CARBON DIOXIDE INJECTION TRIALS AT NELSON WATER TREATMENT PLANT, NEW ZEALAND - IMPACT ON PH, COAGULATION AND MEMBRANE FILTRATION PERFORMANCE

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ABSTRACT

The Tantragee water treatment plant in Nelson, New Zealand was built to provide upgraded 'A' standard drinking water quality for a population of 40,000 people. The new NZ$26M plant, commissioned in 2004 provides coagulation, flocculation, ultrafiltration and sodium hypochlorite disinfection. The plant treats water from three sources. Colour levels from the River sources are typically low. However, colour from the Dam source can be high, requiring chemical precipitation. A key feature of the raw water quality from the Dam source is the combination of low alkalinity and high pH. When raw water is sourced from the Maitai Dam, ferric chloride is dosed at the plant inlet for both coagulation and pH adjustment to achieve a pH of 6.2 prior to the membranes. The ferric chloride dose is flow paced at a typical dosing rate of 20 to 30 mg/L as $FeCl_3$. When ferric chloride dosing is practiced, the final water is pH corrected to 7.9 after the membranes by the addition of soda ash. Iron precipitation in the treated water reticulation has been reported, believed to be associated with the residual iron remaining in the permeate water. Preliminary calculations indicated that the cost of ferric chloride dosing may be reduced if an alternative chemical, such as sulphuric acid or carbon dioxide is used for pH adjustment and the ferric chloride is used only for coagulation and flocculation. Estimates suggested that operating cost savings could be made as well as reducing the residual iron concentration remaining in the permeate water. It was decided to undertake a full scale trial of carbon dioxide dosing to demonstrate the predicted reduction in ferric chloride dose and examine concerns about the potential effect on the performance of the flocculation and membrane filtration stages. A skid mounted carbon dioxide dosing system was sourced and installed at the plant inlet and a series of trials undertaken with varying carbon dioxide and ferric chloride dosing rates. Plant performance was monitored using on-line instrumentation and sampling. This paper describes the background to the project, the operation of the carbon dioxide full scale trial and presents results including the impact on the flocculation stage pH, ultra-violet transmissivity and membrane performance.

Keywords: water treatment, ferric chloride, carbon dioxide, pH adjustment, ultrafiltration

1. Introduction

The Tantragee water treatment plant in Nelson, New Zealand treats water from the Maitai Dam, the Maitai River and the Roding River. The treatment plant capacity is 42,000 cubic metres per day maximum with average flow of 20,000 to 25,000 cubic metres per day. Colour levels from the Rivers are typically 3° Hazen. No chemical dosing is required. However, colour from the Dam source can be 70° Hazen requiring coagulation. Issues with iron precipitation in the treated water reticulation have been reported. Raw water is typically low alkalinity and high pH. The pH of the raw water ranges from 7.5 to 8.2 prior to any addition of chemicals with alkalinity of 50 to 70 mg/l as $CaCO_3$. Raw water is dosed with ferric chloride with no prior pH correction. Typical dosing rates are 20 to 30 mg/l as $FeCl_3$. Mixing is achieved in a contact tank (hereafter referred to as the delay tank) prior to the flocculators where floc growth is promoted prior to the membrane filtration stage. The resulting pH after addition of the ferric chloride dose is 6.2.

Membrane filtration using Zeeweed® 500 hollow fibre modules is used. The membranes were 8.5 years old against a guaranteed life of 10 years at the time of the trial. The membranes are operated with a 45 second back pulse every 50 minutes, a daily maintenance clean with sodium hypochlorite and clean in place (CIP) every 6 weeks using citric acid and sodium hypochlorite. When ferric chloride dosing is practised the final water is pH corrected to 7.9 by the addition of soda ash. A key concern is the residual iron remaining after the ferric chloride dose and the potential impact on the membranes in addition to issues with iron precipitation in the reticulation. Correction of the pH using acid prior to the addition of metal based coagulants is widely recognised as best practise for water treatment (Kawamura, 2000a). The use of ferric chloride to both depress the pH and coagulate solids is practiced but requires additional coagulant dose, additional cost and reduced process efficiency and performance including potentially higher residual iron concentrations. An estimate of sulphuric acid dosing was made using water chemistry modelling which indicated that a cost saving could be achieved by replacing part of the ferric chloride dose with acid. However, due to concerns over handling sulphuric acid at the plant, liquid carbon dioxide was considered as a safer alternative.

Liquid carbon dioxide can be delivered by bulk tanker and stored on site in a pressured and refrigerated vessel. Typical bulk storage pressure vessels are operated at 20 Bar and -20°C (AirLiquide, 2014). Liquid carbon dioxide has a solubility in water of 0.35g/100ml at 10°C (Kawamura, 2000b) and can be dosed into the raw water flow by a dosing controller linked to downstream pH measurement. Control of the pH to a target set point can be achieved by adjusting the dosing rate to the raw water as a function of the raw water flow and feedback trim from the downstream pH instrument. The advantages of carbon dioxide over mineral acids are improved safety and easier handling, lower maintenance costs and no residuals (such as sulphate which can foul membranes) remaining in the water. It was decided to pilot the use of liquid carbon dioxide at the plant. The aims and objectives of the trial were to:

- Evaluate the effectiveness of dosing whilst still achieving the Drinking Water Standards for New Zealand (Ministry of Health, 2008)
- Assess carbon dioxide dosing capability and performance for pH correction to reduce the ferric chloride dose requirement on the Dam water source
- Determine whether there are any negative impacts on the performance of the membrane filters
- Determine the carbon dioxide dosing control that can be achieved over a range of influent parameters including pH and flow

2. Results and discussion

A skid mounted liquid carbon dioxide storage and dosing system was procured and installed at the plant inlet, dosing carbon dioxide into the incoming raw water by a simple sparge pipe inserted into the mains pipework. The approach taken for the full scale trial was to operate the plant on the Maitai Dam water source and establish steady state ferric chloride dosing as a base line. It became apparent that the plant exhibits regular fluctuations in flow rate as a result of the periodic back pulsing of the membranes. Back pulsing was inhibited to establish and maintain steady state conditions. Once steady state had been established, the pH after mixing in the delay tank was noted. The ferric chloride dose was then reduced in stages while monitoring the pH of the raw water and the rise in the pH of the delay tank until steady state was re-established. This required several delay tank volumes equating to one hour at the plant flow. Once the delay tank pH had stabilised at the new higher level, carbon dioxide was then dosed at a calculated rate to reduce the delay tank pH back to the original target value of approximately 6.2. Once more this required approximately 1 hour allowing for the delay tank volume.

This procedure was repeated in stages to demonstrate the reduction in ferric chloride dose that could be achieved by replacement with carbon dioxide while achieving the same target pH of

6.2 in the delay tank. Permeate after the membranes was sampled for residual iron and colour (allowing for delay time through the plant) to determine any impact on permeate quality. Permeate ultraviolet transmissivity and membrane flux were monitored by the plant supervisory control and data acquisition (SCADA) system.

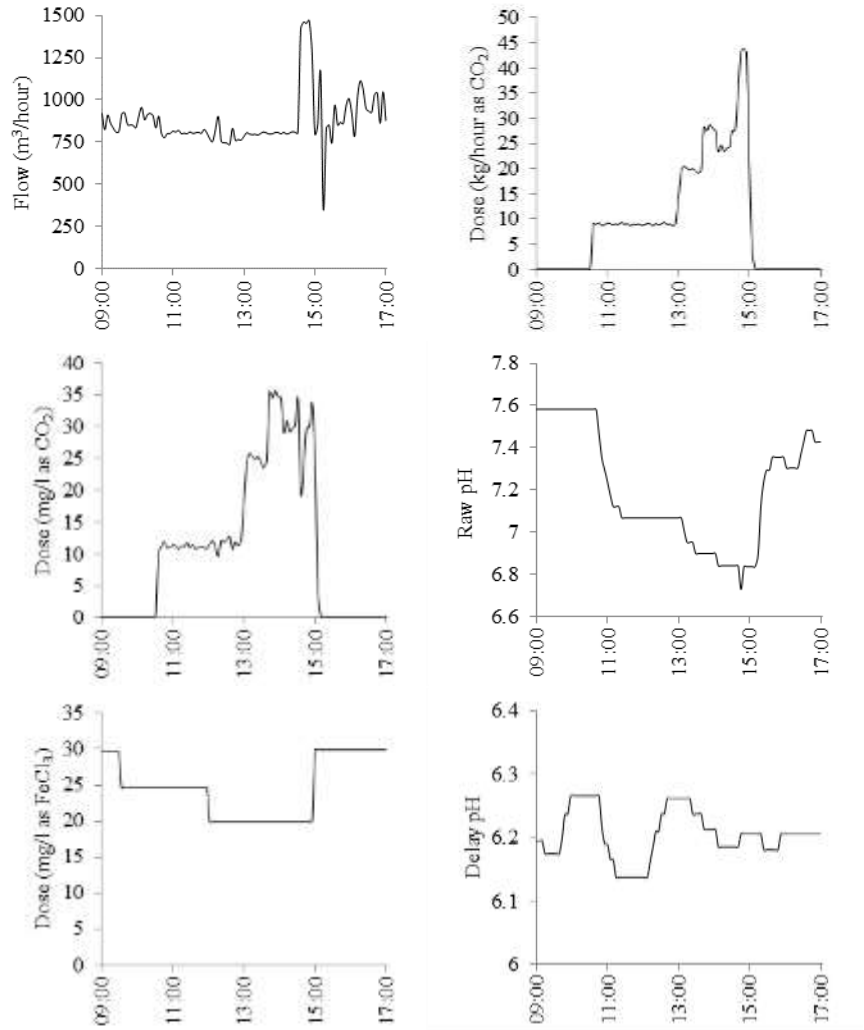

Figure 1: Carbon dioxide dosing trial results (flow, carbon dioxide dose, raw pH, ferric chloride dose, delay pH)

Figure 1 presents the plant flow rate (m^3/hour), carbon dioxide dosing rates (kg/hour as CO_2 and mg/l as CO_2), raw water pH, ferric chloride dose (mg/l as $FeCl_3$) and delay tank pH over the course of one working day. The plant flow was maintained at 800 to 900 m^3/hour for most of the day. The raw water pH was approximately 7.6 at the start of the trial from the Maitai Dam source with a delay tank pH of approximately 6.2 after application of the ferric chloride dose of 29.7 mg/l as $FeCl_3$. The ferric chloride dose was reduced to 24.6 mg/l as $FeCl_3$ at 9.30am. The delay tank pH rose marginally to 6.26 as a result a short time later. The carbon dioxide dosing was commenced at 10:30am at 9 kg/hour as CO_2 equating to a concentration of approximately 11 mg/l as CO_2. The raw water pH dropped to approximately 7.1 over the period 10:30 to 11:20am as a result (Note: the carbon dioxide dosing point was located upstream of the raw water pH measurement). The delay tank pH was reduced back down to 6.14, marginally less than the target value of 6.2 as desired. This procedure was repeated reducing the ferric chloride dose to 20 mg/l as $FeCl_3$, observing the resulting rise in delay tank pH to 6.25, increasing the carbon dioxide dose to 25 mg/l as CO_2 (approximately 20 kg/hour as CO_2), observing the resulting drop in raw water pH to approximately 6.8 and reducing the delay tank pH back to the target value of approximately 6.2. Further increases up to 35mg/l as CO_2 in the carbon dioxide dose were attempted but were of limited success due to poor mixing and dissolution of the carbon dioxide by the simple sparge pipe arrangement. The plant flow rate was increased to over 1400m^3/hour in the afternoon in an attempt to improve the mixing and dissolution of the carbon dioxide but this was unsuccessful and no further reduction in ferric chloride dosing rate could be achieved with the pilot plant arrangement. The results demonstrate that the ferric chloride dose can be reduced by the application of carbon dioxide while maintaining the original delay tank target pH. However, the dosing arrangement would require consideration during detailed design to achieve efficient carbon dioxide dissolution.

The permeate UV transmissivity (UVT) and membrane flux were monitored during the trial to observe any impact on the membrane performance. The membrane treatment at the plant uses the ultrafiltration ZeeWeed® 500 immersed hollow fibre system (GE Water, 2013). The membranes are arranged in modules approximately 2 metres high, 700 to 800mm width and 50 to 200 mm depth. The hollow fibres are manufactured from polyvinylidene difluoride (PVDF) with a 1.8mm outside and 0.8mm inside diameter and a nominal pore size of 0.04 microns. Permeate ultraviolet transmissivity (%), ferric chloride dose (mg/l as $FeCl_3$) and membrane flux (litres/m^2/hour) are shown in Figure 2.

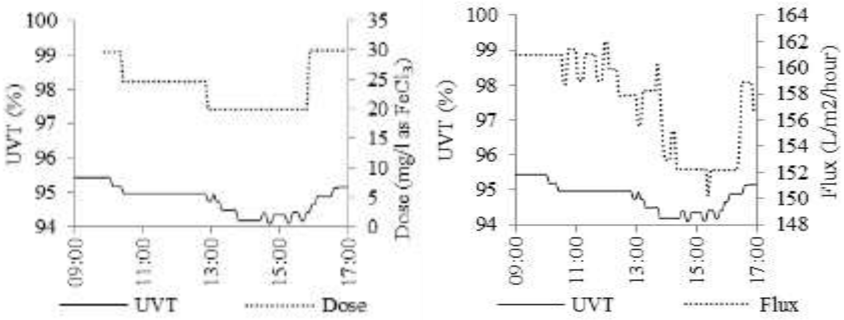

Figure 2: Carbon dioxide dosing trial results (permeate ultraviolet transmissivity UVT, ferric chloride dose and membrane flux)

It can be seen that permeate ultraviolet transmissivity and membrane flux exhibited changes over the course of the day linked to the ferric chloride dose (the ferric chloride dosing has been delayed on the time scale by approximately one hour to allow for the delay time through the plant). As the ferric dose was reduced from 29.9 to 20 mg/l as $FeCl_3$, the ultraviolet transmissivity declined from approximately 95.4 to 94.2 %. Similarly, the membrane flux declined from 160.9 to 152.2 litres/(m^2.hour) equating to a permeability of 321.8 and 304.4 litres/(m^2.hour.bar) at a transmembrane pressure drop of 0.5 bar. Sampling of the permeate indicated no change in the dissolved iron concentration of 0.06 mg/l as Fe but a small increase in colour from 0 to 2° Hazen. On ceasing the carbon dioxide dosing and returning the ferric chloride dose to 29.9 mg/l as $FeCl_3$, the permeate ultraviolet transmissivity and membrane flux recovered somewhat to their original levels. Replacing a fraction of the ferric chloride dose with carbon dioxide impacted the precipitation of dissolved organic matter, the flocculation characteristics and reduced the membrane permeability. Correction of the pH using carbon dioxide is considered a potentially better approach to coagulation and flocculation practise rather than using ferric chloride only. However, based on the trial results, the Maitai Dam raw water required the higher ferric chloride dose to precipitate the organic matter effectively and generate a floc with good membrane filtration characteristics.

3. Conclusions

- The results of the trials demonstrated that the ferric chloride dose could be reduced when operating on the Maitai Dam water source. The ferric chloride dose was reduced by 10 mg/l as $FeCl_3$ by the application of 25 mg/l carbon dioxide as CO_2 while maintaining the same target pH after coagulation.

- The reduction in ferric chloride dose appeared to have a detrimental impact on permeate ultraviolet transmissivity, membrane permeability and permeate colour. This may impact on subsequent disinfection performance and result in more frequent membrane back pulsing and cleaning.
- The impact on ultraviolet transmissivity, membrane permeability and permeate colour requires longer term study. Membrane fouling and recovery during cleaning should be examined over multiple membrane cleaning cycles to determine the impact on trans-membrane pressure drop, recoverable and non-recoverable membrane fouling. Jar testing is required to examine the optimal dosing requirements in greater depth.
- Consideration must be given to the method and location of carbon dioxide dosing to ensure effective dissolution. Changes would be required to the inlet pipework arrangement to inject and dissolve the carbon dioxide effectively.
- The cost versus benefit of this would need to be considered before proceeding with full scale implementation. The cost of implementing carbon dioxide dosing, all associated controls and integrating this with the ferric chloride dosing system may not be justifiable for this plant.

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