



Pilot Testing Project Report:

Effect of Fixed-Bed Ion Exchange Process in Addition to Enhanced Coagulation on the Reduction of High Levels of Organics

Walkerton Clean Water Centre

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Executive Summary

Background

Natural organic matter (NOM) is associated with a variety of water issues, such as colour, taste and odour, and potential regrowth of biofilm in distribution systems. Some NOM may pose threats to public health by reacting with chemical disinfectants to produce disinfection by-products (DBPs), including trihalomethanes (THMs) and haloacetic acids (HAAs). The Ontario drinking water quality standards regulate the maximum acceptable concentration (MAC) of THMs in treated water at 100 µg/L as a running annual average (RAA) of quarterly results (O. Reg. 169/03). The MAC for another group of DBPs, haloacetic acids (80 µg/L as an RAA of quarterly results), will come into effect January of 2020 (O. Reg. 169/03).

Hearst is a town located in Northern Ontario. They have a drinking water treatment plant (WTP) that treats water from the Mattawishkwia River for Hearst's 5,000 residents. They began experiencing higher levels of THMs forming in the treated water; due to the elevated levels of NOM in the source water reacting with their disinfectant. To date, HAA analysis had not yet been investigated. The operators at the Hearst WTP agreed to allow the Centre to conduct pilot-scale testing on-site using ion exchange technology.

Objectives

The aim of this pilot testing project is to provide information to the operators of the WTP regarding the effectiveness of a fixed-bed ion exchange system at reducing levels of NOM in the treated water. The following specific objectives for the project are as follows:

- To apply two different flow rates that demonstrate normal operation of the fixed-bed ion exchange system and assess its effectiveness at reducing NOM. This will be determined by analyzing UV absorbance and dissolved organic carbon (DOC).

- To assess DBP formation potentials in the treated water specifically for THMs and HAAs by simulating the distribution system at a bench-scale.
- To assess the overall water quality produced by the fixed-bed ion exchange process by measuring turbidity, pH and alkalinity.

Approach

Two pilot-scale experiments were conducted using a dual train, fixed-bed ion exchange system targeting organics removal. The pilot system consists of two ion exchange fiberglass tanks and a brine backwashing system, and was installed following the filters in the WTP using the filtered water as influent. During the experiments, flow rates were set at 23 L/min and 11 L/min to achieve 2.5 min and 5.2 min of empty bed contact time (EBCT), respectively.

DOC and UV absorbance were monitored to quantify organics during the experiments. To better understand the relationship between reducing organics in the treated water and DBP formation in the distribution system, THMs and HAAs analysis was conducted using a simulated distribution system (SDS) procedure (APHA, 2012).

Key Findings

On average, the fixed-bed ion exchange system in addition to the WTP's process (enhanced coagulation and filtration) decreased the level of:

- DOC from 5.75 mg/L to 1.78 mg/L, which was an additional reduction of 69%.
- UV₂₅₄ absorbance from 0.102 cm⁻¹ to 0.017 cm⁻¹, which was an 83% reduction.

By reducing the organics in the treated water effluent, the ion exchange system therefore reduced:

- THMs from 142 µg/L to 20 µg/L, which was an 86% reduction.
- HAAs from 126 µg/L to 23 µg/L, which was an 82% reduction.

It is important to note that the ion exchange effluent had a low level of alkalinity and an acidic pH which should be corrected for stability and control of possible corrosion in the distribution system.

The online UV254 absorbance monitoring system was found to be an effective tool for optimization of the performance of the ion exchange system.

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1. Introduction

Natural organic matter (NOM) is associated with a variety of water quality issues, such as colour, taste and odour, and potential regrowth of biofilm in distribution systems. Some NOM may pose a threat to public health by reacting with chemical disinfectant to produce disinfection by-products (DBPs), including trihalomethanes (THMs) and haloacetic acids (HAAs).

The Mattawishkwia River contains elevated levels of natural organic matter (NOM) and is used as the water source for over 5,000 residents in Hearst, a town located in Northern Ontario. The town's existing water treatment plant (WTP) is designed as a dual train conventional process with a capacity of greater than 10,000 m³/day. In this process, each filter bed consists of 600 mm of anthracite and 350 mm of sand. This WTP also uses a chlorine system for primary disinfection and a chloramination system for secondary disinfection.

While the WTP was already practicing enhanced coagulation (dosing approximately 200 mg/L of aluminum sulphate and 0.11 mg/L of polymer) to reduce organics, high levels of organics were still detected in the treated water. Because of this, the operators have experienced issues with high levels of disinfection byproducts (DBPs), specifically THMs. To minimize the formation of THMs, the chlorine system was changed to a chloramination system for secondary disinfection. However, the THM levels in the WTP's effluent still exceeded the maximum acceptable concentration (MAC), which is 100 µg/L as a running annual average (RAA) of quarterly results (O. Reg. 169/03). The MAC for another group of DBPs, haloacetic acids (HAAs, 80 µg/L as an RAA of quarterly results), will come into effect in 2020 (O. Reg. 169/03). Further investigation is required to verify the HAA removal efficiency of this plant.

1.1 Objectives

The anionic ion exchange process has been shown to effectively reduce NOM in drinking water (Sani et al., 2008; Chen et al., 2006). In this study, pilot testing is conducted to:

- 1) Inform the operators on the performance of a fixed-bed ion exchange system with the aim of reducing organic matter and DBPs including THMs in the treated water.
- 2) Investigate the overall effect of the ion exchange process on treated water quality.

It is noted that process optimization, process waste management, treated water stability and possible corrosion in the treatment and distribution system are outside the scope of this project and would require the advice of an engineering consultant.

2. Materials and Methods

2.1 Fixed-Bed Ion Exchange System

This study used a pilot-scale, dual train, fixed-bed ion exchange system. This system consists of two fiberglass tanks and a brine backwashing system (Figure 1). Each fiberglass tank has capacity to hold up to 2 ft³ of resin along with 50% free board for backwashing purposes. Both Tank 1 and 2 contain the same strong base anionic exchange resin. This ion exchange resin is used to remove negative ions, such as NOM, nitrates and sulfates, by replacing them with chloride ions. As is shown in Figure 1, a salt-containing brine tank is designed for resin regeneration. Flow meters and flow control valves were installed on each train allowing flow rate adjustment throughout the system. In this study, filtered water from the WTP was used as the influent to the ion exchange system. Backwash water was discharged directly to the municipal sewer system.

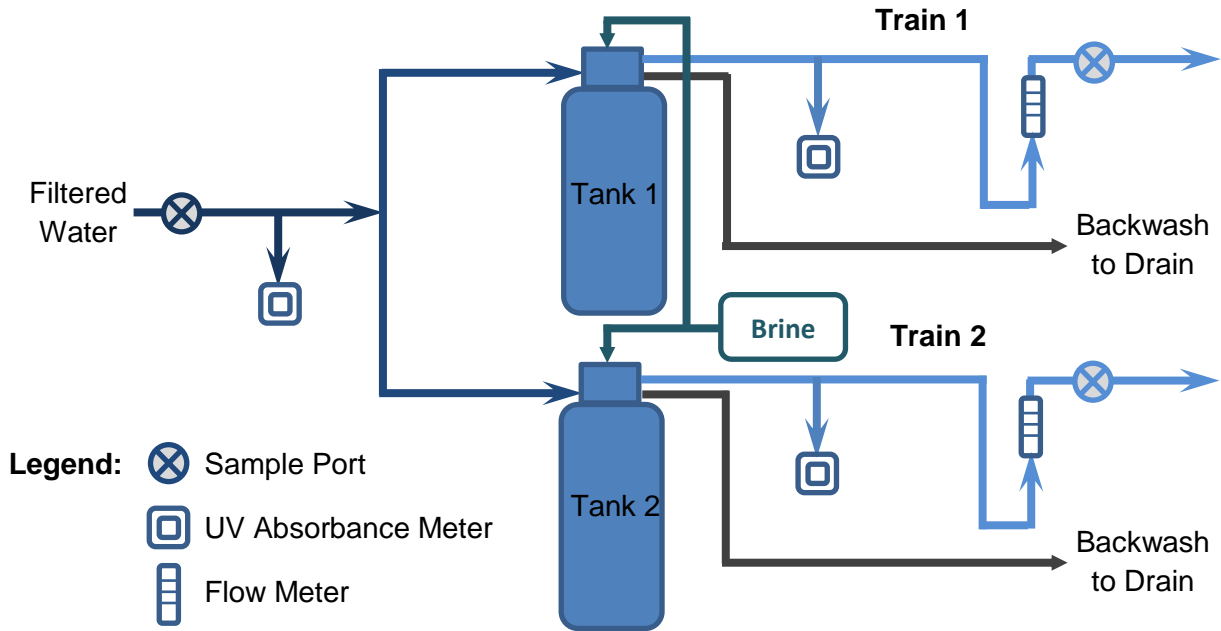


Figure 1. Schematic of the pilot-scale dual train fixed-bed ion exchange system

2.2 Experimental Conditions

Two batches of experiments were conducted with flow rate controlled at 23 L/min and 11 L/min, achieving 2.5 min and 5.2 min of empty bed contact time (EBCT), respectively. The pilot testing experimental conditions are summarized in Table 1.

Table 1. Pilot testing experimental conditions

Experiment	Train	Train Flow (L/min)	EBCT (min)	Sampling Times
1	1	23	2.5	1, 3, 5, 7 hours
	2	23	2.5	1, 2, 3, 4 hours*
2	1	11	5.2	1, 3, 5, 7 hours
	2	11	5.2	1, 3, 5, 7 hours

*Sampling times changed due to desludging operations at the WTP and power failure issues.

2.3 Sampling and Analysis

For each batch of experiments, four samples were taken from each train of the pilot system and the sampling times are summarized in Table 1. The raw water and filtered effluent samples were also collected from the WTP. Water parameters including alkalinity, pH, turbidity, ultraviolet (UV) absorbance, and dissolved organic carbon (DOC) were analyzed for each sample.

To better understand the performance of the ion exchange system on DBPs reduction, a simulated distribution system (SDS) experiment (APHA, 2012) was conducted on samples collected from Experiment 1. Samples were dosed with 6.3 mg/L of sodium hypochlorite with a detention time of 2 days to simulate the conditions in the WTP's distribution system. Free chlorine and pH were monitored initially and after a 2 day contact time. Samples were then quenched and sent to the external laboratory for THMs and HAAs analysis. The SDS tests were also conducted for the filter effluent and raw water samples.

3. Results and Discussion

3.1 Raw Water Characteristics

The raw water quality characteristics are summarized in Table 2. High levels of NOM were obtained in raw water, characterized by DOC of 16.4 - 16.5 mg/L and UV_{254} absorbance of 1.009 – 1.012 cm^{-1} . The average specific ultraviolet absorbance (SUVA) was calculated as 6.14 L/mg-m, indicating a high level of aromatic organics. Given the resulted SUVA value, over 50% of DOC reduction can be expected from a conventional WTP using alum as the coagulant (Edzwald & Tobiason, 1999). As the raw water had low levels of alkalinity (68 – 69 mg/L as $CaCO_3$), soda ash was used by the WTP to increase alkalinity for the enhanced coagulation process.

Table 2. Raw water quality characteristics

Parameter	Experiment 1	Experiment 2
Turbidity (NTU)	7.98	7.15
pH	7.7	7.5
Alkalinity (mg/L as CaCO ₃)	68	69
UV absorbance at 254nm (cm ⁻¹)	1.009	1.012
DOC (mg/L)	16.4	16.5
SUVA (L/mg-m)	6.15	6.13

3.2 NOM Reduction

3.2.1 DOC Reduction

With the aid of the enhanced coagulation process, the WTP achieved a 65% DOC reduction. However, DOC levels of 5.75 mg/L were obtained in the filtered effluent, which is still above the Ontario aesthetic objective of 5 mg/L (MOE, 2006) and capable of generating high levels of DBPs.

The fixed-bed ion exchange system was controlled with EBCTs of 2.5 min (Experiment 1) and 5.2 min (Experiment 2), respectively, and the DOC levels in ion exchange effluent are provided in Figure 2. On average, the ion exchange system provided an additional 69% DOC removal to the filter effluent.

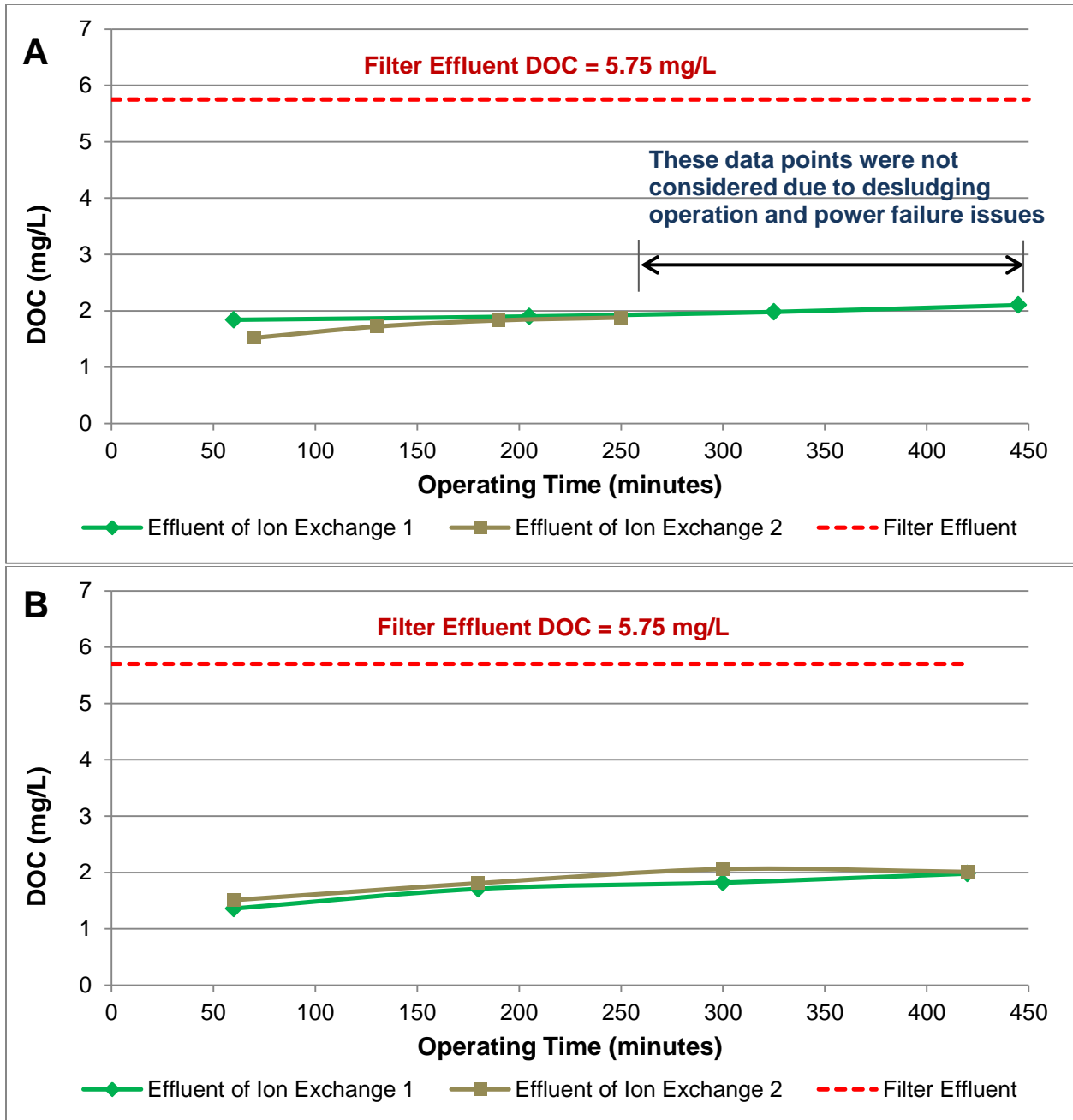


Figure 2. DOC levels of the effluents of the ion exchange system and WTP filter for A) Experiment 1 with EBCT of 2.5 min, and B) Experiment 2 with EBCT of 5.2 min

3.2.2 UV₂₅₄ Absorbance Reduction

The WTP enhanced coagulation and filtration processes reduced UV₂₅₄ absorbance by 90% from that of the raw water. As is shown in Figure 3, the ion exchange system

further reduced UV₂₅₄ absorbance by 84% (Experiment 1) and 82% (Experiment 2) from the filter effluent.

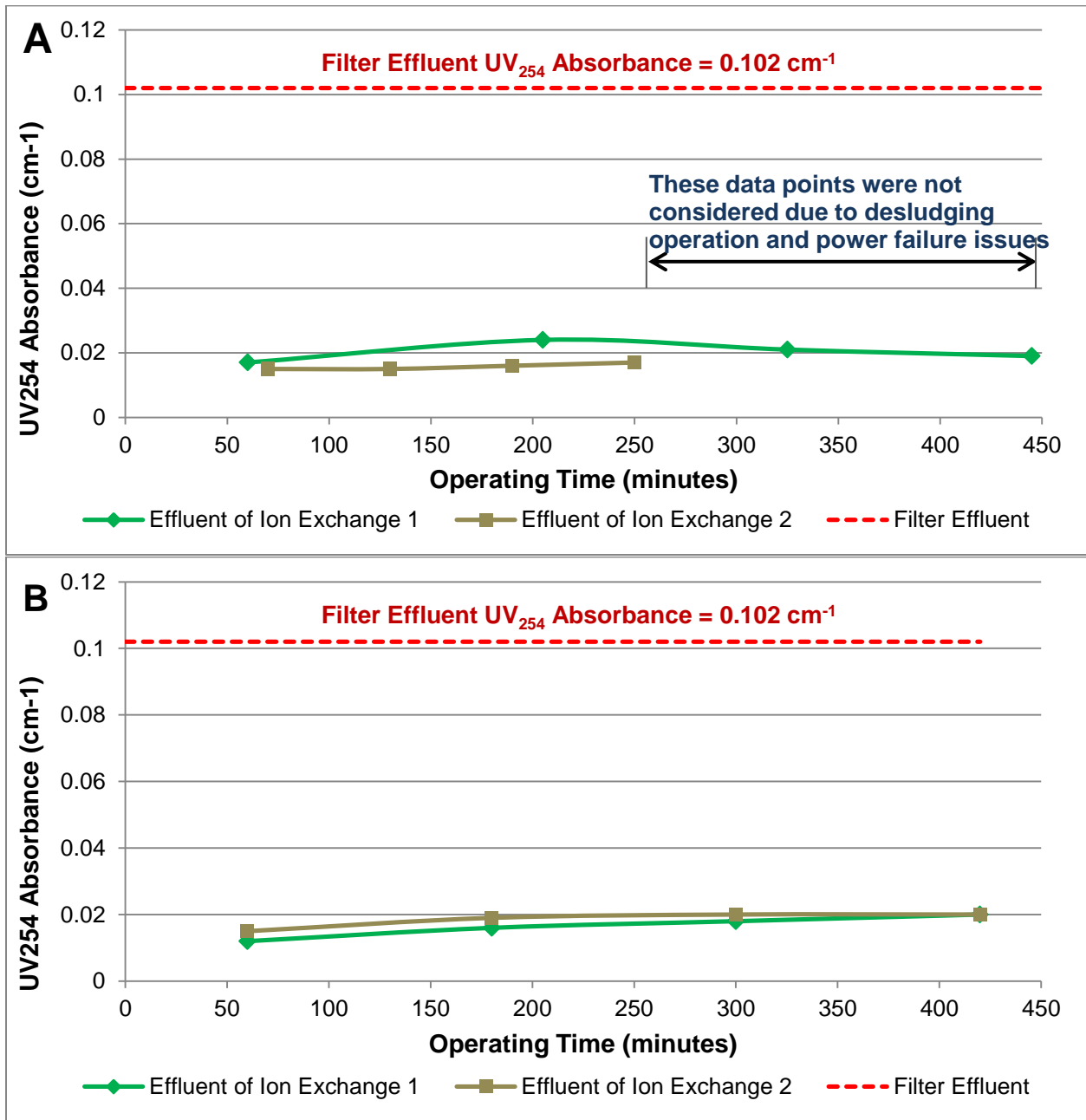


Figure 3. UV₂₅₄ absorbance levels of the effluents of the ion exchange system and WTP filter for A) Experiment 1 with EBCT of 2.5 min, and B) Experiment 2 with EBCT of 5.2 min

On average, the ion exchange systems additionally reduced 69% of DOC and 83% of UV₂₅₄ absorbance from the filter effluent. This indicates that the system removed a

greater amount of the aromatic fraction of organics than the non-aromatic fraction (Weishaar et al., 2003). It should be noted that the aromatic fraction of organics are responsible for THM formation (Lu et al., 2009).

As is shown in Figure 2 and 3, both the DOC and UV₂₅₄ absorbance levels increased gradually with time. Therefore, from an operation perspective, it is important to determine the system regeneration set-points such as runtime, and DOC (or UV₂₅₄ absorbance) breakthrough. It is noted that the runtime was only 7 hours in this study, and confirmation of trend is required for a longer run.

3.3 DBP Reductions

3.3.1 THMs Reduction

A THMs level of 238 µg/L was measured in raw water, exceeding the MAC in drinking water of 100 µg/L based on a RAA (O. Reg. 169/03). The WTP enhanced coagulation and filtration processes reduced the formation of THMs by 40% to 142 µg/L, which was still higher than the target limit.

THM levels were measured for all samples collected from both ion exchange trains during Experiment 1 (Figure 4). Ion exchange treated water showed significant THMs reduction (86%, from 142 µg/L to 20 µg/L, n=6) from the filter effluent, satisfying the regulated RAA level.

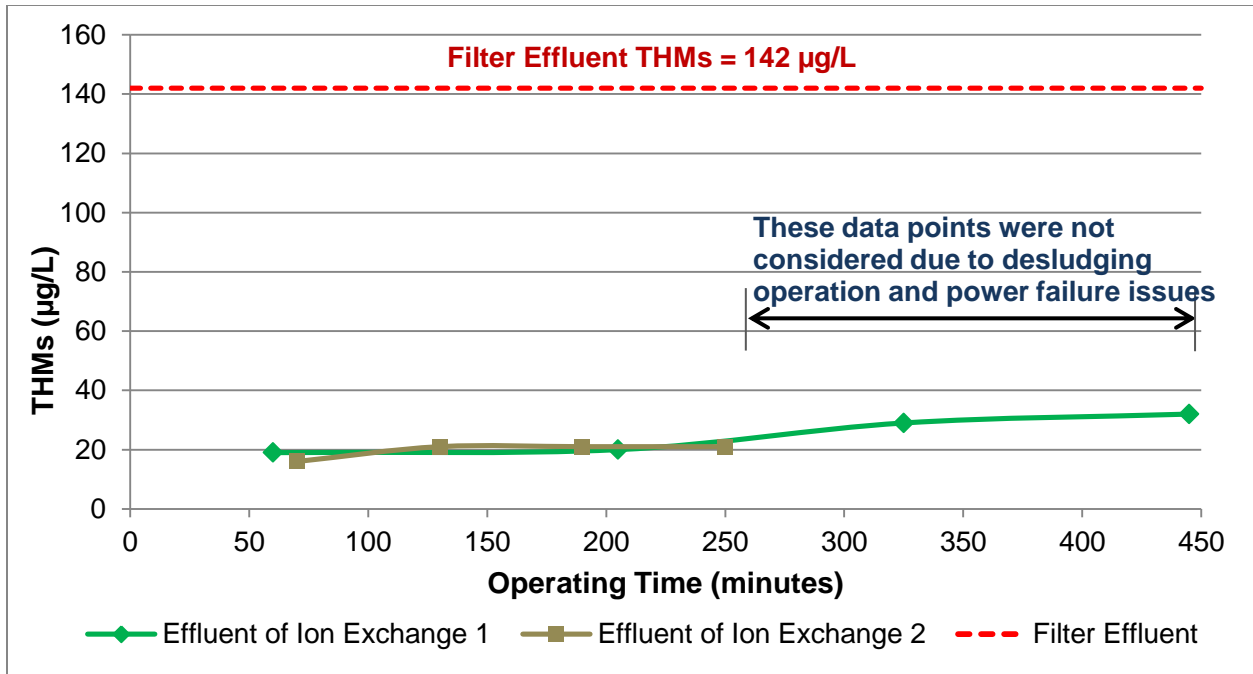


Figure 4. THM levels of the samples collected from both ion exchange trains during Experiment 1 measured by SDS test with 48 hr contact time and 6.3 mg/L of sodium hypochlorite dose

3.3.2 HAAs Reduction

During SDS-HAAs testing, HAAs of raw water were measured as 185 µg/L. The enhanced coagulation followed by the filtration processes of the WTP reduced HAAs by 32% (to 126 µg/L) from the raw water. Ion exchange treatment was effective to reduce 82% (from 126 µg/L to 23 µg/L, n=6) of HAAs from the filtered effluent (Figure 5).

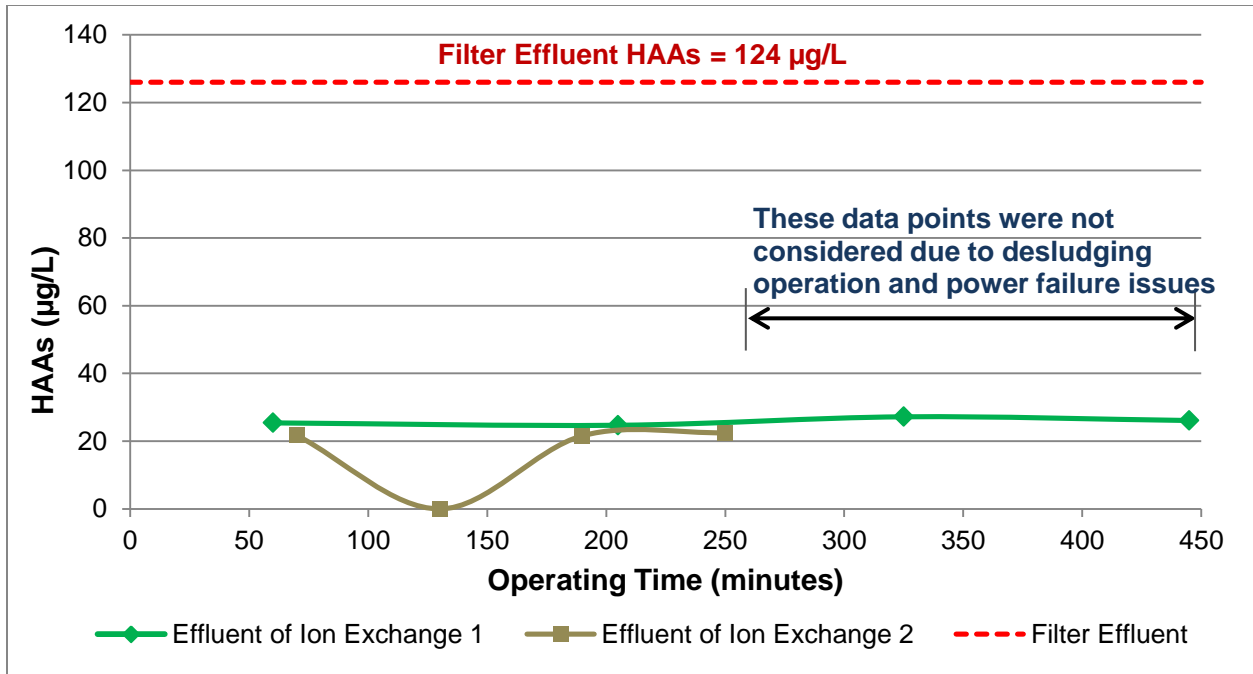


Figure 5. HAAs levels of the samples collected from both ion exchange trains during Experiment 1 measured by SDS test with 48-h of contact time and 6.3 mg/L of sodium hypochlorite dose

3.4 Alkalinity and pH Adjustments

Alkalinity represents a water’s ability to resist the effects of acids (APHA, 2012). Ontario’s operational guideline suggests that alkalinity should be kept between 30 and 500 mg/L expressed as calcium carbonate to maintain an ideal operational condition for WTPs (MOE, 2006). Table 3 summarizes alkalinity levels during Experiments 1 and 2 of the filter and ion exchange effluents. The WTP applied soda ash to raw water (alkalinity of 69 mg/L as CaCO₃) to increase the alkalinity ensuring the effectiveness of coagulation. The residual alkalinity following the enhanced coagulation was 33 mg/L as CaCO₃.

Table 3. Average pH and alkalinity data of raw water, filter effluent and ion exchange effluent

Water Sample	pH	Alkalinity (mg/L as CaCO ₃)
Raw Water	7.6	69
Filter Effluent	6.4	33
Ion Exchange Effluent (average, n = 6)	5.0	8

Alkalinity of most surface waters primarily comprises of HCO₃⁻, OH⁻ and CO₃²⁻ ions, which vary in proportion depending on the level of pH (APHA, 2012). The anionic ion exchange process selectively displaces negative ions (including HCO₃⁻, OH⁻ and CO₃²⁻) and releases chloride ions from the resin into the treated water (Chen et al., 2006). Consequently, the average residual alkalinity is substantially reduced to 8 mg/L as CaCO₃ following the anionic ion exchange process, which is well below the operational guideline of 30 mg/L for treated water (MOE, 2006).

pH is not only important for water treatment and disinfection, but also important for stability in the distribution system. As is shown in Table 3, the average raw water pH was 7.6, which was reduced to an average pH of 6.4 after the enhanced coagulation. The average pH of the ion exchange treated water was 5.0. The reduction of pH is likely due to the reduction of alkalinity as discussed above. When the alkalinity is reduced, water loses its buffering capacity of acids and becomes sensitive to pH changes.

From an operational point of view, the pH and alkalinity levels should be continuously monitored, adjusted and controlled.

4. Conclusions

On average, the ion exchange process decreased the level of:

- DOC from 5.75 mg/L to 1.78 mg/L, which was a 69% reduction.
- UV_{254} absorbance from 0.102 cm^{-1} to 0.017 cm^{-1} , which was an 83% reduction.

The ion exchange process reduced:

- THMs from 142 $\mu g/L$ to 20 $\mu g/L$, which was an 86% reduction.
- HAAs from 126 $\mu g/L$ to 23 $\mu g/L$, which was an 82% reduction.

The ion exchange treated water has a low level of alkalinity and pH which should be monitored and corrected for control of possible corrosion.

The online UV_{254} absorbance analyzer system was found to be an effective tool to monitor and optimize the performance of the ion exchange system.

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