LEARNINGS FROM SEVERAL HIGH CHLORINE EVENTS

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79th Annual WIOA Victorian Water Industry Operations Conference and Exhibition
Bendigo Exhibition Centre
31 August to 1 September, 2016

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ABSTRACT

There are several chemicals that are commercially-available for the disinfection of drinking water; however, disinfection with different forms of chlorine (chlorination) is still the most used form of disinfection throughout the world. Although chlorine has good disinfection properties, it can make the water unpalatable and has the potential to cause adverse health effects if it is present at high concentrations. Therefore, based on health considerations, the 2011 Australian Drinking Water Guidelines (ADWG) provides health-based guideline value of 5 mg/L, as total chlorine, in drinking water. Additionally, chlorine can react with organic substances present in the water and form potentially harmful disinfection by-products (DBPs). Hence, it is important to manage the chlorine dosage, such that it is sufficient to achieve targeted pathogen inactivation, whilst minimising the formation of DBPs or creating other undesirable aesthetic issues. During 2015 Coliban Water had five instances where treated drinking water that contained chlorine at a concentration greater than the ADWG guideline value was either supplied, or could have been supplied, to the customers. The objective of this paper is to share the learnings from these events in order to prevent, or minimise the chance of, similar events occurring elsewhere.

KEY WORDS

Disinfection, Chlorine, Chloramine, Chlorine Residual, Water Quality, Distribution Network

1.0 INTRODUCTION

Coliban Water has nineteen (19) water treatment plants (WTPs) providing drinking water to thirty eight (38) townships in north central Victoria. Out of these nineteen WTPs, seven (7) plants utilise the Chloramination process and eleven (11) plants utilise the Chlorination process for primary disinfection. Additionally, Coliban Water has ten (10) booster chlorination stations to maintain disinfectant residual in certain parts of various distribution networks.

During the calendar year 2015, Coliban Water had five instances where treated drinking water that contained chlorine at a concentration greater than the health-based guideline value in the ADWG, that is 5 mg/L, was either supplied, or could have been supplied, to Coliban Water's customers. Each event was investigated to identify the root cause, learnings and possible mitigation measures to eliminate or minimise similar events occurring in the future. The main intention of this paper is to turn Coliban Water's experience of these high chlorine events into a learning opportunity for the industry to prevent, or minimise the chance of, similar events occurring elsewhere.

2.0 EVENT SUMMARY AND LEARNINGS

2.1 Event 1 – Failure to follow Standard Operating Procedures/Processes (SOP)

Treated water from a conventional water treatment plant that utilises the chloramination process for the disinfection is supplied to two townships, with approximate populations of 2160 and 120. The treated water is supplied to the distribution network of the big town, from which it is pumped to a storage tank at the small town.

Chlorine residual in the small town storage tank is generally close to zero, or very low, due to long retention times in the distribution network, transfer main and storage tank. Therefore, treated water is rechlorinated at the tank via a booster chlorinator, which uses sodium hypochlorite.

On 5 January 2015, it was identified that the booster chlorinator had ceased dosing because the hypochlorite tank had been drained, due to a leak in the dosing line. Therefore, the chlorine residual at the tank outlet was almost zero for a period of time due to this failure of the booster chlorinator. An operator attended the site, repaired the leak and reinstated the booster chlorinator. In addition to that, they added three (3) calcium hypochlorite tablets into the tank in order to rapidly raise the level of chlorine in the system. The chlorine residual started to increase from 1:00 pm on 5 January 2015. Although the dosing pumps stopped when the critical limit was triggered, chlorine residual continued to rise due to the chlorine tablets that were added to the tank. The chlorine concentration reached above 5 mg/L at approximately 10:30 pm that evening. It remained above this level until approximately 9:15 am on 6 January 2015. The tank was drained to 20% and then refilled to dilute the chlorinated water.

Coliban Water's Operation and Maintenance (O&M) contractor has a SOP for the manual addition of chlorine tablets, which requires the operator to seek advice from their Water Quality Manager prior to adding tablets to a storage tank. This process was not followed in this instance, which resulted in the exceedance. This event highlights the importance of following the agreed SOPs and seeking appropriate advise when dealing with chemicals which could create public health issues when used incorrectly.

2.2 Event 2 – Wrong input led to calculation error

A water treatment plant supplies potable water to eight (8) townships with a total population of approximately 16,000. This includes a major town with population of approximately 11,500, and the population of other towns range from 200 to 2000. The treated water from the plant is supplied to the distribution network of the major town and is then transferred to storage tanks at each satellite town. Since the system has tanks and lengthy pipelines, water age at some of the satellite towns is quite long and, as such, the residual chlorine level in those towns is generally below the required standard. Therefore, calcium hypochlorite tablets, with 68% W/W available chlorine, are periodically added manually to the tanks to improve the chlorine residual.

On 10 March 2015, total chlorine results for a routine sample collected from the outlet of the tank at one of the satellite towns, where routine chlorine tablet dosing was in place, returned a total chlorine value of 5.8 mg/L, which exceeded the health-based guideline value specified in the ADWG. The sample was collected around 10:00 am. An operator had visited the site on the same day, at approximately around 7:00 am, and had measured the chlorine level in the tank, and the total chlorine level was 0.09 mg/L. Therefore, it was decided to add chlorine tablets into the tank to raise the residual. The O&M contractor uses a spreadsheet calculator to determine the required number of chlorine tablets, based on the chlorine residual level to be achieved, the residual chlorine in the tank, the volume of water in the tank at the time and the chlorine content of the tablets. As per the output of the calculator, nineteen (19) tablets were added to the tank to raise the chlorine residual in the tank to 1.5 mg/L. A mass balance calculation undertaken in response to the exceedance revealed that the number of tablets added was more than the required number of tablets to raise the chlorine level to the target residual. The reason for this error was the calculator contained the wrong tank capacity.

The system used to have a basin with much larger capacity, which was decommissioned and the tank was built on the same site recently; however, the input data in the calculator was not updated with capacity of the new tank.

An operator attended the site and removed the excess tablets from the dispenser. Since tablets that were added were of the slow releasing type, most of the tablets were still present in the dispenser when the operator attended the site. Chlorine residuals in the tank and in the associated distribution network were checked to confirm that the chlorine concentration was below the health-based guideline value. This event indicates the risks associated with the manual addition of chlorine tablets directly into the tanks and the importance of periodically checking and reviewing the input data of a calculator. A permanent booster chlorine station has since been installed at this site, which eliminated the need to add chlorine tablets.

2.3 Event 3 - Instrument drift

Chlorination with chlorine gas is used as the disinfection process at one of Coliban Water's treatment plants that supplies potable water to a small town with a population of approximately 960. The chlorine is dosed into the filtered water prior to the clear water storages (CWSs). The concentration of free chlorine in the water entering the CWS and leaving the CWS are monitored online via chlorine analysers on the inlet (i.e. filtered water chlorine analyser) and the outlet (i.e. treated water chlorine analyser) of the CWS. The critical control limits are monitored and controlled by the filtered water chlorine analyser. Whilst the treated water chlorine analyser is used to monitor the free chlorine residual (FCR) leaving the plant and to provide alert alarms to the operators, this analyser does not have a shutdown protocol.

On 2 March 2015, it was observed that the SCADA trend for the treated water chlorine analyser had flat lined at 5.0 mg/L for about 5 hours between 9:50 pm on 1 March 2015 and 2:50 am on 2 March 2015; at the same time the filtered water chlorine analyser was reading less than 1.0 mg/L. It was also noted that the free chlorine concentration in the filtered water was reasonably high (i.e. greater than 4.0 mg/L) between 1:00 pm and 6:00 pm on 1 March 2015, and went above 5 mg/L for a very short period of time during that time. Neither critical alarm was activated nor breached, but alert alarms were activated. In response to the alert alarms the operator adjusted the chlorine dosage remotely via SCADA.

Since high chlorine was recorded at the inlet analyser a few hours before the high chlorine readings recorded in outlet analyser, and the operator attended the site on 2 March 2015 during business hours to verify the readings of the analysers, it was suspected that treated water containing chlorine greater than 5 mg/L could have been supplied to customers. When the analysers' readings were checked against a handheld meter, a significant discrepancy in the readings between the handheld and the outlet analyser was observed, whereas the handheld and the inlet analyser readings were reasonably close. Furthermore, an estimation of the average chlorine dosage during the day, using the available SCADA data, for the amount of chlorine gas consumed and treated water processed, indicates that no excessive amount of chlorine was dosed. Therefore, it can be concluded that the high chlorine reading was due to instrument drift.

This event shows importance of verifying issues in a timely manner to eliminate any doubts associated with the quality of drinking water supplied to customers.

Instrument drift seems to be a regular occurrence with some instruments, hence the need for a robust instrument maintenance regime to reduce the frequency of this occurrence. This maintenance regime should also be regularly reviewed.

2.4 Event 4 - The plant control system mystery

A water treatment plant that serves a small town with a population of 328 utilises chlorination with sodium hypochlorite for disinfection. On 17 August 2015, at around 6:50 pm, during a routine check of the plant performance, via SCADA, the On-Call operator noticed that the CWS level was lower than the trigger level for the plant to start; however, the plant had not started. On further investigation, the operator found that the Sodium Hypochlorite dosing pump No.1 was turned to manual mode and pump No.2 had been turned manually to the off position. The SCADA data also showed that dosing pump No. 1 was running while the plant was not in operation. The operator remotely put both the pumps into automatic mode, via SCADA, and the plant started. Consequently, a slug of sodium hypochlorite sitting in the dosing lines was transferred into the CWS, resulting in a high chlorine concentration in the CWS. When the plant auto started the High Lift Pumps (HLPs), the pumps that supply treated water to the distribution network and the elevated storage tank also started. The HLPs operated for a very short period of time, transferring treated water containing chlorine at a concentration above 5 mg/L into the distribution network.

The operator then attended site to respond to the incident. The operator changed the CWS tank level set points so that the plant would not start automatically and transfer the overdosed water into the distribution system. The operator immediately isolated the HLPs to doubly ensure that the transfer of water from the CWS tanks to the distribution system could not occur while the issue was being resolved. The operator used the highly chlorinated water from the CWS to backwash the filter, as the process configuration has no other method to drain the water. Plant operation was then brought back to normal. Simultaneously, networks crew arrived on site to assist with the incident. The chlorine concentrations in the distribution network were measured, and high chlorine results were only observed in a short section of main close to the plant. The affected section of main was flushed and the chlorine residual was lowered within 5 minutes.

It is not known how the dosing pumps ended up in manual mode on 17 August 2015. When the operator left the site, they believed that the plant was in auto and running in compliance, as they had not altered the control mode of the dosing pumps. Further investigation through Coliban Water's IT department revealed that four staff, with full plant access had logged onto the SCADA system on that day. Therefore, it is suspected that one of these staff members may have accidently changed the control mode. However, it wasn't possible to identify who, if anyone, altered the control mode. This event exposed the inherent risks embedded in the current control system and operational set up.

2.5 Event 5 - Limitation in the system configuration

A water treatment plant supplies potable water to four (4) small townships with a total population of approximately 1200. The treated water from the plant is directly supplied from the CWS to one of the towns and to storage tanks at the other towns, from which treated water is then supplied to the distribution networks of these towns. Since the system has tanks and lengthy pipelines, water age at one of the towns is quite long and, as such, the residual chlorine level in the town is generally below the required standard.

Therefore, sodium hypochlorite is dosed at the outlet of the tank via a booster chlorine station to improve the chlorine residual in the distribution network of the town.

On 7 November 2015, as part of Coliban Water's mains cleaning program, air scouring of the distribution network was undertaken by contractors. The flow rate in the system was higher than usual due to the air scouring, even though customers were requested to turn off their stop taps between 9:00 am and 2:00 pm whilst the work was completed. Typical flows in the system are usually less than 3 L/s. Flows on this day were at times exceeding 10 L/s. The booster chlorinator is located on the outlet of the local storage tank and uses a flow paced, with residual trim, control philosophy. Additionally, coding to the PLC was added in August 2015 to limit the dosing to a fixed rate of 2 mg/L if the flow rate became greater than 2 L/s.

The configuration of the outlet pipes to the tanks is such that there is an isolation valve a few meters after the tank outlet which is permanently closed. All flow from the tank is diverted around this isolation valve through a bypass line. The bypass line includes a flowmeter and the sodium hypochlorite dosing points, all of which are on 50mm pipework. This configuration restricts the amount of flow into the town's distribution network. With the increase in the flow due to the scouring a venturi effect occurred and resulted in the syphoning of sodium hypochlorite from the storage tank at a rate much higher than the dosing point was set at. The critical high chlorine alarm was activated, which shutdown the dosing pumps. However, the sodium hypochlorite continued syphoning through the dosing pumps into the distribution network due to the venturi effect. The system was fitted with an anti-syphon valve; however, due to the conditions on the day, it proved to be inadequate. The result was that water with a chlorine concentration above 5 mg/L was supplied to customers.

The duty operator checked the SCADA trends as soon as they received the high chlorine alarm, which confirmed that the residual was above the critical limit. A network crew was dispatched to assist with the incident. The network was flushed until residuals were less than 1 mg/L at all extremities. Further chlorine tests were undertaken to confirm that the chlorine residual in the network was within the ADWG guideline value.

The incident exposed a significant limitation in the configuration of the system and the inadequacy of the preventive mechanisms allowed in the chlorinator. It also emphases the importance of considering all the possible failure modes in the design. The system is currently turned off until it can be reconfigured and recommissioned.

3.0 CONCLUSION

Although the outcome of each event was the same, the investigations revealed that the root cause for the elevated chlorine in each event was different, and there is no indication of systematic failure with the chlorine dosing systems operated by Coliban Water. However, each event exposed various issues associated with the dosing systems and/or processes and procedures for the management of the operation and maintenance of Coliban Water's chemical dosing systems. It should be noted that some of the root causes may seem insignificant under normal circumstances, but they could lead to adverse consequences. This shows the importance of attention to detail and following proper processes and procedures.

In response to these events, Coliban Water has undertaken a complete review of all its chlorine dosing systems.

We are currently in the process of developing an action plan to implement the recommendations of the review.

4.0 ACKNOWLEDGEMENTS

All the operational staff for their commitment in responding to the issues and their assistance in obtaining the necessary information to assist with the investigations described in this paper.

Coliban Water's Water Quality Performance Team for their hard work on the investigations and the review of Coliban Water's chlorine dosing systems.

5.0 REFERENCES

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