CASE STUDIES AND LEARNINGS FROM TREATMENT INCIDENTS AT RECYCLED WATER PLANTS

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ABSTRACT

In February 2013, the Department of Health (the Department) published the *Guidelines for validating treatment processes for pathogen reduction – Supporting Class A recycled water schemes in Victoria* (the validation guidelines). The validation guidelines were developed for use by Class A recycled water scheme proponents, water treatment technology manufacturers, researchers and regulators. Their main focus is on managing the acute health risks posed by pathogens in recycled water and the guidelines apply to both the design and operation of Class A recycled water schemes. Using a number of case studies, this paper outlines recent experiences of treatment incidents at Class A recycled water plants. Through sharing these experiences, the Department aims to highlight what can go wrong at treatment plants and emphasise on the importance of treatment validation and having appropriate operational and verification monitoring at the treatment plant. This paper will also highlight the importance of understanding treatment processes and having an appropriate control philosophy in place to minimise the microbial hazards in recycled water.

1.0 INTRODUCTION

Class A recycled water derived from sewage or greywater can be a valuable alternative water resource for a variety of end uses. Class A end uses include but are not limited to uses in dual pipe residential developments, unrestricted irrigation of public open spaces and irrigation of crops that are consumed raw or unprocessed. As Class A recycled water involves high exposure end uses (that is, non drinking water uses that have a high risk of direct human exposure), the highest level of treatment is required to ensure the appropriate microbial quality recycled water is produced for the intended uses.

Under the Victorian Government regulatory framework, the primary role of the Department of Health's Water Program is to protect the health of Victorians from waterborne diseases. In support of the safe and effective use of alternative water supplies, the Department of Health has an endorsement role with Class A recycled water schemes in Victoria as detailed in the Environment Protection Authority Victoria's *Guidelines for environmental management: Dual pipe water recycling schemes – health and environmental risk management* (2005), and the *Guidelines for environmental management: Use of reclaimed water* (2003). This role requires the Department to assess the treatment capability of recycled water plants to achieve the defined water quality objectives through the submission of a recycled water quality management plan by scheme proponents.

2.0 DISCUSSION

Using three case studies as examples, this paper highlights a number of issues and challenges faced by scheme proponents with the operation of Class A recycled water plants. For each case study, the information provided is from recycled water incidents reported to the Department of Health.

2.1 Case Study 1

The first case study involves a scheme supplying Class A recycled water to a dual pipe residential development. To meet the overall microbial treatment objective of the scheme, the scheme proponent proposed to claim a log reduction value (LRV) of 3 log virus from its chlorination process. Based on the plant's maximum flow rate and the Ct (disinfectant concentration multiplied by contact time) required for effective disinfection, the required size of the chlorine contact tank was determined to be 3.5 ML.

In contact tanks and storage reservoirs, it is possible that some short-circuiting will occur. In order to address this in the establishment of the required Ct for disinfection, the United States Environmental Protection Agency's (USEPA) Disinfection Profiling and Benchmarking Guidance Manual (1999) has adopted 'T10' in calculations for the required contact time, which is the detention time in which 90% of the water passing through the contact tank is retained within the tank. The USEPA describes two potential methods which can be used to determine T10: the use of theoretical baffle factors based on simple baffling descriptions and tank geometry, and the use of empirical tracer studies, which provide a real measure of the contact time by measuring the time it takes for a tracer to flow through the tank. (*Baffle factors described in USEPA (1999) range from 0.1 for an unbaffled tank in an agitated basin to 1 for plug (or pipeline) flow*). Studies which informed the USEPA (1999) guidance indicated that baffle factors were intended to be used for determination of T_{10} where conducting tracer studies was not practical.

In this case study, the scheme proponent initially adopted a baffle factor of 0.3 from the USEPA (1999) guidance, based on an unbaffled tank with poor mixing. The scheme proponent subsequently engaged a treatment expert to carry out a tracer study on the 3.5 ML contact tank to verify the estimated contact time (T_{10}). The result from the tracer study was surprising in that the T_{10} observed during the tracer study was significantly less than the theoretical T_{10} based on a baffle factor of 0.3. The result indicated significant short-circuiting was occurring within the contact tank and that the baffle factor for the tank should be down rated from 0.3 to 0.1. Following the tracer study result, the scheme proponent notified the Department of the issue and as a precautionary measure ceased supply of Class A recycled water to customers pending further investigation into a resolution as to the cause of the short-circuiting.

Investigation summary:

- A poor T10 result of 71 minutes was observed during the tracer study which was considerably shorter than the estimated T_{10} of 180 minutes based on a baffle factor of 0.3.
- The scheme proponent determined the poor T_{10} result was unacceptably low from an operational perspective and improved performance was required through modification of the tank flow regime.
- The tracer study result highlighted tank mixing is a complex process and is often poorly interpreted. T_{10} will be different for specific tank designs, configurations and flow conditions. Tracer studies need to be performed under the most conservative conditions.

Corrective actions:

- A series of baffle systems were developed using Computational Fluid Dynamics modelling, installed and trialled in the contact tank using Rhodamine WT as a tracer.

- Due to the inherent design of the tank, the preferred tank modification used curtains that were not fixed to the floor or walls of the tank. Curtains were hung in the tank with 50mm gaps between the curtains to the tank floor and 150 mm gaps between the curtains and the tank walls.
- Tracer studies demonstrated the preferred baffle design to have a contact time (T_{10}) of 269 minutes under the most conservative flow condition and tank level.
- As a result of the tank modification, the T_{10} demonstrated from the tracer study was determined to be equivalent to a baffle factor of 0.35. The improvement is attributed to the induced effect of one dimensional flow through the serpentine path created by the hanging curtains.
- The tank modification also included an improved inlet diffuser design and a modified vertical standpipe outlet.

The first case study reaffirms the importance of validating each treatment process for its capability of achieving the required treatment objectives under specific operating conditions unique to each plant. Whilst the use of theoretical baffle factors is useful in design to predict treatment performance of chlorine contact tanks, validation results reported to the Department such as in case study 1 highlight the use of baffle factors may not accurately predict the actual hydraulic performance of tanks. This is made in reference to not only overestimating actual treatment performance, but also for underestimating treatment performance. It is for this reason the Department requires onsite validation via tracer studies under each plant's specific operating conditions for scheme proponents to demonstrate the actual hydraulic performance of chlorine contact tanks. Where tracer studies validate improved treatment performance, these study results can be used in establishing the required critical limits for the process. In some instances, the chemical cost savings can be significant.

2.2 Case Study 2

The second case study involves a Class A recycled water treatment plant where repeated routine verification samples detected the presence of fRNA phage in the permeate of its Reverse Osmosis (RO) process. These results indicated a breakthrough of virus sized particles through the RO membranes. Questions of the validity of the fRNA phage detections were initially raised by the scheme proponent as continuous indirect monitoring of the electrical conductivity (EC) of the permeate during the same operational period did not show any abnormalities. That is, no EC spikes were observed on SCADA. As the RO process claims virus log removal credits, the failure of the RO membrane meant the scheme was no longer achieving the required microbial water quality objective. As a consequence, the issue was reported to the Department of Health with supply ceasing until the investigation into the cause of the failure of the RO membranes was complete.

Investigation summary:

- An autopsy of an RO membrane module revealed delamination of the membrane material. The delamination resulted in the loss of membrane integrity and breakthrough of the fRNA phage into the permeate stream.
- Delamination of the membrane material was most likely caused by increased differential pressure of the RO membrane through:
  - excessive permeate backpressure which pushed the membrane from the permeate side to the feed spacer during the start-up and shutdown sequence of the RO process.
  - excessive feed pressure caused by organic and biological fouling of the RO

membrane. Existing membrane cleaning methods had predominantly only targeted the removal of inorganic membrane fouling.

- The EC differential critical limit had not been programmed into the control system correctly and therefore the issue was not picked up through operational monitoring.

Corrective actions:

- Replacement of the entire skid of RO membranes due to membrane delamination.
- Implementation of a more proactive cleaning regime to manage membrane fouling. Cleaning is triggered when a 15% reduction in normalised flow or a 25% increase in normalised differential pressure is detected.
- Changes to the start-up and shutdown sequence to minimise the risk of permeate pressure exceeding reject pressure.
- Inclusion of an automated plant shutdown when the calculated LRV from salt rejection falls below the critical limit (1.7 log). Previously, the system had been programmed to trigger a shutdown based only on permeate conductivity.
- Introduction of chloramination to the RO feed to control the biological fouling on the RO membranes, including dosing excess ammonia during chloramination to ensure no free chlorine residual is present.
- Installation of a chlorine analyser and inclusion of an online free chlorine residual critical limit to protect the long term integrity of the membranes against free chlorine damage.

The second case study has highlighted the following:

- The importance of undertaking routine verification monitoring to assess whether the treatment process has been effective. In this case study, it was through verification monitoring that the loss in integrity of the RO membranes was identified. The selection of the pathogen or pathogen indicator to test for is also important, as purely testing for *E. coli* and not fRNA phage may not have resulted in this issue being identified.
- There are current limitations with the sensitivity of indirect monitoring of electrical conductivity to detect breaches of RO membranes. With no current practical online direct integrity test for RO membranes during normal operation, the LRV which can be attributed to the RO membrane system for pathogen removal is limited to the sensitivity of the RO monitoring.
- With respect to membrane systems with claims for virus log removal credits, the Department of Health has included in its validation guidelines the requirement for annual challenge testing to be conducted on membrane systems. The annual challenge test is necessary as it is the only viable method for scheme proponents to demonstrate ongoing integrity of their membrane system for virus pathogen removal.
- To maintain the long term integrity of membranes, appropriate chemical cleaning regimes need to be developed to manage membrane fouling.

2.3 Case Study 3

The third case study details an incident which occurred at a Class A recycled water treatment plant which resulted in the supply of out of specification recycled water due the loss of chlorine disinfection.

At midday on a Sunday, the on-call operator attended the treatment plant as part of a normal routine check on the status of the Class A recycled water plant. During his attendance, a routine manual check of the chlorination system was carried out. A compliant free chlorine residual reading of 1.3 mg/L was recorded, confirming normal operation.

On the Monday morning, the duty operator carried out the next manual check of the chlorine residual and noticed that there was no chlorine residual present. Further checks of the treatment operation on SCADA revealed almost 24 hours of production (around 9ML) had occurred without a chlorine residual present. During this period of time, the plant's ultrafiltration and ultraviolet disinfection systems were performing as required. The plant was therefore achieving the required log reduction for protozoa but not viruses due to the loss of chlorine disinfection. The scheme proponent immediately commenced an investigation into the incident and reported the issue to the Department of Health.

Investigation summary:

- Around 2 pm on the Sunday afternoon, the level sensor in the duty sodium hypochlorite storage tank started to become erratic and signalled the tank was empty when it was over 50% full. Nevertheless, the process control system at the plant was programmed to switch to the standby sodium hypochlorite tank when low level is detected in the duty tank. This occurred.
- The problem was the standby hypochlorite tank was almost empty as the scheme proponent had decided to not store any sodium hypochlorite in the standby tank due to the rapid deterioration in chemical strength of the sodium hypochlorite when exposed for long periods to hot weather. Whilst the standby tank level sensor indicated the tank was close to empty, there was no control alarms programmed to warn the operators of this status.
- The common delivery line for the duty and standby hypochlorite storage tanks has a flow switch installed which would have indicated that there was no flow along the dosing delivery line. However, this flow switch had previously performed erratically and was triggering multiple alarms to the operators. To overcome this issue, the scheme proponent decided to feed a simulated value to ensure it would not send future alarms to the operators.
- At the time of the incident, three chlorine analysers were reading the free chlorine residual at the end of the chlorine contact tank (two of the three chlorine analysers were on trial). One of the trial analysers was used as the duty analyser while the original chlorine analyser was reading but its output control function was disabled as the analyser was considered to be unreliable.
- The duty trial chlorine analyser was connected to the process control system and detected the falling chlorine residual. As the duty analyser was used for residual trim dosing, the analyser did signal for the dosing pump to increase chlorine dose rate, but since there was no sodium hypochlorite in the standby tank, this request was not of any use. As the chlorine residual fell below the critical limit, the analyser did trigger an alarm, but the alarm had not been ranked as critical and therefore did not initiate a call out to the duty operator.
- During the handover period of the treatment plant, the treatment operators had been overwhelmed with alarms that were inappropriately prioritised. In order to cope, they had temporarily reduced priority to all alarms and were working through the rationalisation of alarms when this incident occurred. Manual chlorine checking had been increased to three times a day during the transition period but only once a day on weekends.

Corrective actions:

- The treatment plant's chlorination system was reverted back to operating with sufficient sodium hypochlorite in both the duty and standby sodium hypochlorite tanks. Low levels in the storage tank triggered critical alarms to plant operators and shuts down the recycled water plant.
- Signal instability of the flow switch was investigated.
- Procedures were put in place to require completion of proof of performance testing prior to changeover of monitoring equipment. Authority from senior operation management would be required prior to any changes to the process control and critical alarms. The Class A recycled water plant would run in diversion mode during the trialling and commissioning of new plant equipment.
- The priority alarm issue was resolved and independent verification testing of process control system was initiated prior to bringing the recycled water plant back online.

Unlike the previous two case studies, the root cause for this incident was not related to issues with the design or failure of any treatment process. Rather, it was caused by a combination of changes in plant operation and process control by the scheme proponent. If the plant was still operating under the original mode of operation and process control setting as designed, this incident would not have occurred. This case study is another reminder to the water industry that in most treatment incidents, the cause of failure is usually not due to one particular failure but a combination of multiple failures. Many of the failures could have been avoided if more attention and care had gone into the decision making process prior to making the actual operational changes. This incident also highlights the importance of establishing change of operation procedures and on the appropriate use of alarms to alert operators of treatment issues.

3.0 CONCLUSION

From the three case studies, one can appreciate the complexity with the operation and process control of Class A recycled water treatment plants. In order to minimise the production of out of specification recycled water, lessons must be learnt from past experience of others. Fundamental to this learning, is the need to understand your treatment process through treatment validation. That is, whether the treatment process can be effective. In addition, establishing appropriate operational and verification monitoring to confirm the effectiveness of your treatment processes is paramount. Failure to do so can result in the production of out of specification recycled water that can pose a risk to public health. The third case study highlights the importance of good treatment practices.

It is also worth noting that the control of fundamental treatment processes is consistent between Class A recycled water plants and drinking water plants. Therefore, the issues with the operation of recycled water plants highlighted in this paper can equally be valuable learnings for the operation of drinking water treatment plants.

4.0 ACKNOWLEDGEMENTS

To the water businesses who have generously allowed the Department of Health to use their treatment incidents as case studies.

5.0 REFERENCES

USEPA (1999) Disinfection Profiling and Benchmarking Guidance Manual. Washington D.C. US EPA Office of Water.