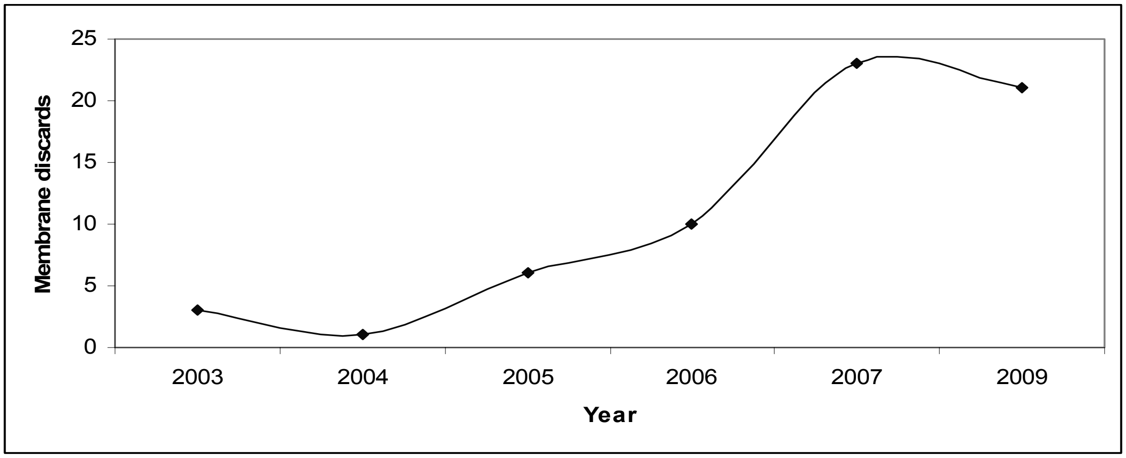

Figure 2: ***Module-Map maintenance database results for yearly membrane discards***

2.4 Membrane Autopsy

In late 2009 it was decide to send a number of membrane modules away for a complete membrane autopsy to determine the extent and characteristics of fouling on the 8 year old membranes, as well as the effectiveness of the CIP regime on cleaning and recovery. Membranes were sent to the UNESCO Centre for Membrane Science and Technology at the University of New South Wales (Cox, 2009), as well as Veolia's own Centre d'Analyses Environnementales (Jacquement, 2009) in Paris, France. The modules sent away for autopsy included membranes immediately before and after CIP.

Visual inspections found a brown clay-like substance fouling all of the membranes. Severity varied between the modules and within a module itself. The substance resulted in clumping of membrane fibres and may have resulted in lower local flux in these regions. Microscopic analysis indicated both organic and inorganic fouling. The inorganic foulants were mainly aluminium silicates. This foulant had penetrated the microfiltration membranes and was attributed to the reaction between aluminium from the coagulant, silica in the raw water and the caustic cleaning agent, and would have built up slowly over time. The presence of aluminium silicates is difficult to clean and previous work has recommended ammonium bifluoride as the cleaning agent. However, this chemical is hazardous and should only be used in extraordinary circumstances. A comparison of the typical cleaning methods indicated that the CIP showed improvements in the membrane permeability of between 45-73%. Hence the current cleaning methods were considered to be effective on all but the irreversible (aluminium silicate) fouling.

3.0 CONCLUSIONS

Over 8 years of microfiltration plant operations the Bendigo Operations team has put together a large amount of information on membrane performance.
This has included a data base for maintenance activities monitoring and reporting on the process, membrane recovery after backwashing and chemical cleans, as well as membrane autopsy. The combined monitoring and maintenance information has facilitated better understanding of membrane behaviour as follows:

- New water supplies, changing turbidity and colour and lower alkalinity has increased chemical pretreatment and resulted in more frequent backwashing of membranes.
- The membrane integrity tends to improve over the first year of operation as membranes take time to wet properly. Membrane integrity is impacted as membranes get older (> 5 years) due to membranes drying out.
- LRV is the best measure of membrane integrity with particles and turbidity used mainly as supporting data.
- The change in membrane resistance relative to volume of water filtered (DR/DV) is a good measure of the trends in membrane fouling and recovery after CIP. Membranes older than 5 years require significantly more effort to recover performance after high flow and fouling events.
- Recording and trending maintenance activities is useful for tracking the deterioration of membranes and numbers of membranes discarded. This is important information for planning for membrane change-outs and routine maintenance regimes.
- Membrane autopsies are a valuable tool for determining the effectiveness of backwashing and CIPs for membrane recovery, as well as identifying long term trends in development of fouling layers on the membranes.

4.0 ACKNOWLEDGEMENTS

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