DIAGNOSIS AND RECTIFICATION OF CLASS A PLANT PERFORMANCE ISSUES

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ABSTRACT

The Aurora Recycled Water Treatment Plant was commissioned in 2009 to provide sewage treatment services and Class A recycled water supply via third pipe to new developments in Melbourne's northern suburbs. The plant includes a conventional activated sludge treatment followed by advanced treatment to Class A quality via ultra-filtration and disinfection with ultra-violet light and chlorination. The plant was built with a capacity of 2 ML/day and expanded to 4 ML/day in 2010 with installation of a second ultra-filtration skid.

In 2011, plant operators started experiencing membrane performance issues and found it increasingly difficult to meet recycled water demands. Investigation into plant performance issues commenced and included;

- membrane autopsy to identify membrane fouling
- undertaking of targeted cleaning regimes
- identification and elimination of potential sources of fouling contaminants
- review and revision of process control philosophy and PLC logic.

This investigation project provided valuable learning and experience for Yarra Valley Water's operators and engineers in the potential pitfalls of membrane operations and the level of quality assurance required on highly automated PLC programming.

1.0 INTRODUCTION

The extended drought conditions along with the increasing awareness of the environmental impacts associated with discharging treated wastewater to stream, created a shift in urban water supply strategies in the early 2000's. Recycled water was considered a valuable resource. The Aurora recycled water scheme was born out of this revolution and was Yarra Valley Water's (YVW's) first Class A third pipe reuse schemes. The site of the treatment facility, situated on farm property in Melbourne's outer northern suburbs, was first established in 2005. However, low rates of development resulted in construction and commissioning being delayed until early 2009.

The treatment facility consists of two separate process trains. The first incorporates activated sludge treatment, multimedia filtration and ultra-violet disinfection producing Class B effluent for irrigation reuse on the farm site. Effluent can also be treated further via a second process train that was validated for pathogen reduction levels to achieve Class A quality. This second train consists of ultra-filtration, ultra-violet disinfection and chlorine disinfection.

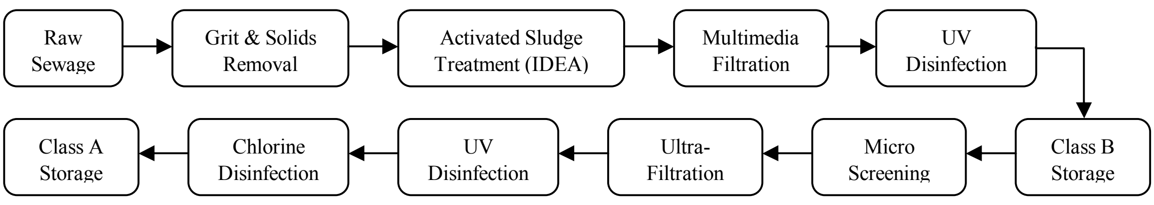

Figure 1: ***Flow diagram of the recycled water treatment process train.***

YVW commenced operation of the plant in May 2009 at a time when membrane filtration was still relatively new to their treatment plant operations team. Within 12 months, the prospect of significant industrial demand resulted in the plant capacity being doubled to 4 ML/day by duplicating the existing ultra-filtration skid. Ultimately, this industrial demand did not eventuate resulting in excess plant capacity. This combined with the nature of the process being largely automated meant that demand could easily be met with limited operator intervention. As a result, opportunities to diagnose and rectify Class A plant operational issues were either overlooked or not prioritised.

In late 2010, treatment plant operators raised concerns with the plant operation. Demand for Class A water could no longer be met through plant operation. The issues were focussed largely around the membrane plant performance. Filtration run times had been reduced on both skids significantly due to high trans-membrane pressure (TMP) and frequent backwashing. Net production of Class A water was negligible and this was a result of membrane fouling.

2.0 DISCUSSION

The initial troubleshooting focussed on being able to remove the fouling by conducting intensive chemical cleaning. In addition, as YVW had limited experience with troubleshooting membrane performance they employed the technical services of a membrane operations consultant to review the plant operations and provide recommendations for improvement. While it was thought that this would go a long way to rectifying the issues, what was exposed throughout these initial investigations and subsequent rectification attempts ensured that the pathway to complete recovery was much longer than what was originally expected.

2.1 Phase 1 – Membrane Technical Support & Initial Chemical Cleaning

An independent review was carried out by a consultant with experience in membrane plant design and operation. The issues identified by the consultant and recommendations given included the following items;

1. Review and modification of numerous PLC program sequences to ensure filtration and backwash sequences were designed to prolong membrane life.
2. Conduct a membrane autopsy to identify specific fouling contaminants.
3. Carry out targeted cleaning of membranes.
4. Initiation of ongoing monitoring of plant performance indicators.

As is typical for membrane systems, the ultrafiltration plant was designed for periodic chemical cleans in addition to standard backwashing. This plant incorporates chemical enhanced backwash (CEB) sequences with soak phases as opposed to clean in place sequences or cycles. There are two types of CEBs that occur during normal plant operation. A high pH (pH=12) clean with Cautic and Sodium Hypochlorite (CEB1) and a low pH (pH=2) clean with Hydrochloric Acid (CEB2). This initial phase of chemical cleaning was largely unsuccessful in removing membrane fouling but uncovered the following plant issues;

1. CEB sequences were not always completing successfully due to PLC programming faults that could not determined.
2. Target pH's were not being achieved due to reduction in dosing pump performance, incorrect rinsing of CEB1 and/or variable alkalinity in the feed water.
3. The design Backwash Flux Rates (LMH) were not being achieved due to the

increased backpressure from the membrane fouling and limited backwash pump capacity. It was also noted that standard backwash flux rates were much closer to design than CEB backwash flux rates which was a result of the additional head of the CEB backwash waste tank.

4. The plant could not be run long enough in filtration mode to ensure sufficient water was available for the next backwashing sequence. This was resulting in CEB2s, which follow a CEB1, not completing successfully.

It was clear that there were some issues related to the design and control of the plant that were limiting membrane recovery but what wasn't clear was if these issues were a symptom of the fouling that was present or whether they were actually a contributing factor to why the fouling occurred. Plant historical data was also limited which inhibited the ability to pinpoint whether the loss in performance was due to an acute event or chronic problem.

2.2 Phase 2 – Membrane Autopsy

The intention of this phase was to identify the fouling contaminant/s in order to tailor a targeted chemical cleaning regime. The membrane skid consists of 8 vessels, each containing 4 modules (32 in total). One membrane module was removed from the worst performing skid, sent for autopsy and replaced with a new module. A module consists of a solid outer surface and potted ends with numerous membrane fibres running along the length of the module. The filtration path is from the inside to the outside of the fibre.

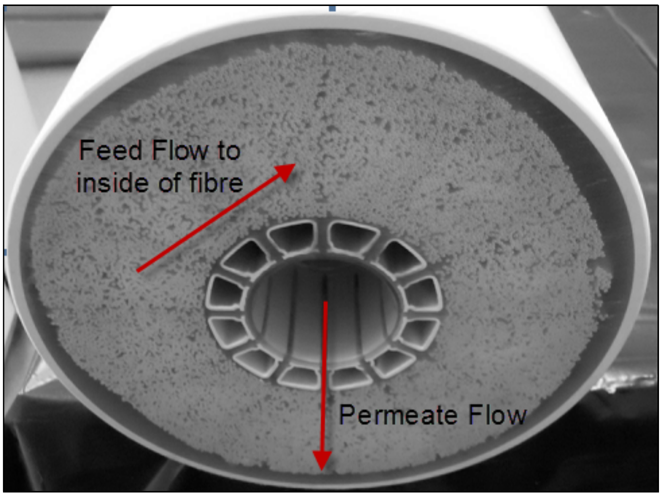

Figure 2: ***Potted end of Membrane Module.***

The module was sent to a consultant with expertise in membrane autopsy. The autopsy involved numerous testing on both the shell and lumen side of the membrane to determine the extent and type of fouling present. Numerous types of testing were conducted on sections of fibres from the module. These tests included; Visual inspection, Loss of Ignition testing to determine the level of volatile or incombustible fouling, Total Organic Carbon testing on a dissolved solution of fouling, Inductively Coupled Plasma – Atomic Emission Spectroscopy to quantify the level of inorganic fouling, Scanning Electron Microscopy – Energy Dispersive X-Ray Spectroscopy to produce highly magnified three-dimensional images and determine the elements present in the fouling and Fourier Transform Infrared to identify specific organic compounds.

The autopsy findings suggested that;

1. Fouling was present on both the shell and lumen side of the membrane but the nature of fouling on the lumen side was likely responsible for high TMPs.
2. The nature of the fouling was largely inorganic and highest in aluminium and silica content.
3. The fouling on the lumen side could be dissolved in nitric acid.

This suggested that fouling may have been attributable to overdosing with coagulant (Aluminium Chloro Hydrate) and that at some stage clay particles may have been present in the feed and backwash water.

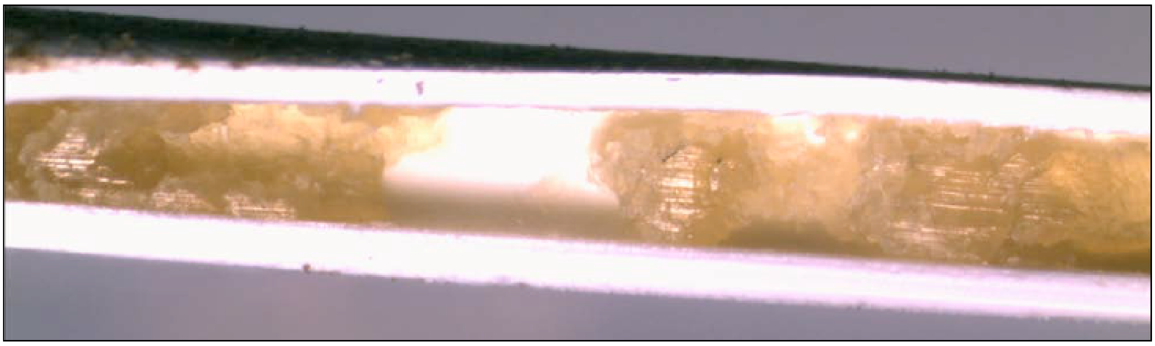

Figure 3: ***Stereomicroscope image of fibre cross-section.***

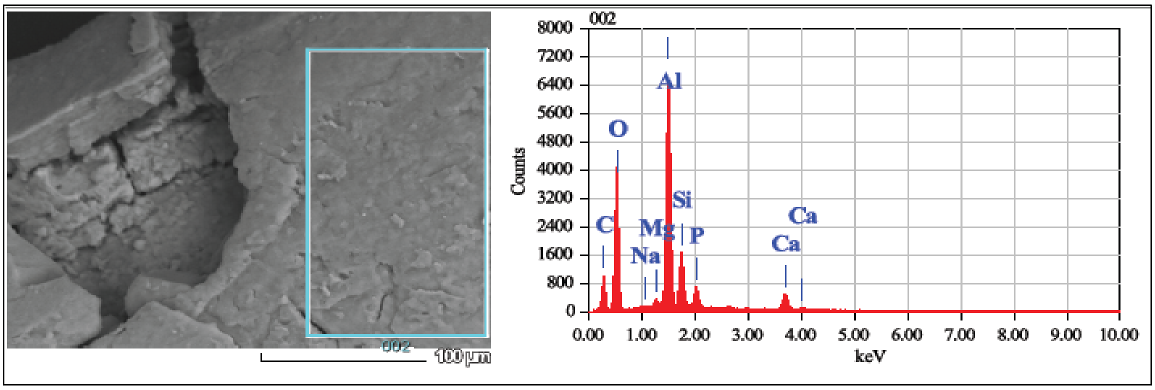

Figure 4: ***Scanning Electron Microscopy image and Energy Dispersive X-Ray Spectroscopy spectrum identifying Aluminium as major content.***

2.3 Phase 3 – Minor PLC Modifications & Targeted Cleaning Regimes

With the fouling identified as aluminium and silicate deposit and removal possible with acid soaks, the next step was to achieve some dedicated long acid soaks. This would determine whether membrane recovery was possible or whether new membranes would be required to be purchased and installed. Regardless, the issues identified with the PLC programming in Phase 1 of the troubleshooting were of priority concern. If these were not rectified, this would only promote further fouling and improper cleaning.

Initial interrogation of the PLC program determined that it was complex, with limited commenting and numerous redundant sections making it difficult to work with. An original detailed control philosophy was not available so it was difficult to decipher what the original design intent was. Compounding the situation was that the two ultrafiltration skids were not identical and their functionality varied significantly.

Furthermore, the interaction between the skids during normal filtration and backwash cycles was resulting in extended filtration cycles beyond normal run times due to long CEB soaks. Plant functionality also appeared to be variable dependent upon plant conditions, however, alarms were not descriptive enough to be able to diagnose these issues. In summary, there appeared to be major flaws with the plant PLC programming. A decision was made that it would be easier to re-write the program afresh than manipulate the existing program with a view that it would be done in a similar timeframe and the outcome would be much more robust.

Minor changes were undertaken immediately to the existing program to enable dedicated manual cleaning of the membranes in the interim period. In addition, a potable supply was added to the backwash tank to enable continuous backwashing without the need for filtration. Chemical dose rates, dilution flow rates and rinse cycles were also optimised in order to achieve the target pH for chemical soaks. This targeted cleaning was somewhat successful in reducing the fouling levels and TMPs while increasing membrane permeability. However, it was still evident that the PLC program was unreliable so the decision to start afresh was vindicated.

2.4. Phase 4 – Review of Control Philosophy and Plant re-commissioning

The plant control philosophy was re-written afresh in a structured manner that could easily be interpreted by a PLC programmer. While it was largely based on the existing plant operation, the new control philosphy incorporated changes and additions to prolong membrane life. It also provided an opportunity to define the SCADA interface and alarm requirements to provide greater transparency of plant status and control of specific sequences.

It was also decided to upgrade the existing plant PLC with new technology that allowed a greater degree of function block programming. This saved time on programming as well as making it more robust by eliminating the need to cut and paste or duplicate functionality througout. Significant benchtop testing of the new program was undertaken to ensure the program met the design intent of the control philosophy prior to works commencing onsite.

Upon commencement of commissioning onsite, it became evident that several workarounds had been implemented in the original program to allow the plant to run. To rectify this additional electrical wiring of some plant and instrument statuses were required to ensure true status was being received by the PLC. As an example, a fault from one critical instrument produced a 20mA or 100% analog signal and allowed operation to continue as opposed to generating a fault signal output which was not wired and received by the PLC. The final independent verification of the critical control point functionality, as required by Department of Health, was also very important to confirm appropriate plant funcitionality. Maintenance on plant that had not operated for significant periods of time was also a stumbling block during commissioning and the operation that followed.

3.0 CONCLUSION

YVW operators and engineers have made the following learnings from this project;

- Regular monitoring of membrane plant permeability and the effectiveness of the different chemical cleans is critical to ensure ongoing membrane plant reliability.
- Feed water alkalinity and CEB soak pH levels should be recorded periodically so that dosing rates can be adjusted for optimum cleaning.
- Optimal coagulant dose rates are important for enhanced membrane operation.
- Regular membrane inspection and autopsy, if required, is critical to realising maximum membrane life.
- Equipment selection should allow for additional capacity from operational design point (eg. Backwash or Chemical Dosing Pump capacities)
- Allowance should be made during design for an additional source of backwash water other than filter permeate.
- A detailed control philosophy should be completed during design phase for programmers to work from. Updates should be made during programming and commissioning and the document should be received at handover.
- SCADA controls which are often overlooked in the control philsophy should be detailed as much as possible in order to give operators full transparency of plant operations.
- Significant quality assurance protocols should be applied during commissioning. It is usually frantic and time constrained, however, testing should be conducted in a thorough and meticulous manner and as many scenarios as possible.
- Process plant should be operated at capacity following handover and further testing should be conducted so that issues missed during commissioning can be rectified.
- Ongoing PLC change control protocols are required to maintain the plant control integrity.
- PLC programming should be fully commented and easily readable by any programmer.
- Ensure that your electrical design has true feedback being sent to the PLC for all critical equipment.
- Verification of scaling and functionality on all Class A critical control points is vital for assurance that your operation is within validated limits.

4.0 ACKNOWLEDGEMENTS

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