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An agency of the Government of Ontario

CWAE Centre de Walkerton pour l'assainissement de l'eau
Un organisme du gouvernement de l'Ontario

Final Report

Optimizing Coagulant Doses by Jar Tests

Walkerton Clean Water Centre

Research & Technology

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Acknowledgements

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List of Acronyms

AO	Aesthetic objective
CSMR	Chloride-to-sulphate mass ratio
DOC	Dissolved organic carbon
HC	Health Canada
MAC	Maximum acceptable concentration
NTU	Nephelometric turbidity units
OG	Operational guideline
Pt-Co	Platinum-cobalt unit
TCU	True colour unit
UVA	Ultraviolet absorbance
UVT	Ultraviolet transmittance

Executive Summary

Background

A First Nation community (community) has been under a boil water advisory for 26 years due to inadequate water treatment. The community approached the Walkerton Clean Water Centre (Centre) to assist with testing its coagulation process.

The community's water treatment plant uses a surface water source. Raw water from this source is low in temperature (less than 1°C to 10°C), low in alkalinity (52.7 mg/L as $CaCO_3$), and low in turbidity (1.7 nephelometric turbidity units [NTU]), but has high levels of organics (dissolved organic carbon [DOC] of 11.4 mg/L and true colour of 66.4 true colour units [TCU]). The water treatment plant is designed as a dual-train conventional treatment system, which consists of coagulation, flocculation and upflow clarification followed by filtration. The plant uses ClearPAC 180 as its coagulant with a flocculation aid, Clearfloc CP1065. The plant is currently experiencing issues with floc carry-over from the clarifier, which in turn, is clogging the filters. This leads to frequent filter backwashing and possible breakthrough.

Objectives

The objectives of the bench-scale jar test study are:

1) to determine the optimum doses of the plant's coagulant and flocculation aid based on water quality parameters; and
2) to compare the performance of the plant's coagulant with two commercially available coagulant products designed for water with low temperature, pH and alkalinity.

Approach

Raw water samples were collected at the plant and then shipped to the Centre. Six conventional jar tests were conducted at the Centre to determine the optimum doses of selected coagulants and flocculation aid.

Key Findings

The following conclusions were drawn from the jar testing:

- The optimum dose of ClearPAC 180 was determined as 40 mg/L, as it provided the lowest turbidity, colour, aluminum residual and over 80% reduction of UV absorbance. The jar with 40 mg/L of ClearPAC 180 was also easier to filter compared to the other doses;
- Similarly, the optimum doses of PAX-XL19 and PAX-XL52 were both determined as 60 mg/L;
- At their optimum doses, all tested coagulants provided over 80% UVA reduction and over 70% DOC removal;
- Compared to ClearPAC 180, both PAX-XL19 and PAX-XL52 had similar but less impact on water pH and alkalinity;
- ClearPAC 180 had a narrower operating dose range than the other two products;
- The flocculation aid, Clearfloc CP1065, increased the size of flocs for all tested coagulants, but had limited impact on water quality;
- ClearPAC 180 had a higher chloride-to-sulphate mass ratio (CSMR) than PAX-XL19, while PAX-XL52 had the lowest. Therefore, PAX-XL19 or PAX-XL52 may have less potential for lead leaching in the distribution system if lead materials are present.

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1. Introduction

The First Nations community is located northeast of Thunder Bay, Ontario and is accessible by air, ice road, and water travel. The population of the community is about 400 people, of whom 300 people live on the reserve. The community has been under a boil-water advisory for 26 years due to inadequate water treatment. On November 28, 2020, the Centre received a request from the community to conduct a bench-scale jar test study to optimize the doses of the plant's coagulant and flocculation aid.

The community's water treatment plant uses a surface water source. Raw water from this source is low in temperature (less than 1°C to 10°C), low in alkalinity (52.7 mg/L as $CaCO_3$), and low in turbidity (1.7 NTU), but has high levels of organics (DOC of 11.4 mg/L and true colour of 66.4 TCU). The water treatment plant is designed as a dual-train conventional treatment system, which consists of coagulation, flocculation and upflow clarification followed by filtration. The plant uses ClearPAC 180 as its coagulant with flocculation aid, Clearfloc CP1065. The plant is currently experiencing issues with floc carry-over from the clarifier, which in turn clogs the filters. This leads to frequent filter backwashing and possible breakthrough.

2. Objectives

The objectives of the bench-scale jar test study are:

1) to determine the optimum doses of the plant's coagulant and flocculation aid based on water quality parameters, such as turbidity, colour, DOC, aluminum residual and alkalinity; and
2) to compare the performance of the plant's coagulant with two commercially available coagulant products designated for water with low temperature, pH and alkalinity.

3. Materials and Method

3.1 Raw Water Quality

Raw water was collected on-site from the existing water intake line on December 1, 2020. Raw water pH and temperature were measured on-site and the results are summarized in Table 1.

Table 1. Raw water quality on-site on December 1, 2020

Water Quality Parameters	Rep 1	Rep 2	Rep 3	Average
pH	6.76	6.85	6.88	6.83
Temperature (°C)	1.6	0.7	0.6	0.97

After collection, raw water samples were shipped and bench-scale jar tests were then completed at the Centre. Due to the transportation time, the Centre received the raw water samples six days after the raw water samples were collected, on December 7, 2020. Raw water samples were analyzed when the sample containers arrived at the Centre and stored in a refrigerator (at 4°C) until the days of the experiments (Table 2).

Table 2. Raw water quality at the Centre on December 7, 2020

Water Quality Parameters		Results
Temperature (°C)		14.1
pH		7.4
Turbidity (NTU)	Rep 1	1.35
	Rep 2	1.32
	Rep 3	1.24
	Rep 4	1.40
	Average	1.33
UVA (cm^{-1})		0.535
UVT (%)		29.1
DOC (mg/L)		14.46

Raw water temperature increased to about 14°C during transportation. pH measurements are dependent on water temperature. This could explain why the raw water pH measured at the Centre upon arrival (7.39) was slightly higher than measured on-site during collection (6.83). The raw water had relatively low levels of turbidity (an average of 1.33 NTU), but high levels of organics (UVA of 0.535 cm^{-1}, UV transmittance [UVT] of 29% and DOC of 14.5 mg/L).

To ensure the consistency of raw water quality, daily raw water tests were conducted during the period of jar test experiments, December 9 – 14, 2020 (Table 3).

Table 3. Raw water quality during jar test experiments

Water Quality Parameters		Dec. 9, 2020	Dec. 10, 2020	Dec. 11, 2020	Dec. 14, 2020
Turbidity (NTU)	**Rep 1**	1.15	0.97	1.02	1.21
	Rep 2	1.03	1.00	1.01	0.99
	Average	1.09	0.99	1.02	1.10
pH		7.2	7.5	7.4	7.5
Alkalinity (mg/L as $CaCO_3$)		61	64	61	56
Apparent Colour (Pt-Co)		79	78	82	84
True Colour (Pt-Co)		69	66	23	71
DOC (mg/L)		15.00	15.10	15.10	15.20
UVA (cm^{-1})		0.536	0.531	0.533	0.529
Filtered Chloride (mg/L)		2.1	2.9	2.2	1.7
Filtered Aluminum (mg/L)		0.012	0.041	0.008	
Filtered Iron (mg/L)		< 0.02			
Filtered Manganese		0.014	0.013	0.011	0.014

3.2 Coagulants and Flocculation Aid

The Centre completed jar test experiments with three different coagulants and one flocculation aid. The details of the tested coagulants and flocculation aid are summarized in Table 4. Coagulants with high levels of basicity are expected to have less impact on water pH and alkalinity.

Table 4. Coagulant and Flocculation Aid Information

Product Name	Description	Major Ingredients	Details (Product technical data sheets)
ClearPAC 180*	Coagulant	Polyhydroxyl aluminum chloride	Basicity of 43 wt.%. Reduced alkalinity stripping, reduced pH impact, reduced sludge volume, faster cold water response, reduced coagulant dose, increased organic removal, better floc characteristics.
PAX-XL19 (or ACH)	Coagulant	Aluminum chlorohydrate (highly charged polyaluminum chloride)	Basicity of 82-83.7 wt.%. Highly concentrated and charged product. Reduced sludge production, less pH adjustment, longer filter funs, improved cold water performance.
PAX-XL52	Coagulant	Aluminum chloride hydroxide sulfate	Basicity of 70-77 wt.%. Reduced sludge production, less pH adjustment, longer filter runs, improved cold water performance.
Clearfloc CP1065*	Flocculation Aid	Cationic polyacrylamide powder	pH of 2.5 – 4.5 at 5 g/L.

*Currently in use at the community's water treatment plant.

3.3 Jar Tests

The jar tests were conducted using a 6-jar Phipps & Bird conventional jar tester. The steps of the jar test included coagulation, flocculation and sedimentation. All jar tests were conducted under cold water conditions using an ice water bath. Water temperatures for each jar were measured before and after each jar test. The water temperatures prior to all jar tests were measured in a range of 5.3 – 7.9 °C, and the water temperature after jar tests remained in a similar range of 6.0 – 8.5 °C. The experimental design of all the jar tests is summarized in Table 5. Jar test settings including doses of coagulant and flocculation aid are provided in Tables 6 & 7. Coagulant and flocculation aid doses in this report are expressed as a dry dose. The equivalent wet doses are provided in Appendix A.

Table 5. Summary of Jar Tests

Jar Test #	Description	Purpose
1-A	ClearPAC 180 at 20 – 120 mg/L	Identify optimum dose of ClearPAC 180
1-B	ClearPAC 180 at optimized dose (40 mg/L) with the addition of various doses of Clearfloc CP1065 (0 – 2.5 mg/L)	Identify optimum dose of Clearfloc CP1065
2-A	PAX-XL19 at 10 – 80 mg/L	Identify optimum dose of PAX-XL19
2-B	PAX-XL19 at optimized dose (60 mg/L) with the addition of various doses of Clearfloc CP1065 (0 – 2.5 mg/L)	Identify optimum dose of Clearfloc CP1065
3-A	PAX-XL52 at 10 – 80 mg/L	Identify optimum dose of PAX-XL52
3-B	PAX-XL52 at optimized dose (60 mg/L) with the addition of various doses of Clearfloc CP1065 (0 – 2.5 mg/L)	Identify optimum dose of Clearfloc CP1065

Table 6. Settings for Jar Test 1-A, 2-A, and 3-A

	Conventional Jar Conditions					
Jar	1	2	3	4	5	6
Coagulant Dose (mg/L)	Jar Test 1-A: 20 – 120 mg/L of ClearPAC 180 Jar Test 2-A: 10 – 80 mg/L of PAX-XL19 Jar Test 3-A: 10 – 80 mg/L of PAX-XL52					
Flocculation Aid Dose (mg/L)	0 mg/L					
Step 1:	Rapid Mixing: 100 RPM for 1 minute					
Step 2:	Flocculation: 20 RPM for 30 minutes					
Step 3:	Settling: 0 RPM for 60 minutes					

Note:
1. Coagulant doses of each jar are provided in Appendix A.
2. PAX-XL19 and PAX-XL52 doses were adjusted to a lower range (10 – 80 mg/L) after the optimum dose was determined for ClearPAC 180. All selected coagulants were expected to have similar optimal operating ranges.

Table 7. Settings for Jar Test 1-B, 2-B, and 3-B

	Conventional Jar Test Conditions					
Jar	1	2	3	4	5	6
Coagulant Dose (mg/L)	Jar Test 1-B: ClearPAC 180 at 40 mg/L Jar Test 2-B: PAX-XL19 at 60 mg/L Jar Test 3-B: PAX-XL52 at 60 mg/L					
Flocculation Aid Dose (mg/L)	0.05	0.10	0.15	0.20	0.25	0.30
Step 1:	Rapid Mixing: 100 RPM for 1 minute					
Step 2:	Flocculation: 20 RPM for 30 minutes					
Step 3:	Settling: 0 RPM for 60 minutes					

Note: Flocculation aid doses of each jar are provided in Appendix A.

3.4 Water Quality Analysis

After each jar test was completed, samples were collected from each jar and analyzed at the Centre for the parameters listed in Table 8. For each jar test, one selected sample was sent to an accredited laboratory to measure filtered sulphate.

Table 8. Methods of Water Quality Analysis at the Centre

Parameter	Preparation	Method	Range
Unfiltered Turbidity	N/A	USEPA Method 180.1	0 – 1000 NTU
Filtered Turbidity	0.45 µm filtered	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 colour units
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 – 50 mg/L
Alkalinity	N/A	Hach Method 10244 Phenolphthalein and Total Alkalinity	10 - 4,000 mg/L as $CaCO_3$
Aluminum Residual	0.45 µm filtered	Hach Method 8326 Eriochrome Cyanine R Method	0.006 – 0.250 mg/L
Filtered Chloride	0.45 µm filtered	Hach Chloride Probe Method	0.1 – 35,500 mg/L
Filtered Iron	0.45 µm filtered	Hach Method 10249 FerroVer® Method	0.02 – 3.0 mg/L
Filtered Manganese	0.45 µm filtered	Hach Method 8149 1-(2-Pyridylazo)-2-Naphthol PAN Method	0.006-0.700 mg/L

4. Jar Test Results

4.1 Determination of Optimum Doses for Coagulants (Jar Test 1-A, 2-A & 3-A)

4.1.1 Unfiltered & Filtered Turbidity

Jar Tests 1-A, 2-A and 3-A were conducted using coagulants, ClearPAC 180, PAX-XL19 and PAX-XL62, respectively. The unfiltered and filtered turbidity results for those three jar tests are shown in Figure 1. In terms of unfiltered turbidity, ClearPAC 180 at 40 mg/L had the lowest reading, while 30 mg/L was identified as the point of diminishing return for both PAX-XL19 and PAX-XL52. For filtered turbidity, consistent low readings were measured for all tested ClearPAC 180 doses (20 – 120 mg/L). Similar to unfiltered turbidity, 30 mg/L was observed as the point of diminishing return for both PAX-XL19 and PAX-XL52.

Overall, given the low raw water turbidity (unfiltered turbidity of 1.02 – 1.85 NTU and filtered turbidity of 0.10 – 0.21 NTU), it was difficult to achieve high turbidity removal. PAX-XL19 and PAX-XL52 had similar turbidity removal at a dose of 30 – 60 mg/L. ClearPAC 180 was not able to reduce unfiltered turbidity, but had similar performance as the other coagulants at doses of 30 – 60 mg/L.

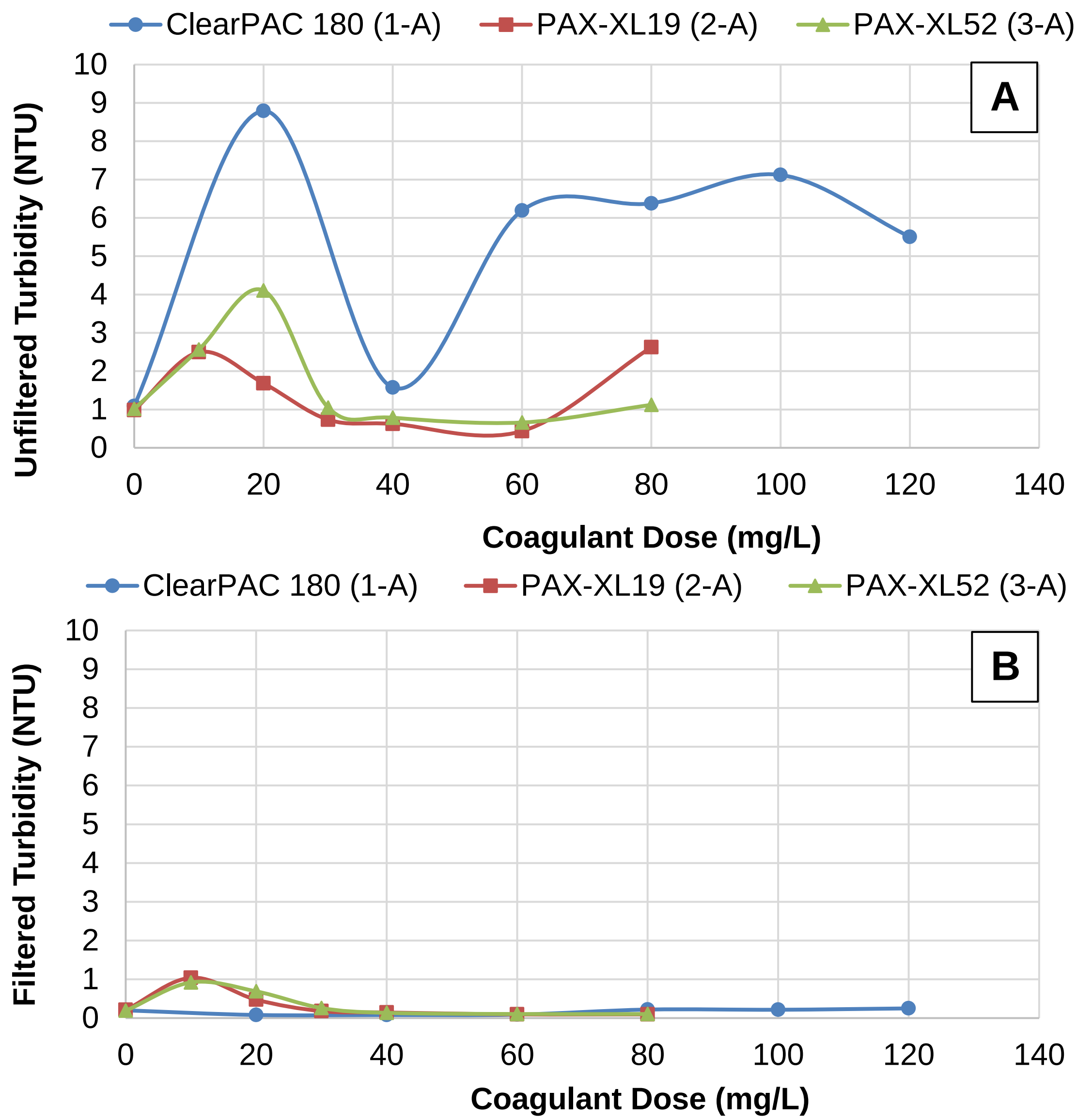


Figure 1. Unfiltered turbidity (A) and filtered turbidity (B) results of ClearPAC 180 (Jar Test 1-A), PAX-XL19 (2-A), and PAX-XL52 (3-A)

To prepare samples for filtered turbidity analysis, water collected from each jar was filtered through a 0.45 µm membrane filter using a bench-scale vacuum pump. Significantly different filtration rates were observed during the filtration process. Observations on floc size during jar testing and filtration rate during vacuum filtration for Jar Tests 1-A, 2-A and 3-A were summarized in Table 9 & 10.

Table 9. Observation summary of Jar Test 1-A

Coagulant	Observations	Coagulant Dose (mg/L)					
		20	40	60	80	100	120
ClearPAC 180	**Floc Size**	Barely Visible	Small	Small	Barely Visible	Barely Visible	Barely Visible
	Filtration Rate	Slow	Very Fast	Medium	Very Slow	Very Slow	Very Slow

Table 10. Observation summary of Jar Test 2-A & 3-A

Coagulant	Observations	Coagulant Dose (mg/L)					
		10	20	30	40	60	80
PAX-XL19	**Floc Size**	Barely Visible	Small	Small	Medium	Medium	Barely Visible
	Filtration Rate	Very Fast	Very Fast	Very Fast	Very Fast	Very Fast	Slow
PAX-XL52	**Floc Size**	Barely Visible	Small	Small	Medium	Medium	Medium
	Filtration Rate	Very Fast	Very Fast	Very Fast	Very Fast	Very Fast	Very Fast

ClearPAC 180 at 40 mg/L had visible floc and the highest filtration rate compared to the other doses. Flocs for ClearPAC 180 started to disappear from 80 mg/L to 120 mg/L, which could be an indicator of overdosing. Aside from the 80 mg/L dose, PAX-XL19 had rapid filtration rates for all doses. PAX-XL19 could be overdosed at 80 mg/L as flocs disappeared at this dose and filtration rate became slower. All PAX-XL52 samples had rapid filtration rates and visible flocs, except for the lowest dose.

4.1.2 Organics Removal as Indicated by DOC & UVA

DOC and UVA are commonly used surrogates for organics in drinking water. DOC measures the dissolved portion of organics, which is harder to remove than the suspended portion. UVA measures an aromatic proportion of DOC, which is more readily removed by coagulants. Figure 2 shows the DOC and UVA results of Jar tests 1-A, 2-A and 3-A.

Overall, all tested coagulants had similar performance and effectively reduced organics as indicated by DOC and UVA. ClearPAC 180 at 60 mg/L had the highest DOC and UVA reduction (79% DOC reduction and 91% UVA reduction), while 40 mg/L also provided a similar and significant reduction of organics (70% DOC reduction and 84% UVA reduction). Both PAX-XL19 and PAX-XL52 had points of diminishing return at 60 mg/L for both DOC and UVA. At 60 mg/L, PAX-XL19 had 78% DOC reduction and 90% UVA reduction, while PAX-XL 52 had 78% DOC removal and 88% UVA removal.

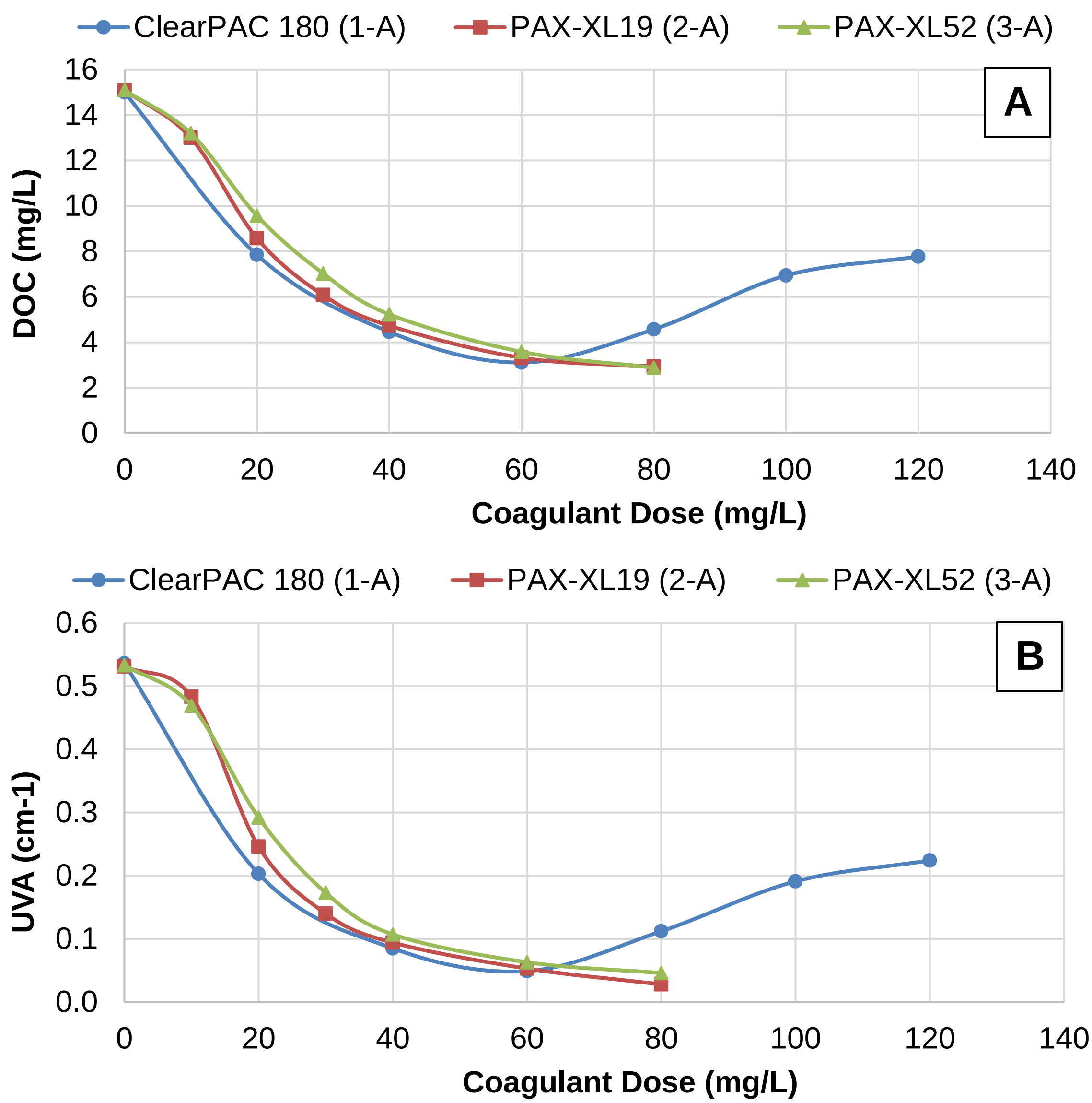


Figure 2. DOC (A) and UVA (B) results of ClearPAC 180 (Jar Test 1-A), PAX-XL19 (2-A), and PAX-XL52 (3-A)

4.1.3 Apparent & True Colour

Colour is the measurement of the yellow to brown hue of the sample water. Apparent colour is measured from the unfiltered samples; therefore, it represents the combination of dissolved and suspended portion of colour. True colour only represents the dissolved portion, so filtration is required as pretreatment. True colour could be related to dissolved organic matter. Figure 3 shows the apparent and true colour results of Jar tests 1-A, 2-A and 3-A.

In terms of apparent colour, ClearPAC 180 had the lowest reading at the 40 mg/L dose. The lowest apparent colour results for PAX-XL19 and PAX-XL 52 were observed at doses of 30 – 60 mg/L and 40 – 60 mg/L, respectively. At 30 – 60 mg/L, all tested coagulants had similar and low true colour results.

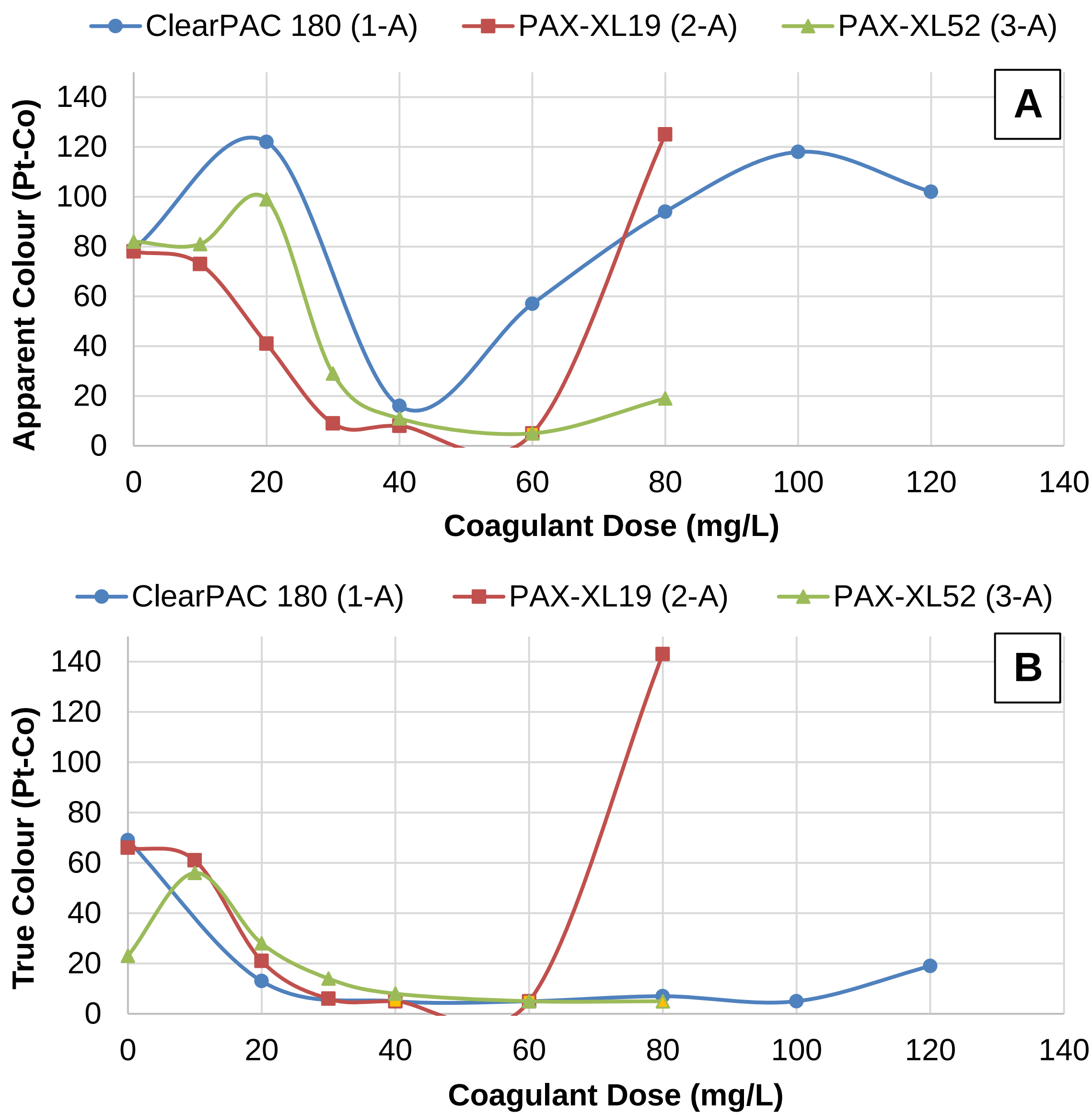


Figure 3. Apparent colour (A) and true colour (B) results of ClearPAC 180 (Jar Test 1-A), PAX-XL19 (2-A), and PAX-XL52 (3-A)
Note: Results lower than the method detection limits (5 platinum-cobalt unit [Pt-Co] for both apparent colour and true colour) were plotted as the detection limits and were marked in orange.

4.1.4 pH and Alkalinity

pH and alkalinity play important roles in floc formation. Each coagulant has its optimum pH range to effectively form flocs. Alkalinity is the water's buffering capacity that ensures the stability of pH during the coagulation-flocculation reaction. Alkalinity above 30 mg/L as $CaCO_3$ assists floc formation (MECP, 2006).

In general, coagulant reactions reduce water pH and alkalinity while forming flocs. Yet, to ensure effective and efficient treatment, the operational guideline (OG) in Ontario requires that pH and alkalinity be maintained in the ranges of 6.5 – 8.5 and 30 – 500 mg/L as $CaCO_3$, respectively (MECP, 2006). The raw water had relatively low alkalinity (56 – 64 mg/L as $CaCO_3$); therefore, adding coagulant may reduce alkalinity to a level that is below the OG range.

ClearPAC 180 addition dropped water pH below 6.5 at dosages of 40 mg/L and greater. Meanwhile, the other two coagulants kept the water pH within the OG range for all tested doses (10 – 80 mg/L). Furthermore, ClearPAC 180 reduced alkalinity below 30 mg/L as $CaCO_3$ at doses of 60 – 120 mg/L, while the other two coagulants kept alkalinity within the OG range for doses of 10 – 80 mg/L.

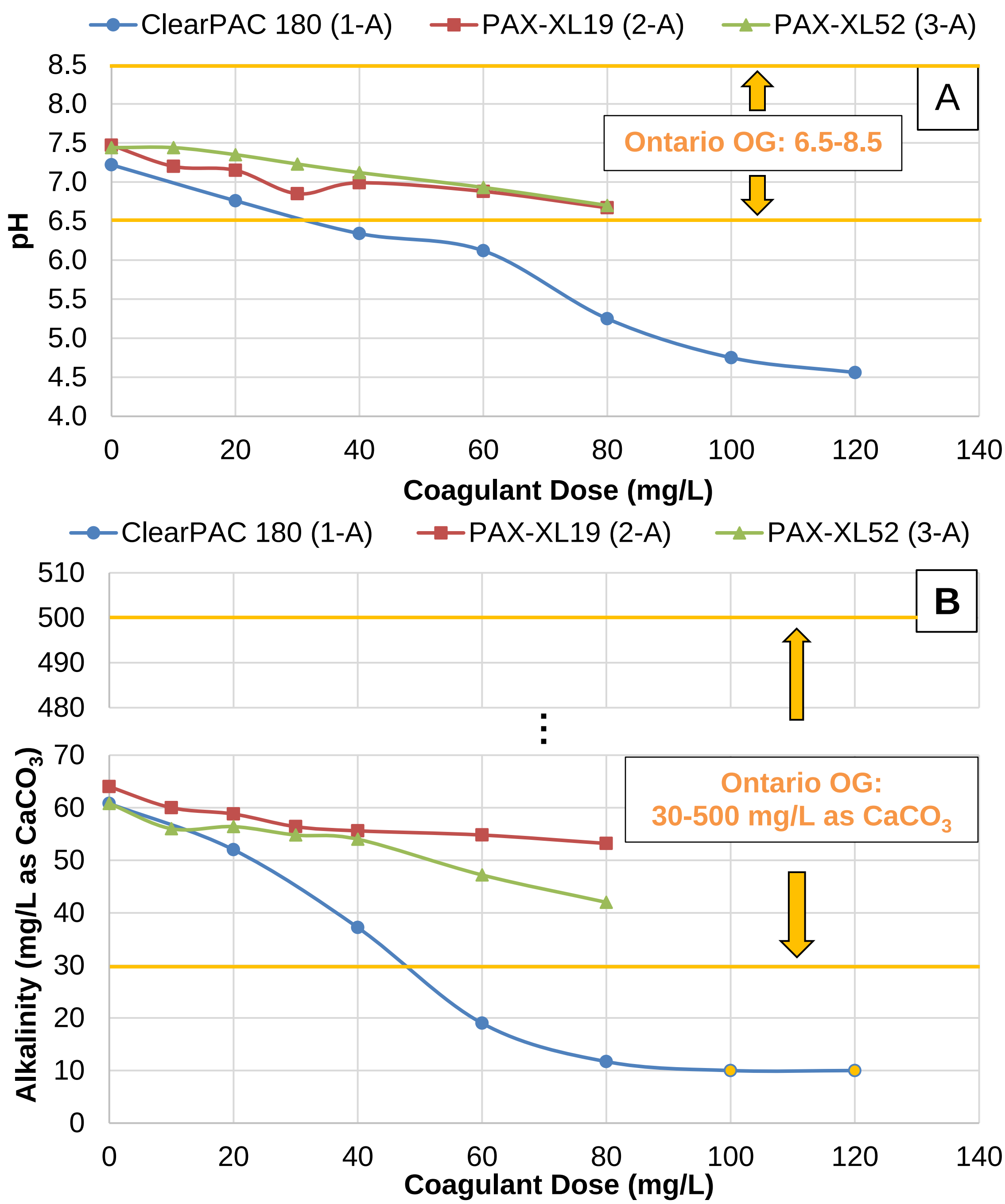
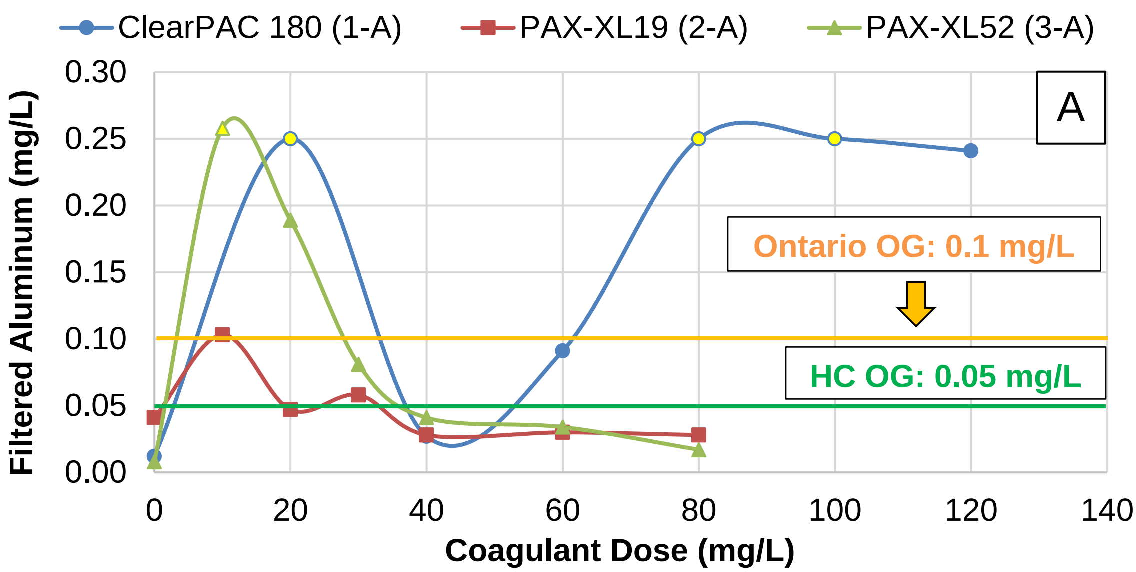


Figure 4. pH (A) and alkalinity (B) results of ClearPAC 180 (Jar Test 1-A), PAX-XL19 (2-A), and PAX-XL52 (3-A) with Ontario OG
Note: Results lower than the method detection limit (10 mg/L as $CaCO_3$ for alkalinity) were plotted as the detection limits and were marked in orange.

4.1.5 Filtered Aluminum, Manganese & Iron

The filtered aluminum and filtered manganese results are plotted in Figure 5.



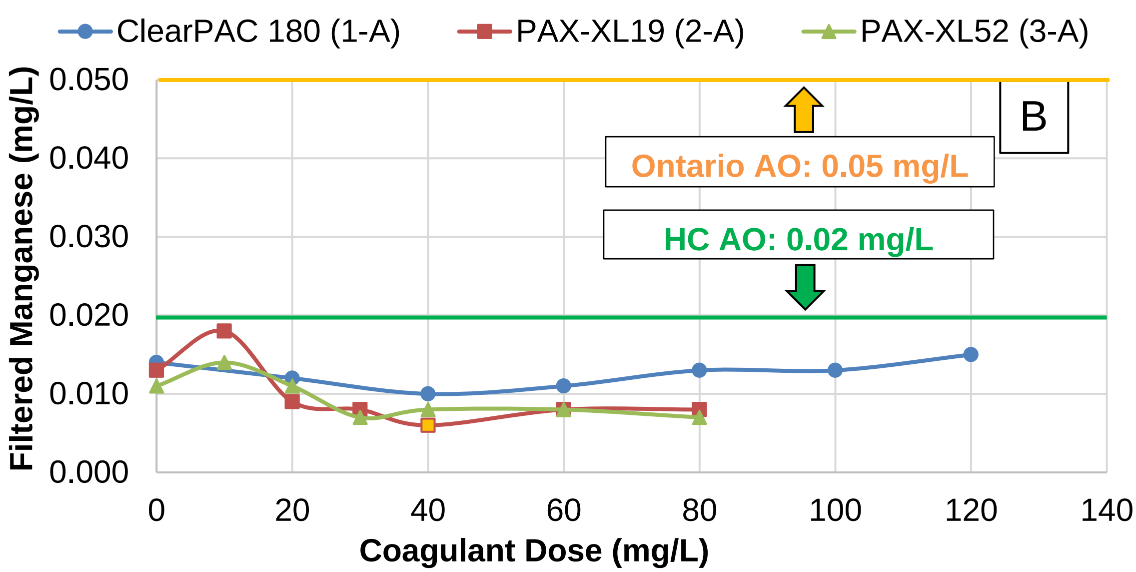


Figure 5. Filtered aluminum (A) and filtered manganese (B) results of ClearPAC 180 (Jar Test 1-A), PAX-XL19 (2-A), and PAX-XL52 (3-A) with Health Canada (HC) and Ontario OG and AO

Note:

1. Results lower than the method detection limit (0.006 mg/L for manganese) were plotted as the detection limits and were marked in orange;
2. Results beyond measurement range (0.250 mg/L for aluminum) were plotted as the upper boundary of the measurement range and were marked in yellow.

All the tested coagulants are aluminum based. Therefore, dosing those coagulants could result in elevated levels of aluminum residual in the treated water. Ontario's

The OG for aluminum residual in Ontario is currently 0.1 mg/L (MECP, 2006), while Health Canada recently proposed an OG for aluminum of 0.05 mg/L and a health-based maximum acceptable concentration (MAC) of 2.9 mg/L (Health Canada, 2019a). Based on Health Canada's proposed OG, ClearPAC 180 had an optimum dose of 40 mg/L. PAX-XL19 and PAX-XL52 had the same optimum dose ranges of 40 – 80 mg/L.

Ontario's aesthetic objective (AO) for manganese is 0.05 mg/L (MECP, 2006). In 2019, Health Canada published a new AO for manganese of 0.02 mg/L with a health-based MAC of 0.12 mg/L (Health Canada, 2019b). Regardless of coagulant doses, all the manganese levels in the jar test study were below Health Canada's AO.

Health Canada and Ontario have the same AO for iron at 0.3 mg/L (Health Canada, 1978; MECP, 2006). In this study, filtered iron was measured during Jar Test 1-A and the raw water level was less than the instrument's method detection limit (0.02 mg/L). Therefore, filtered iron was not measured in the other jar tests as results would all fall below measuring range (<0.02 mg/L).

4.1.6 Filtered Chloride and Sulphate

Commercially available coagulant products could contain chloride and/or sulphate. Therefore, adding coagulant to water may increase the levels of chloride and/or sulphate in the finished water. In this study, all selected coagulants contain chloride in their major ingredients, and PAX-XL52 contains sulphate. Ontario and Health Canada have the same AOs for both chloride and sulphate of 250 mg/L and 500 mg/L, respectively (MECP, 2006; Health Canada, 1987; Health Canada, 1994). The filtered chloride and filtered sulphate results are shown in Figure 6.

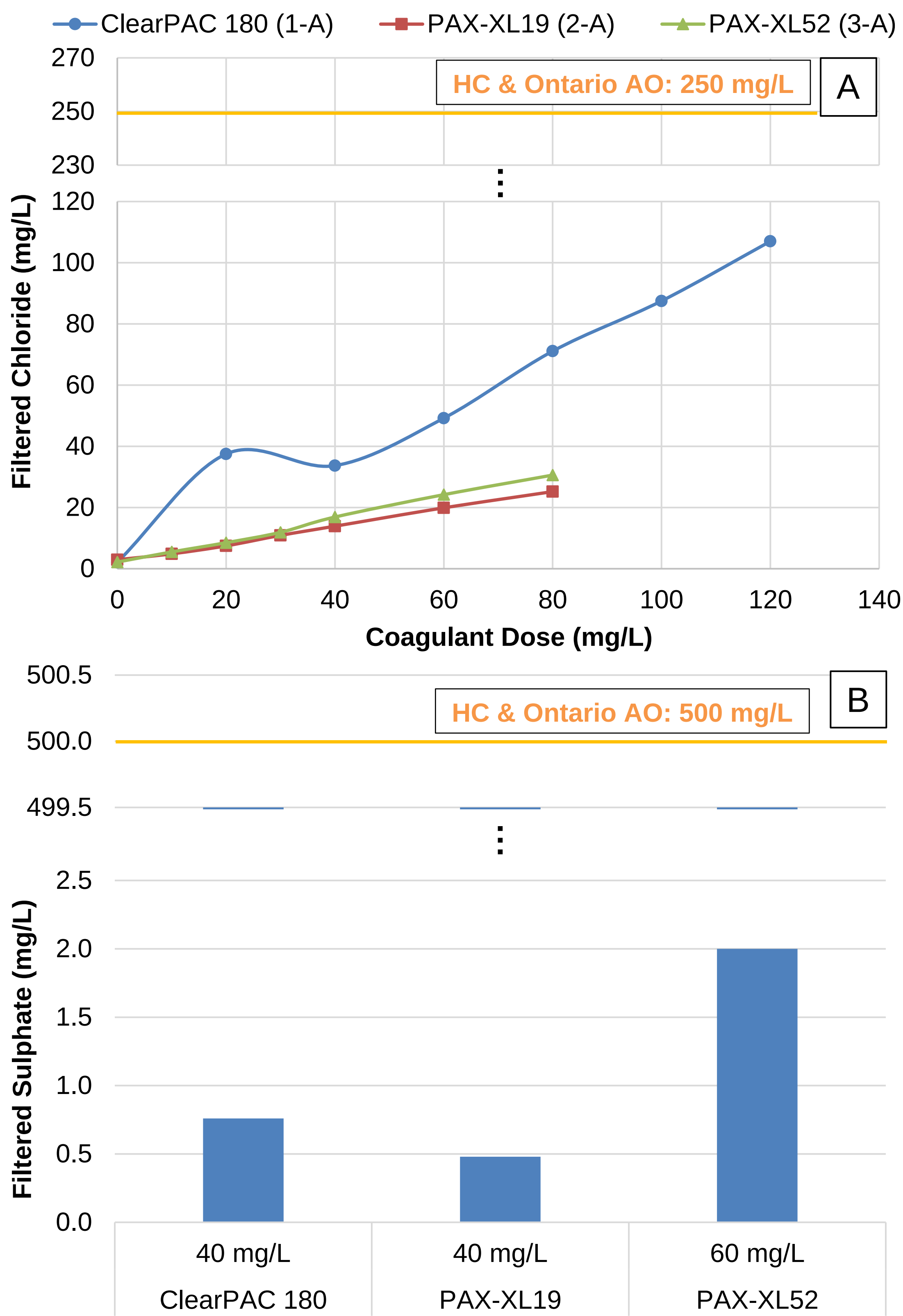


Figure 6. Filtered chloride (A) and filtered sulphate (B) results of ClearPAC 180 (Jar Test 1-A), PAX-XL19 (2-A), and PAX-XL52 (3-A) with HC and Ontario AO

As all selected coagulants are chloride based, the levels of filtered chloride increased with the increase of coagulant doses for each coagulant. However, ClearPAC 180 contributed to higher filtered chloride levels than the other two products. PAX-XL19 and PAX-XL52 had similar trends of filtered chloride. At a dose of 80 mg/L, ClearPAC 180 had over 2 times the filtered chloride than the other two products.

One filtered sulphate sample of each jar test was outsourced to the accredited lab for analysis. PAX-XL52 had a higher filtered sulphate level compared to the other coagulants, as it is a sulphate-containing product. However, all filtered sulphate results were much lower than the AO suggested by Health Canada and Ontario.

4.1.7 Chloride-to-Sulphate Mass Ratio (CSMR)

Changes in water treatment, such as changes from one coagulant to another, that have high chloride-to-sulphate mass ratios (CSMRs) in the finished water, could cause lead leaching problems (WRF, 2010). In general, a utility that has a CSMR greater than 0.5 and an alkalinity of less than 50 mg/L as $CaCO_3$ could potentially have serious lead problems following treatment changes that increase the CSMR (WRF, 2010). This needs to be considered prior to changing treatment chemicals if the distribution system and the service line connections downstream are made from lead-containing materials. Sampling should be conducted for lead in the distribution system and the service line connections downstream to indicate any potential issues.

Based on the sulphate results, a CSMR was calculated for one sample of each jar test. As indicated by Figure 7, the plant's existing coagulant (ClearPAC 180) had the highest CSMR at 45 with alkalinity of 37 mg/L as $CaCO_3$. Both PAX-XL19 and PAX-XL52 had much lower CSMRs compared to ClearPAC 180 (Figure 7). Particularly, PAX-XL52, the sulphate-containing coagulant, dropped the CSMR in the finished water. Therefore, based on the WRF report (2010), the CSMR calculated for PAX-XL19 or PAX-XL52 may indicate less potential for lead leaching.

CSMR in this study was calculated for filtered water from jar tests. As recommended by the aforementioned WRF report (2010), CSMR should be confirmed for the full-scale finished water.

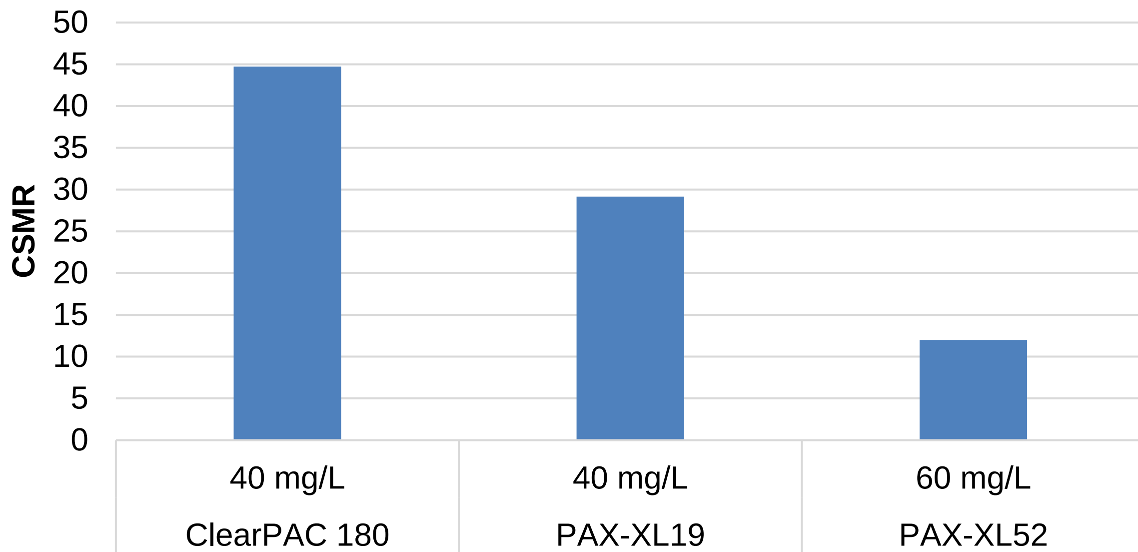


Figure 7. CSMR results for 40mg/L of ClearPAC 180 in Jar Test 1-A, 40 mg/L of PAX-XL19 in Jar Test 2-A and 60 mg/L of PAX-XL52 in Jar Test 3-A.

4.1.8 Summary: Optimum Doses

Overall, the optimum dose of ClearPAC 180 was determined as 40 mg/L, as it achieved the lowest unfiltered and filtered turbidity, apparent and true colour, aluminum residual, over 70% DOC removal and over 80% UVA reduction. It also had much higher filtration rates compared to the other doses. Meanwhile, it kept acceptable levels of alkalinity, although pH was slightly lower than the recommended Ontario OG range.

PAX-XL19 and PAX-XL52 performed similarly in this study and 60 mg/L was selected as the optimum dose for both. At the selected optimum dose, PAX-XL19 and PAX-XL52 had the lowest unfiltered and filtered turbidity, apparent and true colour, aluminum residual, and had high levels of organic removal (over 75% DOC removal and over 85% UVA reduction). Both coagulants had minimal impact on water pH (8% reduction for PAX-XL19 and 7% reduction for PAX-XL52). As expected, PAX-XL52 had more impact on alkalinity (23% reduction) than PAX-XL19 (14% reduction), as PAX-XL19 had higher basicity (82-83.7 wt.% of basicity for PAX-XL19, 70-77 wt.% of basicity for PAX-XL52).

4.2 Effect of Flocculation Aid (Jar Test 1-B, 2-B & 3-B)

4.2.1 Floc Size

Overall, the flocculation aid used in this study, Clearfloc CP1065, significantly increased the floc size for all selected coagulants (Table 11). However, it performed better with ClearPAC 180, compared to its performances with the other two coagulants.

Table 11. Photos of flocs for Jar Test 1-B with the dose of ClearPAC 180 of 40 mg/L and the doses of flocculation aid (Clearfloc CP1065) of 0 – 2.5 mg/L.

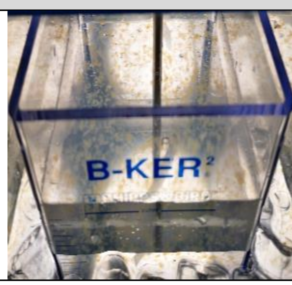
Flocculation Aid Dose	**0.0 mg/L**	**0.2 mg/L**	**0.5 mg/L**
Floc Photo			
Flocculation Aid Dose	**1.0 mg/L**	**1.5 mg/L**	**2.5 mg/L**
Floc Photo			

Table 12 summarizes the observations of floc sizes and filtration rates for Jar Tests 1-B, 2-B and 3-B. As suggested by the manufacturer (ClearTech Inc.) of the flocculation aid, the optimum operating range of Clearfloc CP1065 is around 1 – 3 mg/L. But, overdosing Clearfloc CP1065 may also clog the filters. As is shown in Table 12, Clearfloc CP1065 significantly increased floc size for ClearPAC 180, but filtration rates started to drop when the dose of Clearfloc CP1065 was beyond 1 mg/L.

Table 12. Observation summary of Jar Test 1-B, 2-B & 3-B

Coagulant	Observations	Flocculation Aid Dose (mg/L)					
		0	0.2	0.5	1.0	1.5	2.5
ClearPAC 180	**Floc Size**	Small	Medium	Large	Large	Very Large	Very Large
	Filtration Rate	Very Fast	Very Fast	Very Fast	Fast	Slow	Very Slow
PAX-XL19	**Floc Size**	Small	Small	Medium	Medium	Large	Large
	Filtration Rate	Very Fast	Very Fast	Very Fast	Very Fast	Very Fast	Very Fast
PAX-XL52	**Floc Size**	Small	Small	Medium	Medium	Large	Large
	Filtration Rate	Very Fast	Very Fast	Very Fast	Very Fast	Very Fast	Very Fast

Floc sizes and hydraulics in a clarifier tank could significantly affect the settling rates of flocs. Bigger and heavier flocs tend to have faster settling rates. However, the jar test is not designed to mimic the hydraulics in full-scale clarifier; therefore, it is not able to provide a reliable selection of floc size for full-scale applications.

4.2.2 Unfiltered & Filtered Turbidity

Unfiltered and filtered turbidity were tested for all samples in Jar Tests 1-B, 2-B and 3-B (Figure 8). Adding flocculation aid increased the unfiltered and filtered turbidity for ClearPAC 180 but had limited impact on the turbidity for samples dosed with PAX-XL19 and PAX-XL52.

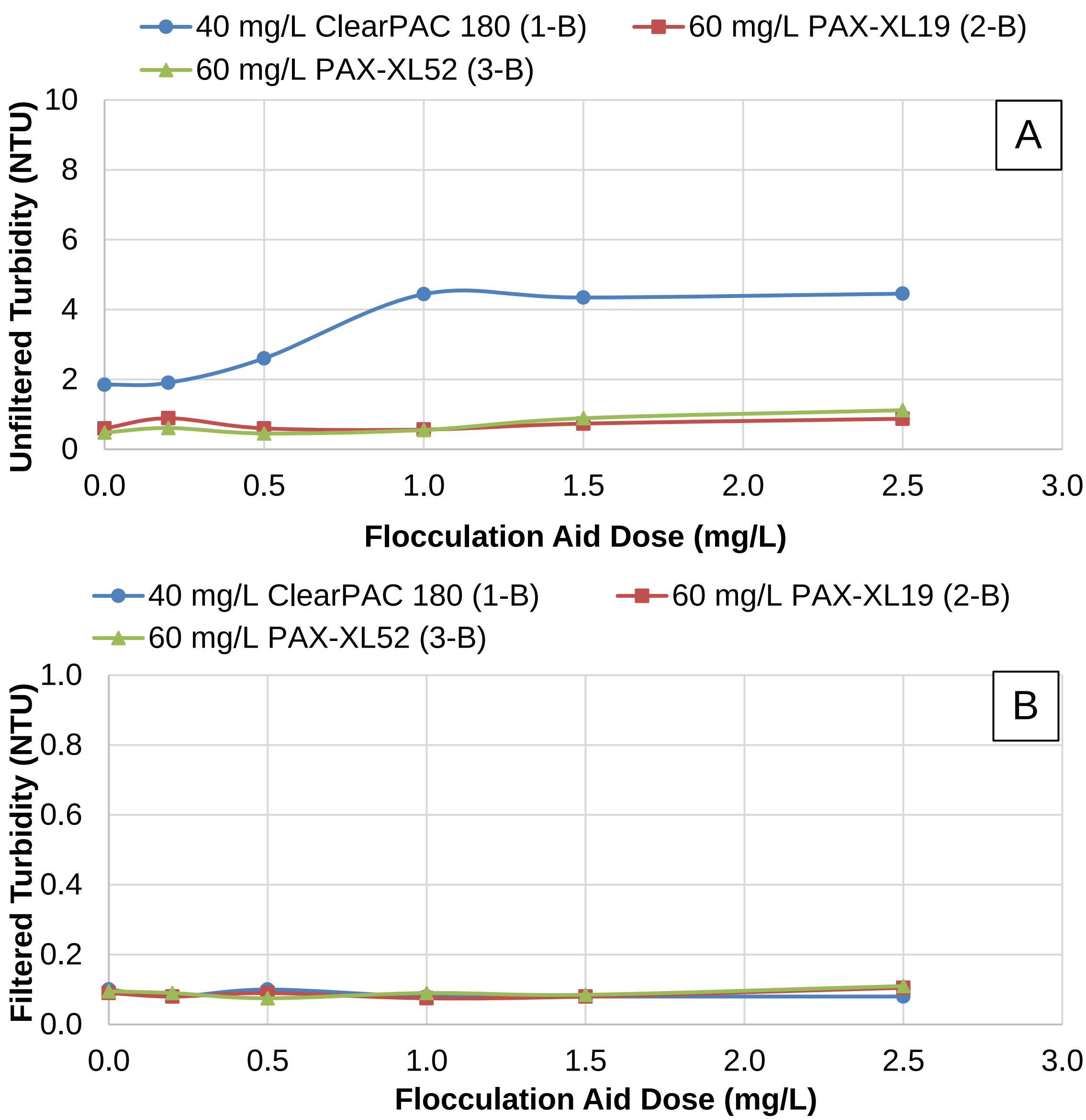


Figure 8. Unfiltered turbidity (A) and filtered turbidity (B) results of ClearPAC 180 (Jar Test 1-B), PAX-XL19 (2-B), and PAX-XL52 (3-B) with flocculation aid

4.2.3 Organics Removal as Indicated by DOC & UVA

As shown in Figure 9, flocculation aid had limited impact on DOC and UVA results of all tested coagulants.

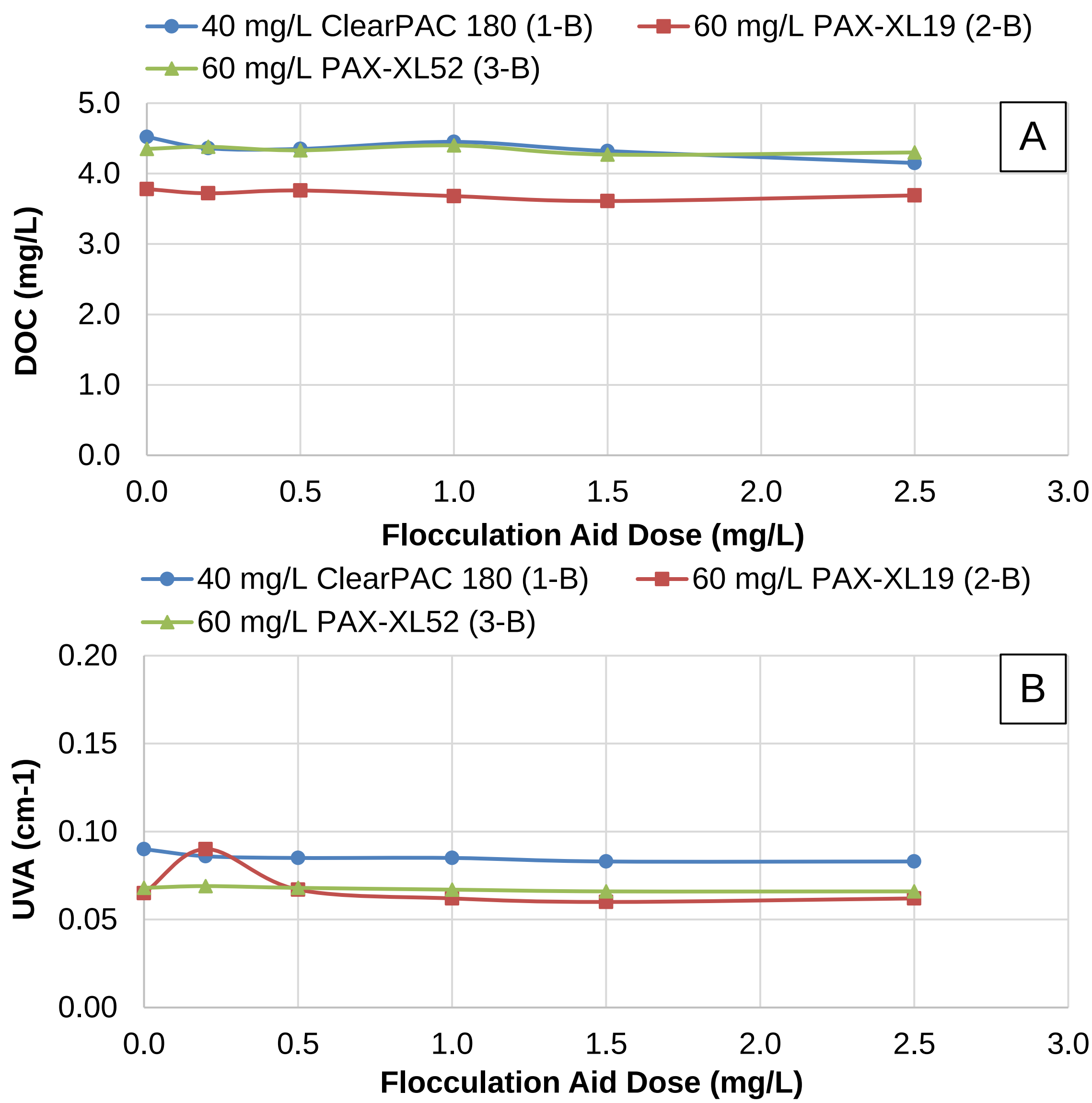


Figure 9. DOC (A) and UVA (B) results of ClearPAC 180 (Jar Test 1-B), PAX-XL19 (2-B), and PAX-XL52 (3-B) with flocculation aid

4.2.4 Apparent & True Colour

Apparent and true colour results for Jar Tests 1-B, 2-B and 3-B are demonstrated in Figure 10. Apparent colour of ClearPAC 180 dosed samples increased with increasing doses of flocculation aid. The apparent colour for the other two coagulants remained stable until flocculation aid was dosed at 1.0 mg/L and above. At a dose of 2.5 mg/L, the apparent colour results for each coagulant almost doubled compared to the blank with no addition of flocculation aid. However, adding flocculation aid did not have much impact on the true colour.

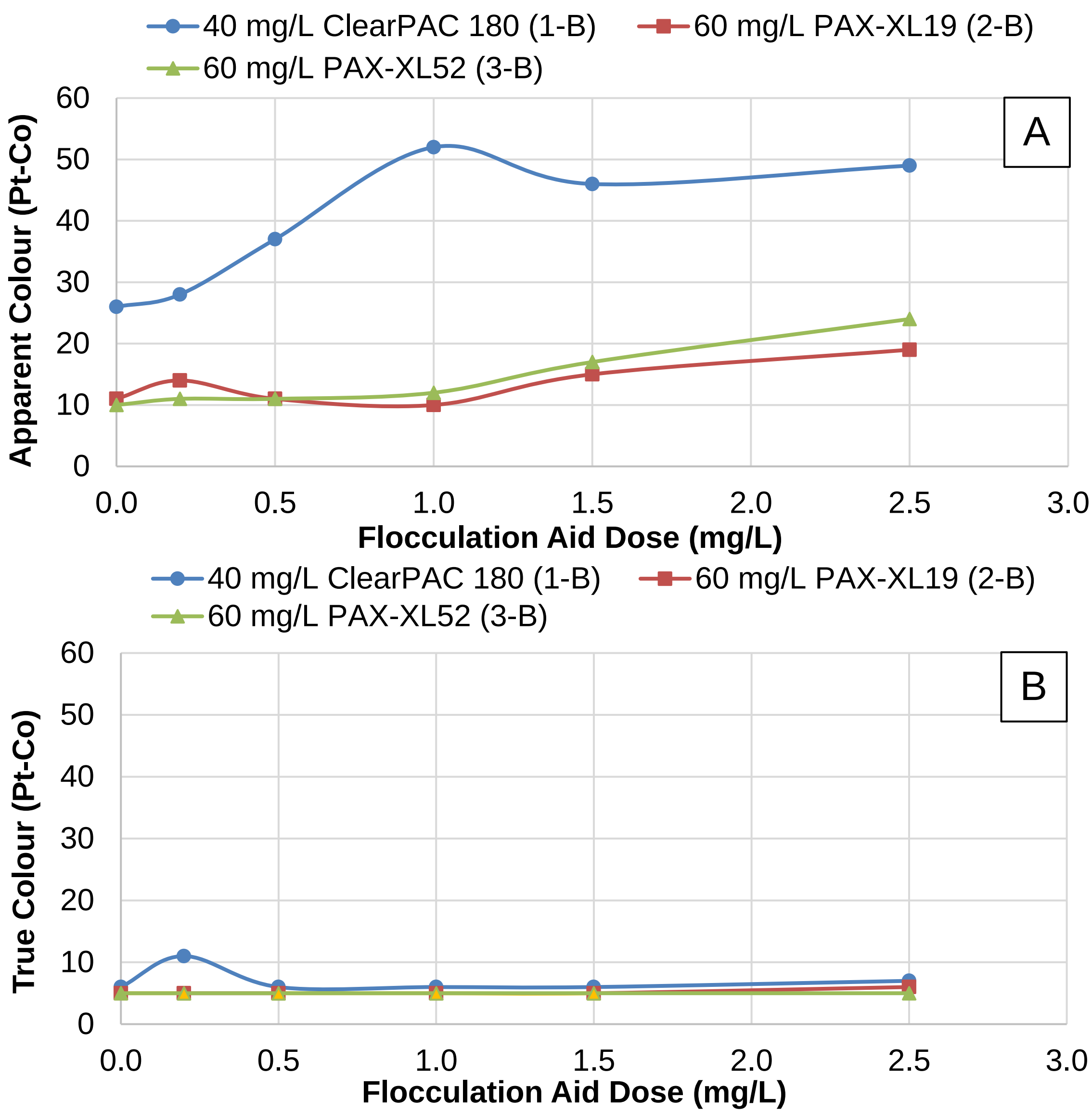


Figure 10. Apparent colour (A) and true colour (B) results of ClearPAC 180 (Jar Test 1-B), PAX-XL19 (2-B), and PAX-XL52 (3-B) with flocculation aid
Note: Results lower than the method detection limits (5 Pt-Co for both apparent colour and true colour) were plotted as the detection limits and were marked in orange.

4.2.5 pH and Alkalinity

Based on Figure 11, the addition of flocculation aid slightly increased the pH for each coagulant (1 – 5%). But, since pH is highly temperature dependent, the increase of pH could be related to the slight temperature differential among the jars due to the uneven distribution of ice in the water bath. Flocculation aid slightly decreased alkalinity for ClearPAC 180 (16%), but had limited impact on the water's alkalinity when using PAX-XL19 and PAX-XL52.

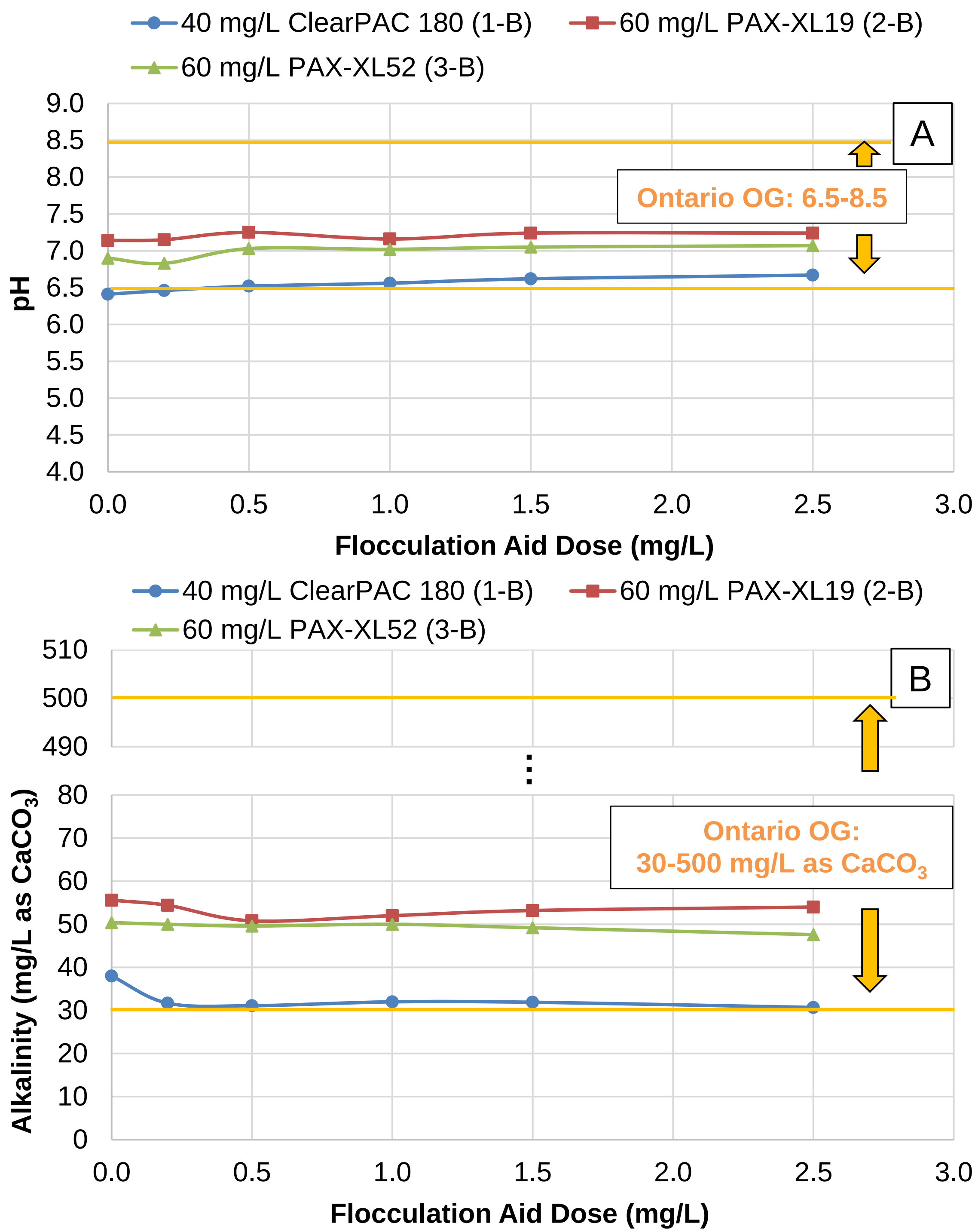


Figure 11. pH (A) and alkalinity (B) results of ClearPAC 180 (Jar Test 1-B), PAX-XL19 (2-B), and PAX-XL52 (3-B) with flocculation aid with Ontario OG

4.2.6 Filtered Aluminum & Manganese

As shown in Figure 12, adding flocculation aid had limited impact on filtered aluminum and manganese levels for all tested coagulants.

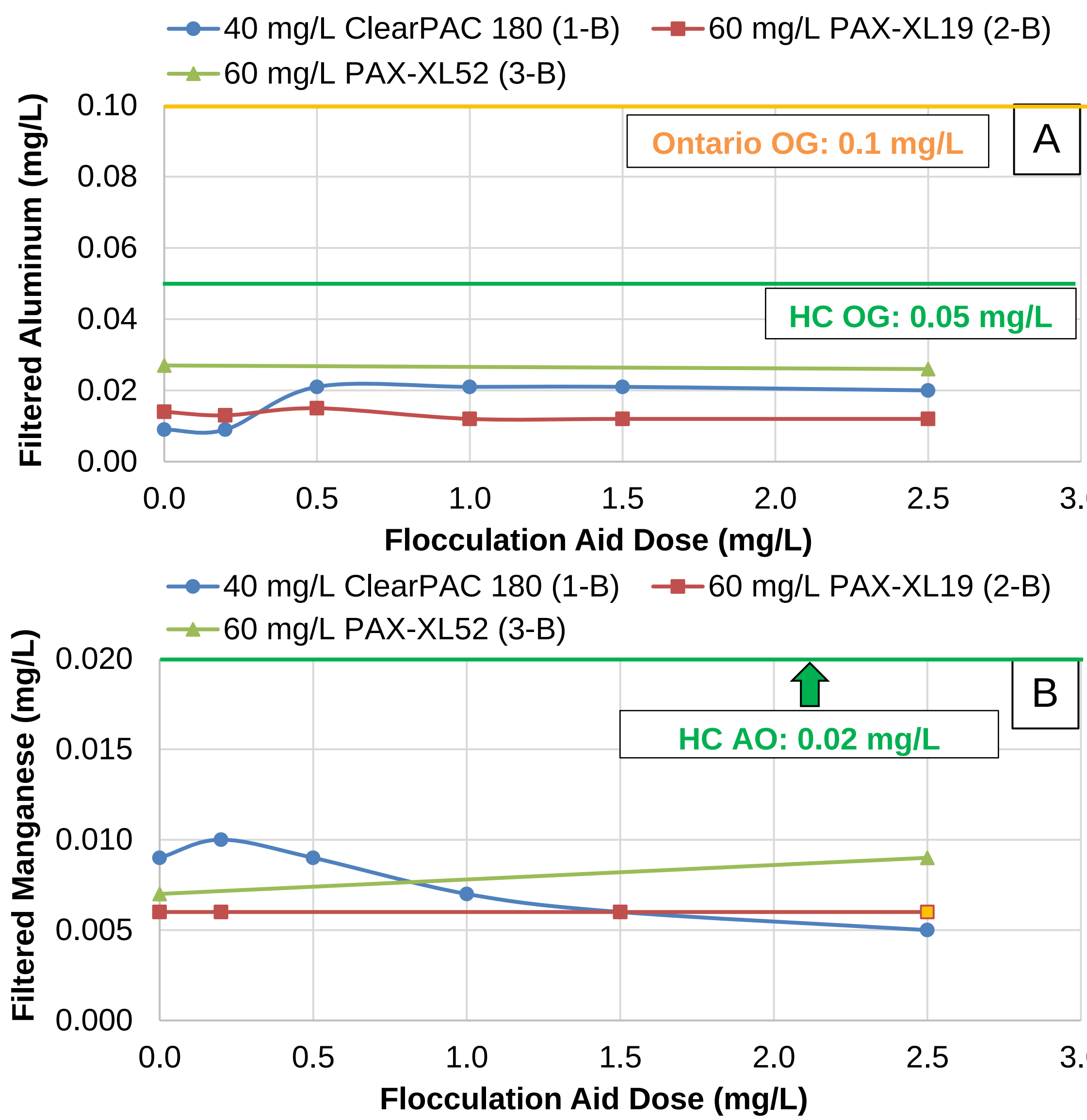


Figure 12. Filtered aluminum (A) and filtered manganese (B) results of ClearPAC 180 (Jar Test 1-B), PAX-XL19 (2-B), and PAX-XL52 (3-B) with flocculation aid with HC and Ontario AO and OG

Note: Results lower than the method detection limit (0.006 mg/L for manganese) were plotted as the detection limits and were marked in orange.

4.2.7 Filtered Chloride and Sulphate

As indicated by Figure 13, the addition of flocculation aid had limited impact on the levels of filtered chloride. As expected, the sulphate-containing coagulant, PAX-XL52 had the highest level of filtered sulphate, while the other two coagulants had similar filtered sulphate levels.

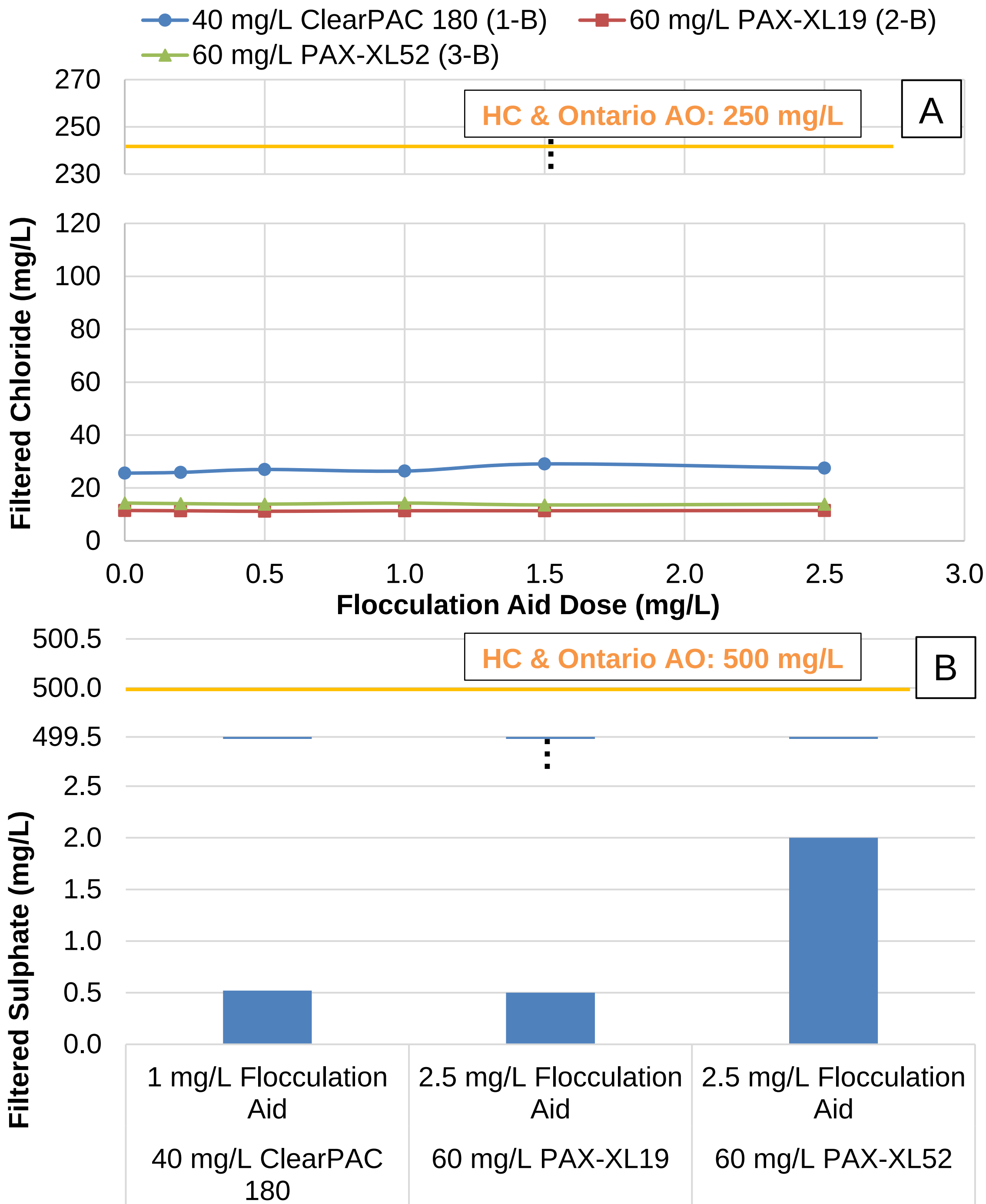


Figure 13. Filtered chloride (A) and filtered sulphate (B) results of ClearPAC 180 (Jar Test 1-B), PAX-XL19 (2-B), and PAX-XL52 (3-B) with flocculation aid with HC and Ontario AO

4.2.8 Chloride-to-Sulphate Mass Ratio (CSMR)

As shown in Figure 14, PAX-XL19 and PAX-XL52 had much lower CSMRs than ClearPAC 180. According to WRF report (2010), PAX-XL19 or PAX-XL52 combined with flocculation aid may have less potential for lead leaching. However, CSMR should be confirmed for full-scale finished water (WRF, 2010).

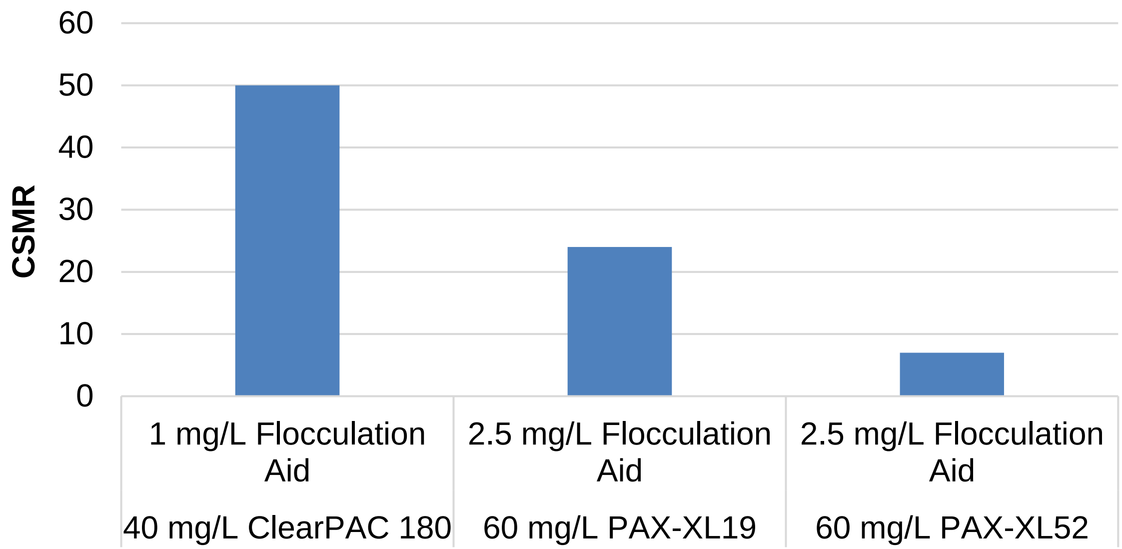


Figure 14. CSMR results for 1 mg/L of flocculation aid in Jar Test 1-A (ClearPAC 180), 2.5 mg/L of flocculation aid in Jar Test 2-A (PAX-XL19) and 2.5 mg/L of flocculation aid in Jar Test 3-A (PAX-XL52).

5. Additional Considerations

This study tested raw water once during one season. The quality of lake water usually changes seasonally; therefore, optimum doses of coagulant and flocculation aid may change seasonally as well. Conducting several rounds of jar tests throughout a year could provide better understanding of fluctuating raw water quality and optimum doses for different seasons.

This study used bench-scale membrane filtration with a pore size of 0.45 µm, which is of different pore size and filter depth than the plant's rapid sand filters. Thus, filtered parameters should be confirmed with full-scale testing.

This study used filtered chloride and sulphate results to calculate CSMR, whereas CSMR is designed for use on a full-scale plant's finished water. To confirm whether changing coagulants could cause issues, a CSMR should be recalculated using the data of the full-scale plant's finished water.

The jar tester used was not designed to mimic the hydraulics of a full-scale clarifier. Therefore, jar testing is not able to identify the optimum floc size based on settling performance.

6. Conclusions

The following conclusions are drawn from the jar test study:

- The optimum dose of ClearPAC 180 was determined as 40 mg/L, as it provided the lowest unfiltered turbidity, filtered turbidity, apparent colour, true colour, aluminum residual and provided over 80% reduction of UV absorbance. The jar with a dose of 40 mg/L of ClearPAC 180 was easier to filter compared to the other doses;
- Similarly, the optimum doses of PAX-XL19 and PAX-XL52 were both determined as 60 mg/L;
- At their optimum doses, all tested coagulants provided over 80% UVA reduction and over 70% DOC removal;
- Compared to ClearPAC 180, both PAX-XL19 and PAX-XL52 had similar but less impact on water pH and alkalinity;
- ClearPAC 180 had a narrower operating dose range than the other two products;
- The flocculation aid, Clearfloc CP1065, increased the size of flocs for all tested coagulants, but had limited impact on water quality;

- ClearPAC 180 had a higher CSMR than PAX-XL19, while PAX-XL52 had the lowest. Therefore, PAX-XL19 or PAX-XL52 may have less potential for lead leaching in the distribution system if lead materials are present.

7. References

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