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CWAE Centre de Walkerton pour l'assainissement de l'eau
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Pilot Testing Project Report

Conventional Treatment Optimization for Big Grassy First Nation

Walkerton Clean Water Centre

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Executive Summary

Background

The Big Grassy First Nation community is located on the Southeast shores of Lake of the Woods in Northwestern Ontario and has approximately 300 residents. This community was under a long-term boil water advisory since 2017 and was still under this advisory at the time of bench scale testing (July - August, 2019). The community was planning to upgrade its conventional water treatment plant (WTP) after a feasibility study was performed by an engineering consultant. The community uses Lake of the Woods as their raw water source which is known to exhibit high turbidity and colour especially when lake turnover events occur. The community contacted the Walkerton Clean Water Centre (Centre) to help them compare different coagulants and provide information on optimization to be used while designing the WTP upgrades.

Objective

The aim of this project is to optimize conditions for the best reduction of turbidity and colour from the community's raw water source.

Detailed objectives of the bench scale experiments were to:

1) Compare coagulants and find the optimum doses for reducing turbidity and colour.
2) Investigate whether polymer addition can improve reduction of turbidity and colour.
3) Investigate if pH adjustment enhances coagulation.
4) Examine the formation of disinfection by-products (DBPs).

Approach

This project focused on bench scale testing to collect information for Big Grassy First Nation. In collaboration with the operators in the community, raw source water was shipped to the Centre in the summer of 2019. The raw water was preserved until testing could commence.

Six jar tests were conducted at the Centre. The coagulants used in jar testing were alum and polyaluminum chloride (PAX-XL52). Preliminary jar tests identified the optimum dose of alum and PAX-XL52. The addition of polymer and the effects of pH reduction were investigated in subsequent jar tests.

Simulated Distribution System (SDS) tests were conducted on selected samples collected during jar testing to assess the formation potential of DBPs, specifically trihalomethanes (THMs) and haloacetic acids (HAAs), using a 4 mg/L chlorine dose and two day detention time. These conditions were selected to best mimic the community's current WTP conditions.

Key Findings

Through the bench scale jar tests, it was determined that:

- When using alum as a coagulant, 70 mg/L was the optimum dose to reduce turbidity (56% reduction).
- When using polymer in addition to alum, 0.25 mg/L yielded the lowest turbidity (57% reduction) and apparent colour levels. Polymer addition did not have any additional effect on reducing organics from the source water.
- When using PAX-XL52, 55 mg/L was the optimum dose to reduce turbidity (88% reduction).
- Reducing the pH of the water for coagulation was not found to reduce turbidity or apparent colour any further.
- Alum and polymer were able to reduce THM levels to less than the Ontario Standard of 100 µg/L but were not able to reduce the HAA levels to below the standard of 80 µg/L. PAX-XL52 was also not able to reduce the level of THMs below the standard but was effective at lowering the HAA levels.
- Decreasing the pH of the water resulted in increasing the fraction of HAAs formed and decreasing the fraction of THMs formed.

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1. Introduction

The Big Grassy First Nation community is located on the Southeast shores of Lake of the Woods in Northwestern Ontario and has approximately 300 residents. This community was under a long-term boil water advisory since 2017 and was still under this advisory at the time of bench scale testing (July - August, 2019). The community was planning to upgrade its conventional water treatment plant (WTP) after a feasibility study was performed by an engineering consultant. The community uses Lake of the Woods as their raw water source which is known to exhibit high turbidity and colour especially when lake turnover events occur. The community contacted the Walkerton Clean Water Centre (Centre) to help them compare different coagulants and provide information on optimization to be used while designing the WTP upgrades.

The aim of this project is to optimize conditions for the best reduction of turbidity and colour from the community's raw water source. This information will be supplied to the community for its application in the design of future water treatment plant upgrades.

Detailed objectives of the bench scale experiments were to:

1) Compare coagulants and find the optimum doses for reducing turbidity and colour.
2) Investigate whether polymer addition can improve reduction of turbidity and colour.
3) Investigate if pH adjustment enhances coagulation.
4) Examine the formation of disinfection by-products (DBPs).

2. Materials and Method

2.1 Raw Water Collection and Transportation

The raw water (120 L) was collected on-site from the existing water intake line and shipped to the Centre. Due to the transportation time, the Centre received the raw water samples three days after they were collected. The raw water was stored in a refrigerator (4°C) until the experiments were conducted. Prior to each jar test, raw water was removed from the refrigerator and allowed to warm up to 19°C before beginning the jar testing as this was the temperature of the source water at the time of collection.

2.2 Jar Test Conditions

A programmable jar tester was used with three memories set to mimic rapid mixing, flocculation and sedimentation. Aluminum sulphate (alum) and polyaluminum chloride (PAX-XL52) were the coagulants selected for testing and a polymer (Magnafloc LT 7981) was tested as well in conjunction with alum. These treatment chemicals were selected after discussion with the community's engineering consultant.

Six jar tests were conducted as follows:

- Jar Test 1A and 1B determined the optimum dosage of alum. Jar Test 1A covered a wide range while Jar Test 1B was used to fine tune the chemical dosage.
- Jar Test 2 determined the optimum dosage of polymer to be added along with the determined optimum dose of alum (70mg/L).
- Jar Test 3 determined the optimum dosage of PAX-XL52.
- Jar Test 4 tested the effect of different pH levels on the optimum alum dose (70mg/L) and optimum polymer dose (0.25mg/L).
- Jar Test 5 tested the effect of different pH levels on the optimum PAX-XL52 dose (55 mg/L).

The jar tester consisted of six jars and details are described below for each test (Table 1):

Table 1. Jar Test Conditions

	Jar Conditions					
Jar	1	2	3	4	5	6
Jar Test 1A – alum dose (mg/L)	0	20	40	60	80	100
Jar Test 1B – alum dose (mg/L)	0	70	75	80	85	90
Jar Test 2 – alum 70 mg/L + polymer dose (mg/L)	0	0.05	0.10	0.15	0.20	0.25
Jar Test 3 – PAX-XL52 (mg/L)	0	40	45	50	55	60
Jar Test 4 – alum 70 mg/L + polymer 0.25 mg/L + sulfuric acid (pH)	7.7	7.2	6.9	6.6	6.3	6.0
Jar Test 5 – PAX-XL52 mg/L + sulfuric acid (pH)	7.7	7.2	6.9	6.6	6.3	6.0
Stage 1:	Rapid Mixing: 100 RPM for 1 minute					
Stage 2:	Flocculation: 20 RPM for 20 minutes					
Stage 3:	Flocculation: 0 RPM for 60 minutes					

2.3 Water Quality Analysis

Samples were collected from each jar and analyzed at the Centre for turbidity, pH, alkalinity, apparent and true colour, UV absorbance at 254 nm (UV_{254}), and dissolved organic carbon (DOC) (Table 2).

Selected samples were sent to an accredited licensed laboratory to analyze total trihalomethanes (TTHMs) and haloacetic acids (HAA_5) after being subjected to an in-house simulated distribution system (SDS) method.

Table 2. Methods of Water Quality Analysis

Parameter	Preparation	Method	Range
In-House Analysis			
Turbidity	N/A	USEPA Method 180.1	0 – 1000 NTU
pH	N/A	Hach Method 8156	0 – 14
True/apparent colour	True colour – 0.45 µm filtered	Hach Method 8025 Platinum-Cobalt Standard Method	5 – 500 Pt-Co
UV_{254} absorbance	0.45 µm filtered	Real Tech UV_{254} Method	0 – 2 Abs/cm
Dissolved organic carbon	0.45 µm filtered	Standard Method 5310C UV/persulfate oxidation with conductometric detection	4 ppb to 50 ppm
Alkalinity	N/A	Hach Method 8203 Phenolphthalein and Total Alkalinity	10 – 4000 mg/L $CaCO_3$
Analyzed at a Licensed Laboratory			
Total Trihalomethanes	4 mg/L chlorine dose for a 2 day contact time	EPA 5030B/8260C	Method Detection Limit: 0.37 µg/L
Haloacetic acids	4 mg/L chlorine dose for a 2 day contact time	EPA 552.3	Method Detection Limit: 5.3 µg/L

2.4 Simulated Distribution System Method

Elevated levels of DOC have been detected in the raw water, which could cause concern as these compounds have the potential to form disinfection by-products (DBPs) when they are mixed with chlorine during the disinfection process. This experiment was performed to assess the amount of DBPs that could potentially be formed in the distribution system. The Ontario Drinking Water Quality Standards (O. Reg. 169/03) set limits for trihalomethanes (THMs) and haloacetic acids (HAAs) in drinking water samples taken from the distribution system. THMs have a maximum acceptable concentration (MAC) of 0.10 mg/L based on a running annual average (RAA) of quarterly results. HAAs have a MAC of 0.08 mg/L as a RAA of quarterly results.

Clarified water samples were collected from Jar Tests 2 – 5 and transferred into 250 mL chlorine demand free, amber glass containers. To achieve chlorine demand-free containers, the glassware was pretreated with 10 mg/L of chlorine solution for a minimum of 3 hours, rinsed with deionized water and left to air dry.

Samples were dosed with approximately 4 mg/L of chlorine and were stored in a dark cabinet at room temperature for 2 days of detention time. This chlorine dose was chosen for the water source as it left approximately 1 mg/L of chlorine residual after the 2 day detention time elapsed. The detention time was based on the estimated maximum detention time of the community's distribution system.

The samples were quenched with sodium thiosulphate and ammonium chloride preservatives for the THMs and HAAs tests, respectively, and shipped to the external laboratory for analysis. This SDS method was adapted from Standard Methods for the Examination of Water and Wastewater (APHA, 2012).

3. Results and Discussion

3.1 Jar Test Results

3.1.1. Reduction of Turbidity and Colour Using Alum and Polymer

Table 3. Raw Water Quality During Jar Tests

Parameter	Results
Turbidity (NTU)	2.42 - 3.07
Apparent Colour (Pt-Co)	56 - 63
True Colour (Pt-Co)	38 - 39
pH	7.74
Alkalinity (mg/L as $CaCO_3$)	10.8 - 11.9
Dissolved Organic Carbon (mg/L)	0.33 - 0.34
UV_{254} (cm^{-1})	0.33
Total Aluminum (mg/L)	0.009 - 0.013

In Jar Test 1A, the lowest turbidity and apparent colour was in the jar dosed with 80 mg/L of alum. In the subsequent Jar Test 1B, alum was dosed in the narrower range of 70 - 90 mg/L to identify the optimum dose. The optimum dose selected was 70 mg/L of alum (Figure 1 (A)). Following the dose of 70 mg/L alum, turbidity started to increase.

Jar Test 2 was conducted using the optimized alum dose and the addition of polymer (Magnafloc LT 7981) from 0.00 to 0.25 mg/L. Polymer doses of 0.10 mg/L and 0.25 mg/L provided the lowest turbidity levels at 1.05 NTU and 1.07 NTU, respectively (Figure 1 (B)).

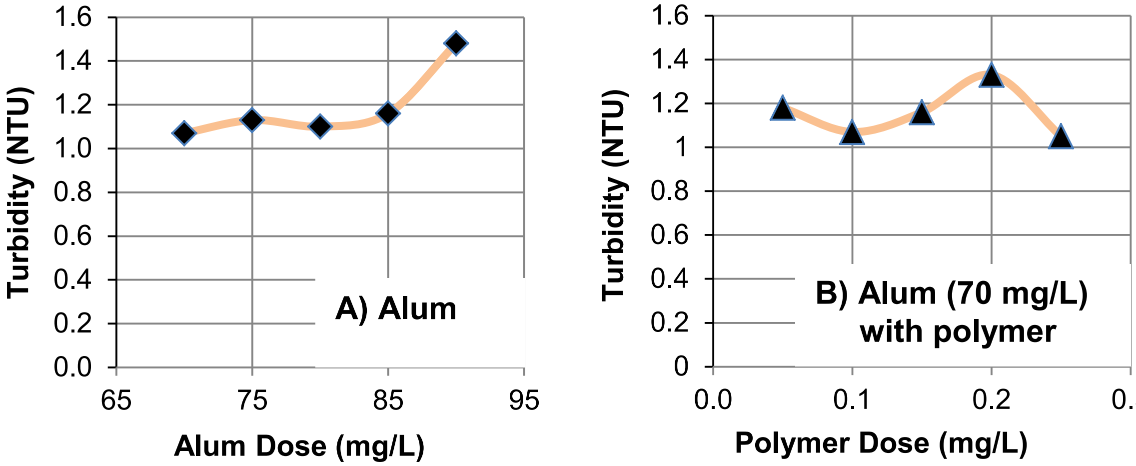

Figure 1. Turbidity from A) dosing alum (Jar Test 1B) and B) dosing 70 mg/L alum with polymer (Jar Test 2)

Apparent colour results from Jar Test 1B can be found in Figure 2 (A). When the samples were filtered and true colour was analyzed, all dosages in the jar test yielded results less than 5 Pt-Co. When the polymer was applied at 0.25 mg/L in conjunction with the optimum dose of alum (70 mg/L), the apparent colour was reduced to its lowest point of 9 Pt-Co (Figure 2 (B)).

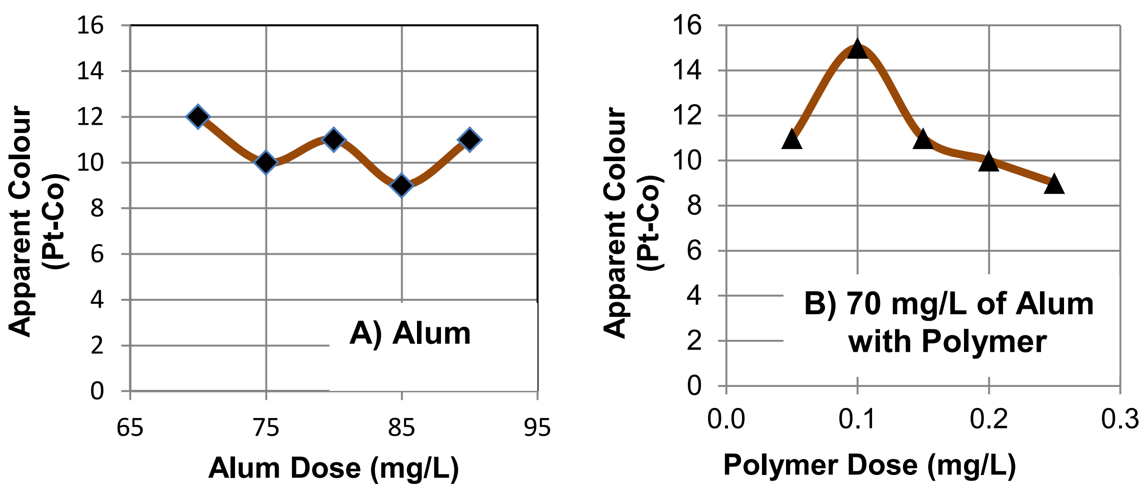

Figure 2. Apparent colour levels during A) dosing alum (Jar Test 1B) and B) dosing 70mg/L alum with polymer (Jar Test 2)

3.1.2. Reduction of Turbidity and Colour Using PAX-XL52

In Jar Test 3, as increasing amounts of coagulant were added, the turbidity continued to drop until 60mg/L of PAX-XL52 was added. At this point, the turbidity began to increase again slightly, indicating the point of diminishing return had been reached (Figure 3 (A)). The water turbidity was reduced from 3.07 NTU to its lowest point of 0.37 NTU when 55 mg/L of PAX-XL52 was used. Therefore, 55 mg/L was selected as the optimum dose for this coagulant.

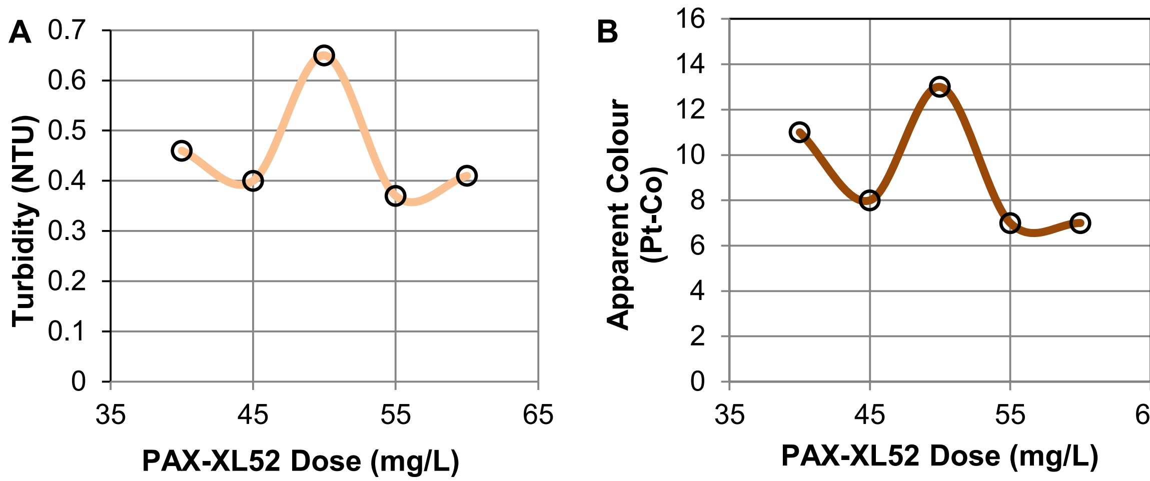

Figure 3. A) Turbidity and B) apparent colour results from Jar Test 3

As shown in Figure 3 (B), the trend for apparent colour was observed to be similar to turbidity. The lowest apparent colour achieved was 7 Pt-Co when dosed at both 55 mg/L and 60 mg/L of PAX-XL52. This confirmed the selected optimum dose of 55 mg/L PAX-XL52.

3.1.3. Effect of pH Adjustment on Turbidity and Colour Reduction

Jar Test 4 was conducted using alum and polymer at their respective optimum dosages (70 mg/L alum and 0.25 mg/L polymer) with different levels of pH adjustment. Alum coagulant generally performs better in lower pH ranges. The raw water pH was 7.74 so sulfuric acid was used lower the pH in a range from 7.2 to 6.0. As shown in Figure 4 (A), the opposite trend was observed as turbidity levels increased when pH was lowered.

Jar Test 5 was conducted using PAX-XL52 at its optimum dose (55 mg/L) with different levels of pH adjustment. Similarly to Jar Test 4, the target for pH adjustment ranged from 7.2 to 6.0. Turbidity levels increased with decreasing pH except for the jar adjusted to 6.0 (Figure 4 (A)). The turbidity dropped in these conditions but was still at a higher level than it was initially at the raw water's true pH (7.74).

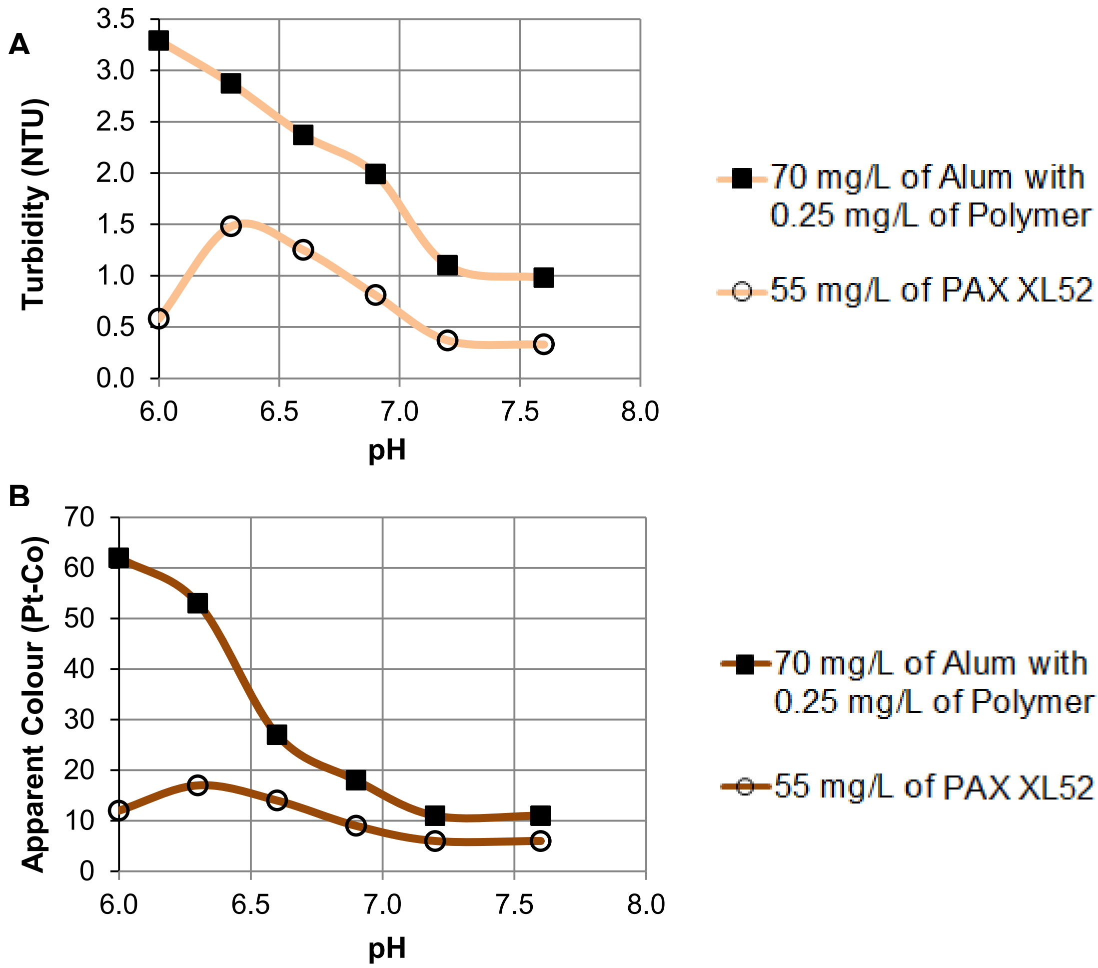

Figure 4. A) Turbidity and B) apparent colour results during Jar Tests 4 & 5

When the pH was lowered, apparent colour behaved similarly to turbidity and increased (Figure 4 (B)); exclusive of the jar adjusted to 6.0 and treated with PAX-XL52. As was observed with turbidity, apparent colour in these conditions was reduced but again was not more effective than the treatment of the raw water with no pH adjustment. Therefore, in both cases it was found that pH adjustment did not provide any advantage to reducing turbidity or apparent colour levels. Figure 4 also demonstrates that PAX-XL52 was more effective at reducing turbidity and apparent colour than the alum and polymer combination.

3.2 Formation Potential of THMs/HAAs - SDS Results

3.2.1. Alum + Polymer and PAX-XL52 Samples (Jar Tests 2 and 3)

Figure 5 below shows the THMs and HAAs analyzed of samples collected from Jar Tests 2 and 3.

Clarified water samples were collected from Jar Tests 2-3 to be subjected to the SDS method and sent for testing of THMs and HAAs. Samples were dosed at 4 mg/L of sodium hypochlorite and had chlorine demands of 2.96 – 3.03 mg/L after 2 days of contact time (free chlorine residual ~ 1 mg/L).

The raw untreated water came back with concentrations of 179 µg/L THMs and 109 µg/L HAAs. All water samples treated with alum and polymer in Jar Test 2 at all concentrations achieved THM levels less than the Ontario Drinking Water Quality Standard (ODWQS) MAC of 100 µg/L (Figure 5 (A)). However, alum with polymer addition was close but not able to reduce the HAA levels to below the ODWQS MAC of 80 µg/L. This corresponded to the fact that the polymer doses were not effective at reducing organics as measured in-house using UV_{254} absorbance and DOC analysis.

As the PAX-XL52 dose increased in Jar Test 3, the THM and HAA levels decreased; however, all water samples dosed with PAX-XL52 were above the MAC of 100 µg/L for THMs. The 55 mg/L and 60 mg/L dosages of PAX-XL52 were the only doses found effective at reducing the HAA levels below the MAC of 80 µg/L (Figure 5 (B)).

Overall, neither coagulant tested was able to meet Ontario Standards for DBPs.

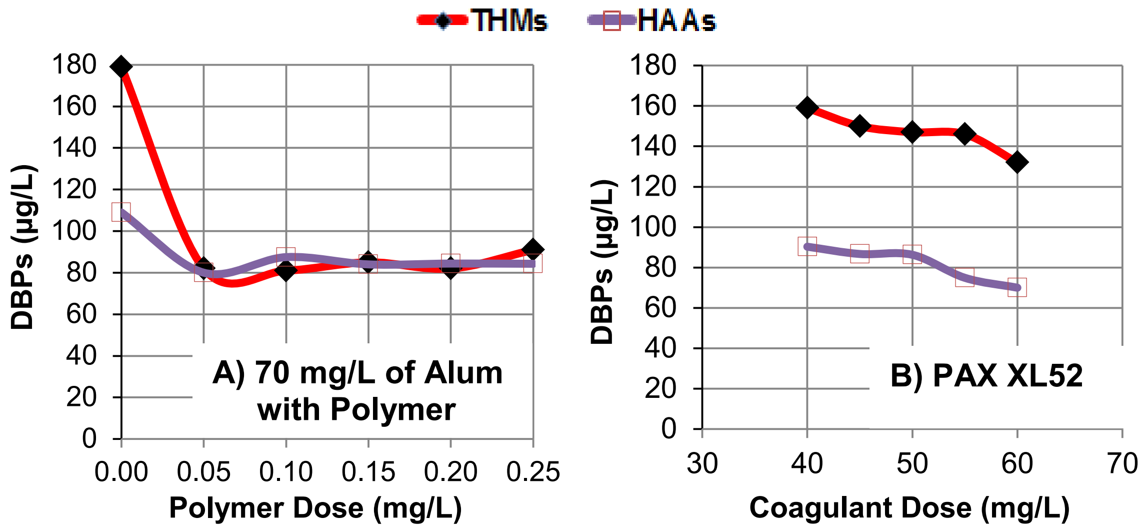

Figure 5. THMs and HAAs results from A) Jar Test 2 using alum with polymer and B) Jar Test 3 using PAX-XL52

3.2.2. pH Adjusted Samples (Jar Tests 4 and 5)

Figure 6 below shows the THMs and HAAs analyzed of samples collected from Jar Tests 4 and 5.

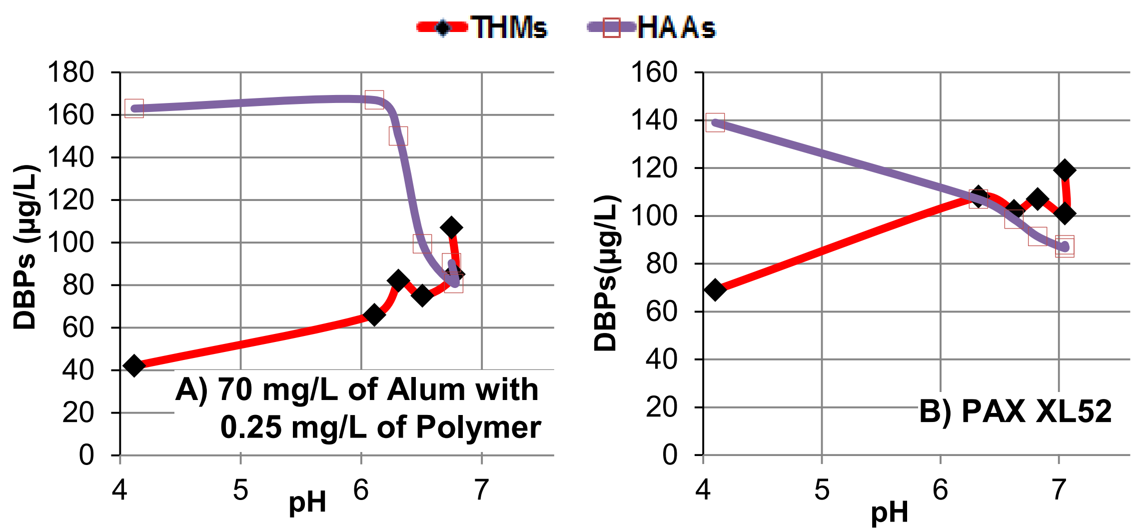

Figure 6. THMs and HAAs results from A) Jar Test 4 using alum and polymer and B) Jar Test 5 using PAX-XL52

In Jar Tests 4 and 5, jars were adjusted to have pH levels from 7.20 to 6. However, the coagulant manufacturer (Kemira) provided information that the PAX-XL52 product performs best in the pH range of 6.77 to 4.12 so additional samples were adjusted to 4.1 for use in the SDS test.

Clarified water samples were collected from Jar Tests 4-5 to be subjected to the SDS method and sent for testing of THMs and HAAs. Samples were dosed at 4 mg/L of sodium hypochlorite and had chlorine demands of ≥2.77 mg/L after 2 days of contact time. The free chlorine residuals were more variable for these samples as the pH adjustment affected the chlorine demand values.

In Jar Test 4, the alum and polymer treated sample with no pH adjustment was found to have 107 µg/L of THMs and 90 µg/L of HAAs. Figure 6 (A) shows that as the pH decreased, the levels of THMs also decreased. The opposite was observed for HAA levels as they increased as pH decreased. These results are supported in the literature published by Hung et al., 2017.

In Jar Test 5, the PAX-XL52 treated sample with no pH adjustment was found to have 119 µg/L of THMs and 87.9 µg/L of HAAs. Similar to Jar Test 4, as the pH decreased, the level of THMs decreased and as the pH decreased, the level of HAAs increased (Figure 6 (B)).
Overall, in these experiments it was found that decreasing the pH of the water resulted in increasing the fraction of HAAs formed and decreasing the fraction of THMs.

4. Conclusions

In conclusion, for this water source from the Lake of the Woods, it was found that when using alum as a coagulant, 70 mg/L was the optimum dose to reduce turbidity (56% reduction). When using polymer in addition to alum, 0.25 mg/L yielded the lowest turbidity (57% reduction) and apparent colour levels. When using polyaluminum chloride (PAX-XL52), 55 mg/L was the optimum dose to reduce turbidity (88% reduction) and apparent colour. Polymer addition did not have any additional effect on reducing organics from the source water.
Alum and polymer were able to reduce THM levels to less than the Ontario Standard of 100 µg/L but were not able to reduce the HAA levels to below the standard of 80 µg/L. PAX-XL52 was also not able to reduce the level of THMs below the standard but was effective at lowering the HAA levels. It is important to note that jar testing lacks the filtration stage of the conventional treatment process so this additional barrier could provide further reduction of THMs/HAAs depending on the media used. For example, granular activated carbon (GAC) is able to adsorb organics and would likely reduce DBPs.

Reducing the pH of the water for coagulation with alum and PAX-XL52 was not found to reduce turbidity or apparent colour any further. Decreasing the pH of the water resulted in increasing the fraction of HAAs formed and decreasing the fraction of THMs formed. Therefore, pH adjustment was confirmed to not be an effective tool for reducing THMs or HAAs as one or the other will be increased. In general, it is more effective to reduce the level of organics, the amount of chlorine disinfectant being added or the detention time of water in the distribution system to lower the levels of THMs/HAAs in treated water.

The source water's low alkalinity and high organic content may cause operational challenges in terms of pH control. This should be taken into account if any pH adjustment is considered for this water source.

5. References

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