CHLORINE DEMAND ANALYSIS IN DISTRIBUTION NETWORKS USING HYDRAULIC MODELS AND LABORATORY TESTS

Paper Presented by:

Raj Mahendrarajah

Author:

Raj Mahendrarajah, *Research & Development Scientist,*

Coliban Water

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ABSTRACT

Though there are many technologies that are commercially available for the disinfection of drinking water, chlorination with different forms of chlorine is still the most widely used form of disinfection throughout the world. One of the main reasons for this is the ability of chlorine to persist in distribution networks, so as to provide a barrier to potential ingress of pathogenic microorganisms into the distribution network. However, maintaining sufficient residual chlorine in distribution networks is a common challenge faced by water suppliers. Chlorine decays in the network, mainly due to the presence of organic material, water age and temperature. This paper outlines investigation work undertaken to improve the chlorine residual in one of Coliban Water's water distribution systems, namely the Castlemaine Water Supply System.

KEY WORDS

Water Quality, Disinfection, Chlorine, Chloramine, Chlorine Residual, Decay Characteristics, Water Age, Distribution Network

1.0 INTRODUCTION

The Castlemaine Water Supply System is one of Coliban Water's major systems. It services a population of approximately 13,500, as well as the needs of commercial and industrial customers. The Castlemaine Water Supply System covers the township of Castlemaine, as well as a number of satellite towns, namely Chewton, Fryerstown, Campbells Creek, Yapeen, Guildford, Harcourt, Maldon, and Newstead (Figure 1).

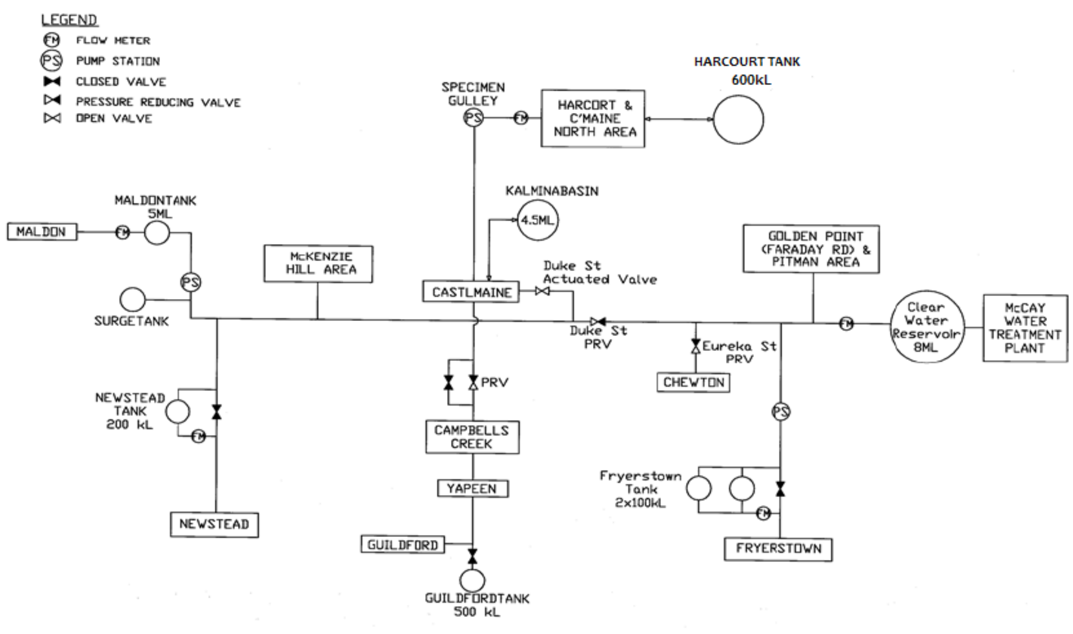

Figure 1: ***Schematic of the Castlemaine Water Supply System***

The Castlemaine Water Supply System is disinfected at the Castlemaine Water Treatment Plant (WTP) using chloramination. Maldon, Newstead, Harcourt and Fryerstown are supplied via storage tanks located at each township. The Guildford distribution network is directly supplied via the Castlemaine distribution network, as the Guildford tank is currently offline due to water quality issues associated with long retention time. Since the Castlemaine system has tanks and lengthy pipelines, water age at the extremities of the system is quite long and, as such, the residual chlorine level at the extremities of the system is generally below the required standard, especially in Harcourt, Maldon, Newstead Guildford and Fryerstown.

At present chlorine tablets are periodically added manually to the tanks to meet the required chlorine residual. However historical water quality data shows that despite the addition of chlorine tablets the chlorine residual in downstream networks is well below the commonly accepted target residual of 0.2 mg/L free chlorine (*Mosse & Deere, 2009*).

In order to improve the chlorine residual, it was proposed to install booster chlorination systems at each storage tank. This includes Guildford, as the intention is to recommission the Guildford tank to address low pressure and security-of-supply issues in Guildford and upstream areas (Yapeen and Campbells Creek) during peak demand periods, as well as to reduce high pressures during periods of low demand.

One of the requirements for implementing booster chlorination systems is a good understanding of the quality of drinking water where the proposed booster chorine systems are to be installed. To this end an investigation was carried out to evaluate chlorine demand and water age across the system.

2.0 DISCUSSION

2.1 Assessment Methodology

Free and total chlorine decay characteristic curves for drinking water over a range of chlorine doses were developed for a number of sites across the system in order to assess the chlorine demand. Water age in the network downstream of the tanks (i.e. setting the water age at the tank outlet to be zero) was assessed using the Castlemaine Water Distribution Network hydraulic model in order to understand what the likely chlorine dose would be to achieve some chlorine residual across the entire, or the majority, of the network.

In order to develop chlorine decay curves for the water entering and leaving the tanks, water samples were collected at tank outlets and locations as close as practically possible to directly upstream of the tank inlets. Total chlorine was measured on site to check the available chlorine in the sample at the time of collection. Free chlorine was not measured, as the system is chloraminated. Table 1 shows the sample location, date, time and onsite test results. Samples were analysed in-house at Coliban Water's laboratory for chlorine demand.

Table 1: ***Onsite test results***

Location	Date and Time	Total. Cl_2 (mg/L)	Comment
Maldon tank outlet	9/10/13 15:05	0.52	
Maldon tank inlet	23/10/13 11:00	0.01	Sample collected at the water pump station upstream of the tank
Newstead tank outlet	7/10/13 14:50	0.52	
Newstead tank inlet	6/11/13 10:45	0.02	Sample collected from Property 2881, Pyrenees Hwy, Green Gully
Harcourt tank outlet	14/10/13 15:30	0.50	
Harcourt tank inlet	05/11/13 10:15	0.05	Sample collected from Property 28, Specimen Gully Rd, Barkers Creek.
Customer tap:	17/10/13 09:30	0.01	3 Templeton St, Guildford

Lab Testing

Each sample was dosed with 2mg/L, 3mg/L, 4mg/L and 5mg/L chlorine, using 0.1% chlorine stock solution. The stock solution was prepared using commercially available sodium hypochlorite solution. Free and total chlorine were tested after 5mins, 10mins, 15mins, 30mins, 60mins, 120mins, 240mins, and after 24 hrs. The test results were plotted against time to generate free and total chlorine decay characteristic curves for each location. It should be noted that according to the material safety data sheet, the concentration of available chlorine in the sodium hypochlorite solution may range between 15% - 10% weight per volume (w/v). Since the exact strength of sodium hypochlorite solution was unknown, it was necessary to evaluate the concentration of sodium hypochlorite solution prior to the preparation of the stock solution to ensure the accuracy of chlorine dose. Therefore the concentration of sodium hypochlorite solution was evaluated prior to each test by titration.

Water Age Assessment

The existing Castlemaine Water Distribution Network hydraulic model, built in InfoWorksWS, was used to undertake water age assessment. The water age assessment was undertaken for peak day demand (PDD) and average summer day demand (ADD) scenarios. The model consisted of a forecasted PDD scenario. The total system demand for the forecast PDD is 14ML/d. The ADD scenario was developed using the demand scaling function in InfoWorksWS, and was done by reducing the total demand to 7ML/d, as the average daily demand during 2012/13 summer was in the order of 7ML/d, based on measured flow data. Water age at the furthest and closest customer to the tanks for both peak and average day demand scenarios were estimated using simulated flows and velocities. Note that the model analysis was undertaken assuming that the Guildford tank was in operation, as it is intended to recommission the tank and install a booster chlorination station at the tank.

Mains Cleaning Trial

In addition to booster chlorination, mains cleaning was proposed as one of the strategies to improve disinfectant residual across the network. In excess of twenty mains have been identified as potentially benefiting from cleaning. As a trial, the Castlemaine-Maldon pipeline was selected to be cleaned first. The cleaning included a portion of the Castlemaine network upstream of the pipeline, up to the Duke Street pressure reducing valve (PRV) station. The cleaning, including flushing and pigging, was carried out on 16 and 17 December 2013. Measurements of total and free chlorine were taken upstream and downstream of the pipeline prior to and after cleaning. Additionally, water samples were collected before and after cleaning for chlorine demand analysis to assess if any reduction in organic and biological matter took place as result of the cleaning.

2.2 Outcomes of the Assessment

It was observed that the Total Chlorine concentration in the samples collected from the tank outlets was in the order of 0.5mg/L (Table 1). This is due to the addition of chlorine tablets into the tanks. Since chlorine tablets are added to the tanks any organic content in the tank is oxidised. Therefore, the rate of chlorine decay is slow for samples collected from the tank outlets compared to samples collected upstream of the tanks.

The addition of chlorine tablets into the tanks is not preferred method to increase chlorine residual as chlorine dose cannot be controlled. Hence there is a risk of supplying water with a high chlorine concentration to customers, especially those customers who are in close proximity to the tanks. Furthermore, the sampling data shows that this method seems ineffective at providing sufficient residual chlorine. It should be noted that if the addition of chlorine tablets is ceased, the water quality measured at the tank outlets would be similar to the water quality upstream (or at the inlet) of the tanks.

Note that the chlorine decay characteristics were developed from grab samples collected at a particular point in time in a laboratory environment. In reality, the chlorine demand in the distribution network would be different to the test results (more likely to be greater than the test results), depending on factors such as flow, temperature and cleanliness of the network. Hence, the results are indicative only. Table 2 provides a summary of the amount of chlorine decay over time for samples collected from upstream of the tanks.

Table 2: ***Summary of amount of chlorine decay over time***

Time (hrs)	Maldon		Newstead		Guildford		Harcourt	
	Tot. Cl_2 (mg/L)	Free Cl_2 (mg/L)	Tot. Cl_2 (mg/L)	Free Cl_2 (mg/L)	Tot. Cl_2 (mg/L)	Free Cl_2 (mg/L)	Tot. Cl_2 (mg/L)	Free Cl_2 (mg/L)
1	0.5 – 0.7	0.8 – 1.0	0.5 – 1.0	1.0 – 1.5	0.5 – 0.8	0.8 – 1.2	0.7 – 0.9	1.1 – 1.2
3	1.0 – 1.2	1.2 – 1.5	1.2 – 1.5	1.5 – 1.8	0.8 – 1.0	1.2 – 1.5	1.1 - 1.3	1.4 – 1.7
24	*2.0 – 2.5	*2.5 - 2.8	*2.5 - 3.0	*3.0 – 3.5	1.5 – 2.0	*2 – 2.5	*2.0 - 3.0	*2.0 – 3.4

**Chorine is completely decayed by or before 24 hours for tests carried out with a chlorine dose of 2 mg/L.*

The chlorine measurements taken before and after the cleaning did not indicate a significant change in chlorine residual. As shown in Table 3, total chlorine concentrations at the upstream end of the system (i.e. at the Castlemaine end) improved slightly following cleaning, from 0.39 to 0.82 mg/L.

However, the latest measurement was lower, only 0.31 mg/L – a lower residual than before cleaning was undertaken. Total chlorine concentrations varied slightly at the downstream end of the system (i.e. at Maldon end), however distinct improvement was not observed.

Table 3: ***Total chlorine concentrations upstream and downstream of pipeline***

Date	**Total Chlorine (mg/L)**		**Comment**
	Upstream	**Downstream**	
12/12/2013	0.39	0.09	Prior to cleaning
23/12/2013	0.82	0.07	One week after cleaning
07/01/2014	0.31	0.11	Three weeks after cleaning

Laboratory testing undertaken on samples taken prior, and subsequent, to mains cleaning showed no significant difference in chlorine decay characteristics. For some unexplained reason the samples collected one week after the cleaning exhibited a faster decay of total and free chlorine than prior to cleaning.

The hydraulic model analysis revealed that:

- Water age at properties furthest from the tanks during maximum flow (peak time) ranged from 4hrs to 10hrs for PDD scenario;
- Water age at properties furthest from the tanks during maximum flow (peak time) ranged from 10 hrs to 1 day for ADD scenario;
- Water age at properties furthest from the tanks during day time flow (off peak) ranged from 1 day to 6 days for both PDD and ADD scenarios;
- Water age at properties closest to the tanks during maximum flow (peak time) ranged from 4 to 12 minutes for PDD scenario except at Maldon; and
- Water age at closest properties from the tanks during maximum flow (peak time) ranged from 8 to 30 minutes for ADD scenario, except at Maldon.
- There are properties very close to the Maldon tank (i.e. within 25m of the tank); therefore water age at the closest property is almost zero.

The Harcourt tank is filled by an upstream booster pump station. When the booster station is in operation, it supplies water to the distribution network and feeds the tank. As per the PDD scenario model simulation results, the pump station is in operation during daylight hours. Water age during the day time for this scenario wasn't assessed since the network is not supplied from this tank.

3.0 CONCLUSION

The investigation revealed that:

1. The manual addition of chlorine tablets into tanks is inefficient, as the chlorine dose cannot be controlled and does not improve the chlorine residual in the network.

2. Although the 2011 *Australian Drinking Water Guidelines* health-based guideline value for total chlorine is 5 mg/L for chlorinated systems, and 4.1 mg/L for chloraminated systems, it is not recommended to dose chlorine at concentrations anywhere as near as high as this, as there are customers in close proximity of tanks, particularly the Maldon tank.

A chlorine residual not exceeding 0.5mg/L at the first customer tap is acceptable, as to avoid water quality complaints related strong chlorine taste and odour (*Mosse & Deere, 2009*). Note that water age from the tanks to the closest properties ranges from 0 to 30 minutes.

3. Adding chlorine into tanks, or adding it prior to tanks, was not an effective means of increasing chlorine residual in the downstream distribution network, as the detention time in some of the tanks is very long, particularly for the Maldon and Guildford tanks.

4. Water age at the extremities of some part of the systems is greater than 24hrs, even during peak flows, and the test results indicate that chlorine decay is greater than 2 mg/L after 24 hrs. Therefore, it is unlikely that desired residual chlorine will be achieved across the entire network with an initial chlorine dose that is less than or equal to 2 mg/L.

5. Though the mains cleaning trial did not show any improvement in chlorine residual in this particular case, the results cannot be interpreted as indicating that mains cleaning is an ineffective measure. Potential reasons for this include very high water age in the pipeline that was cleaned (approximately 17 km long 375mm diameter main), the entire upstream pipeline was not cleaned and nitrification in the distribution system.

6. There is a need to increase monitoring for nitrite and nitrate to identify the areas where nitrification is occurring.

In summary, the provision of permanent or temporary booster chlorine systems for satellite towns, together with routine cleaning of mains and free chlorination at target areas where nitrification is shown to be occurring, will improve drinking water quality and reduce water quality risks significantly, by providing an adequate chlorine residual.

4.0 ACKNOWLEDGEMENTS

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