



Pilot Testing Project Report

Conventional and Dissolved Air Flotation Jar Testing

Walkerton Clean Water Centre

February 15, 2019

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Executive Summary

Background

A First Nation community has a centralized drinking water system that services approximately 108 properties and a population of 330 people. The community has been on a long-term boil water advisory since 2013. The community retained a consulting engineer to complete a feasibility study to recommend treatment solutions. The Walkerton Clean Water Centre (Centre) tested two treatment solutions that were recommended by consultants; conventional treatment and dissolved air flotation (DAF). Jar testing was conducted using the community's source water and different coagulation chemicals in the Centre's laboratory.

Objective

The objective of this bench scale testing project was:

1. To compare the effect of conventional coagulation and DAF on the community's raw water quality, such as turbidity, colour, DOC, aluminum residuals, and alkalinity.
2. To compare the effect of conventional coagulation and DAF on the formation of DBPs, such as total trihalomethanes (TTHMs) and haloacetic acids (HAA₅).

Approach

This project included bench scale jar testing for a First Nation community. The project compared conventional and DAF jar testing using the community's raw water. Raw water was collected from the water treatment plant and shipped to the Centre.

The coagulants that were used in the bench scale jar testing were PAX-XL6 (aluminum chloride hydroxide sulphate), ALS (aluminum sulphate), PAS-8 (aluminum hydroxide sulphate), and ACH (aluminum chlorohydrate).

Key Findings

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

- The conventional jar tests achieved higher turbidity removal than DAF jar tests using PAX-XL6.
- To remove turbidity, the optimal coagulant dose for PAX-XL6 was 40 mg/L and 60 mg/L for conventional and DAF, respectively.
- The conventional and DAF jar tests had similar dissolved organic carbon (DOC), UV absorbance (UV_{254}) and true colour trends.
- To remove DOC with minimal TTHMs and HAA₅, the optimal coagulant dose for ALS and PAS-8 was 60 mg/L and 80 mg/L, respectively, for both conventional and DAF jar tests.
- All THMs and HAAs were above the running annual average maximum acceptable concentration (MAC). The chlorine dosage was high (7 mg/L), therefore a lower chlorine dosage could have reduced the TTHMs and HAA₅.

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1. Introduction

A First Nation community has a centralized drinking water system that services approximately 108 properties and a population of 330 people.

The community is currently on a Boil Water Advisory and has been since 2013. The community retained consultants to complete a feasibility study to assess the current water infrastructure and make recommendations on future water infrastructure. The current water treatment process includes two pressure filters without coagulation, followed by granular activated carbon (GAC) filters.

The community currently uses a small, remote lake as a surface water source in Northern Ontario. Raw water from this source is high in colour (25 – 77 TCU) and dissolved organic carbon (DOC) (9.53 – 14.2 mg/L). Due to the high levels of DOC, there is a potential to form disinfection by-products (DBPs) when chlorination is used for disinfection.

The community and the consulting engineer requested that the Walkerton Clean Water Centre (Centre) complete bench scale testing to compare the effect of conventional coagulation and dissolved air flotation (DAF) on the community's raw water quality and the DBPs formation.

The objectives of bench scale testing are:

1. To compare the effect of conventional coagulation and DAF on the community's raw water quality, such as turbidity, colour, DOC, aluminum residuals and alkalinity.
2. To compare the effect of conventional coagulation and DAF on the formation of DBPs, such as total trihalomethanes (TTHMs) and haloacetic acids (HAA₅).

2. Materials and Method

2.1 Raw Water Collection and Transportation

The raw water 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 seven days after they were collected. Raw water samples were analyzed when the sample

containers arrived at the Centre and stored in a refrigerator (4°C) until the experiments were conducted (Table 1). Prior to each jar test, raw water was removed from the refrigerator and allowed to warm up to 6 - 7°C before beginning the jar testing.

Table 1. Raw Water Quality

Parameter	Day of Arrival	Day of Experiments	
	Nov. 5, 2018	Nov. 9, 2018	Nov. 12, 2018
Turbidity (NTU)	3.19	1.43	1.14
Dissolved Organic Carbon (mg/L)	8.22	8.86	8.64
UV ₂₅₄ (cm ⁻¹)	N/A	0.426	0.423

2.2 Coagulant

Each jar test was completed using a different coagulant. The details of the coagulants are in Table 2.

Table 2. Coagulant Information

Coagulant	Major Ingredients	Details (Gebbie 2006 and product technical data sheets)
PAX-XL6	Aluminum chloride hydroxide sulphate	Reduced sludge production, less pH adjustment, improved cold water performance.
ALS	Aluminum sulphate	Alum is generally lower cost. Raw waters that are coloured, low turbidity, low pH/alkalinity may require lime, soda ash or caustic soda to improve coagulation.
PAS-8	Aluminum hydroxide sulphate	Reduced sludge production, less pH adjustment, improved cold water performance.
ACH	Aluminum chlorohydrate	Compared to alum, ACH generally requires 1/3 of the dose and lower sludge production, but is more costly. Reduced sludge production, less pH adjustment, improved cold water performance.

2.3 DAF Jar Test Conditions

A DAF jar tester was used and included three memories to mimic one coagulation and two flocculation stages (with different mixing rates and detention times). Afterwards, a flotation stage was conducted for each jar. The DAF jar tester consisted of four jars. Each jar test experiment used a different coagulant. See Table 3 below for the DAF jar test details.

Table 3. DAF Jar Test Conditions

	DAF Jar Conditions			
Jar	1	2	3	4
Coagulant Dose (mg/L)	20	40	60	80
Stage 1:	Rapid Mixing: 100 RPM for 1.5 minutes			
Stage 2:	Flocculation: 50 RPM for 4.5 minutes			
Stage 3:	Flocculation: 25 RPM for 6.5 minutes			
Application of Air	Saturation Pressure: 600 kPa			
	Recycle Rate: 8%			
Stage 4:	Floatation: 0 RPM for 12.5 minutes			

Note: The DAF jar test using ACH coagulant was dosed with 10, 20, 40, 80 mg/L, because this coagulant is a concentrated product, and it was anticipated that lower dosages would be sufficient, compared to other coagulants.

2.4 Conventional Jar Test Conditions

The conventional jar tester was used and included four memories to mimic one coagulation, two flocculation (with different mixing rates and detention times), and one settling stage. The conventional jar tester consisted of six jars. See Table 4 below for conventional jar test details.

Table 4. Conventional Jar Test Conditions

	Conventional Jar Conditions					
Jar	1	2	3	4	5	6
Coagulant Dose (mg/L)	20	40	50	60	70	80
Stage 1:	Rapid Mixing: 100 RPM for 1.5 minutes					
Stage 2:	Flocculation: 50 RPM for 4.5 minutes					
Stage 3:	Flocculation: 25 RPM for 25.5 minutes					
Stage 4:	Settling: 0 RPM for 30 minutes					

Note: The conventional jar test using ACH was dosed with 10, 20, 30, 40, 60, 80 mg/L, because it was anticipated that lower dosages would be sufficient, compared to other coagulants.

2.5 Water Quality Analysis

Samples were collected from each jar and analyzed at the Centre for turbidity, pH, true and apparent colour, UV₂₅₄ absorbance, DOC and alkalinity (Table 5). For each experiment, selected samples were sent to an accredited licensed laboratory to measure TTHMs, HAA₅ and dissolved aluminum (Table 5). The significance of in-house and out-sourced water quality parameters are summarized in Table 6.

Table 5. 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 (unfiltered)	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
Parameter	Preparation	Method	Detection Limit
Analyzed at a Licensed Laboratory			
Dissolved aluminum	0.45 µm filtered	Standard Method 3030/ EPA 200.8	Method Detection Limit: 0.3 µg/L
Total Trihalomethanes	7 mg/L chlorine dose for 3 and 5 day contact times	EPA 5030B/8260C	Method Detection Limit: 0.37 µg/L
Haloacetic acids	7 mg/L chlorine dose for 3 and 5 day contact times	EPA 552.3	Method Detection Limit: 5.3 µg/L

Table 6. Background Information on Water Quality Parameters (Health Canada, 2017; MECP, 2006a; MECP, 2006b)

Parameter	Ontario Standards and Guidelines	Health Canada Guideline (Health Canada, 2017)	Background Information and Significance
Turbidity	Conventional: ≤ 0.3 NTU in at least 95% of measurements per filter cycle or per month; never to exceed 1.0 NTU (MECP, 2006a)	Conventional: ≤ 0.3 NTU in at least 95% of measurements per filter cycle or per month; never to exceed 1.0 NTU	Turbidity can shield pathogens from disinfection. Turbidity indicates filtration efficiencies and pathogen removal credits.
pH	Operational Guideline: 6.5-8.5 (MECP, 2006b)	Operational Guideline: 7.0-10.5	pH range is established to prevent corrosion and scaling. pH can impact chlorine disinfection, alum coagulation and integrity of the distribution system.
True/ Apparent Colour	Aesthetic Objective: 5 true colour units (MECP, 2006b)	Aesthetic Objective: ≤ 15 true colour units	Colour can occur from natural organic matter and can contribute to disinfection by-products.
UV ₂₅₄ absorbance	N/A	N/A	UV ₂₅₄ indicates natural organic matter. Aromatic organics absorb UV light at 254 nm.
Dissolved Organic Carbon (DOC)	Aesthetic Objective: 5 mg/L (MECP, 2006b)	N/A	DOC is a precursor to disinfection by-products.
Alkalinity	Operational Guideline: 30-500 mg/L CaCO ₃ (MECP, 2006b)	N/A	Effective coagulation requires sufficient alkalinity (over 30 mg/L) and consumes alkalinity to form floc.
Dissolved Aluminum	Operational Guideline: < 0.1 mg/L (MECP, 2006b)	Operational Guideline: < 0.1 mg/L for conventional treatment of RAA of monthly samples	Aluminum-based coagulants contribute to aluminum levels in water. Aluminum can be used to assess optimal coagulant dosages.
Total Trihalomethanes (TTHMs)	ODWQS 0.1 mg/L as RAA of quarterly samples	0.1 mg/L as RAA of quarterly samples	Disinfection by-product from chlorination.
Haloacetic Acids (HAAs)	ODWQS 0.08 mg/L as RAA of quarterly samples (Effective January, 2020)	0.08 mg/L or as low as reasonably achievable as RAA of quarterly samples	Disinfection by-product from chlorination

Note: RAA = Running annual average, ODWQS = Ontario Drinking Water Quality Standard (O. Reg. 169/03)

2.6 Simulated Distribution System – Total Trihalomethanes and Haloacetic Acids

The TTHMs and HAA₅ were tested on select samples from experiments using the two coagulants that provided the highest DOC removal, ALS and PAS-8. Clarified water samples were collected from the jar tests and transferred into 250 mL chlorine demand free, amber glass containers. To achieve chlorine demand free containers, the glassware was treated with 10 mg/L of chlorine solution for a minimum of 3 hours, rinsed with deionized water and left to air dry.

Each sample was dosed with 7 mg/L of chlorine and bottles were stored at room temperature. After 3 days and 5 days of contact time, samples were transferred to sample vials with sodium thiosulphate and ammonium chloride preservatives for the TTHMs and HAA₅ tests, respectively. TTHMs results reflected the sum of bromodichloromethane, bromoform, chloroform and dibromochloromethane concentrations. The five HAA₅ that were analyzed include bromoacetic acid, chloroacetic acid, dichloroacetic acid, dibromoacetic acid and trichloroacetic acid.

3. Results and Discussions

3.1 Jar Test Comparison

3.1.1. Turbidity

Conventional and DAF jar tests were conducted using four different coagulants, PAX-XL6, ALS, PAS-8, and ACH. Overall, the conventional treatment process achieved higher turbidity removal than DAF, regardless of the type of coagulant (Figure 1). Among the four tested coagulants, PAX-XL6 provided the best reduction of turbidity with both conventional and DAF jar tests, whereas ALS and PAS-8 did not achieve effective turbidity control and caused an increase in turbidity at higher dosages, suggesting that the jars were being overdosed (Figure 1). At the dose of 60 mg/L, ACH with conventional treatment reduced turbidity by 42% (from 1.14 NTU to 0.66 NTU), but all remaining dosages of ACH did not achieve effective turbidity reduction, regardless of the method of jar test (Figure 1D). The

best turbidity removal results were obtained from PAX-XL6 with optimized dosage of 40 mg/L and 60 mg/L from conventional and DAF jar tests, respectively (Figure 1).

Overall, given the low raw water turbidity (1.14 – 1.43 NTU), it was difficult to achieve high turbidity removal. The addition of a flocculant aid (i.e. organic polymer) may improve the coagulation process and reduce turbidity further (Gebbie, 2006).

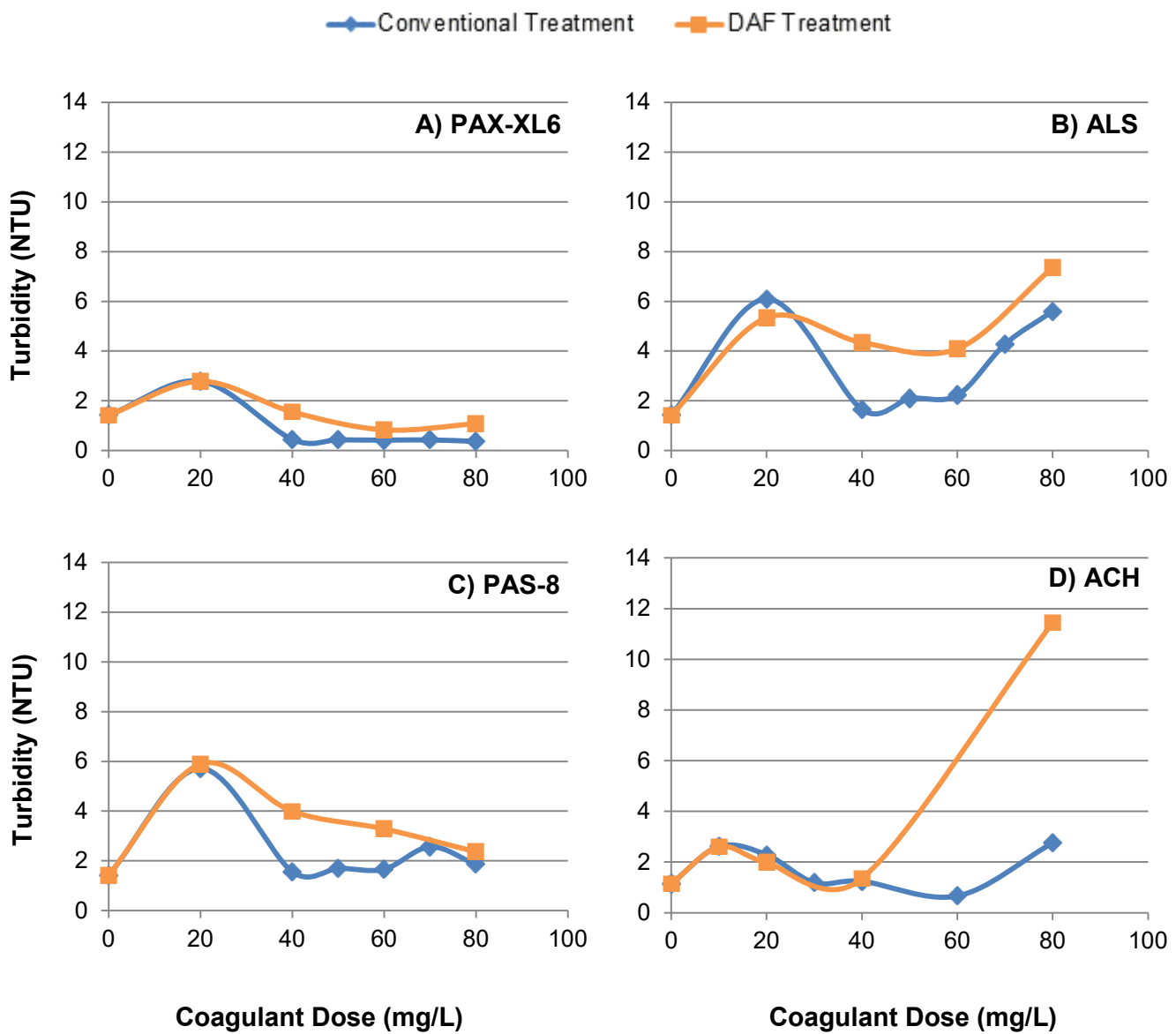


Figure 1. Turbidity (NTU) from conventional and DAF jar tests using (A) PAX-XL6, (B) ALS, (C) PAS-8 or (D) ACH

3.1.2. pH

Overall, the addition of ALS and PAS-8 reduced the water pH for both conventional and DAF jar tests (Figure 2). ALS with DAF jar tests provided the greatest reduction of pH, which may lead to corrosion issues (Figure 2). ACH and PAX-XL6 had a minimal decreasing effect on pH for conventional and DAF jar tests (Figure 2).

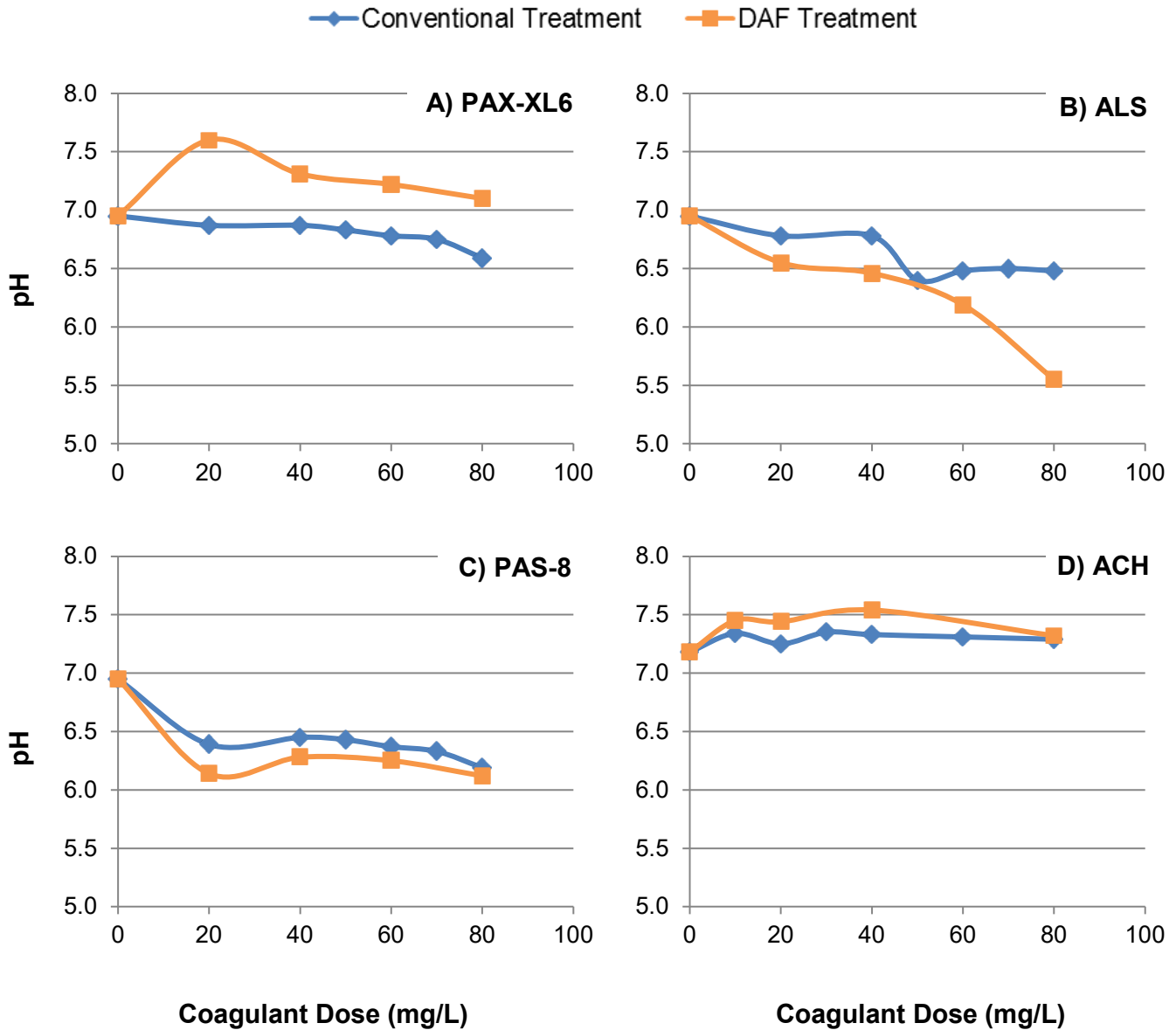


Figure 2. pH from conventional and DAF jar test using (A) PAX-XL6, (B) ALS, (C) PAS-8 or (D) ACH

3.1.3. Dissolved Organic Carbon and UV₂₅₄ Absorbance

Overall, each coagulant effectively reduced DOC, for example, each coagulant at a dosage of 60 mg/L removed 49 - 64% of DOC using either DAF or conventional treatment (Figure 3). Among all tested coagulants, ALS provided the highest DOC removal (Figure 3).

The DAF jar tests appeared to provide consistently higher removal of DOC than the conventional jar tests. However, the DAF jar tests introduced air-saturated deionized water for the flotation process with a recycle rate of 8%. The additional DOC reduction might be attributed to a dilution effect with air-saturated deionized water. By compensating for the 8% recycle rate, both conventional and DAF jar tests performed fairly similarly on the removal of DOC (Figure 3).

Aromatic organics absorb UV light at 254 nm wavelength in proportion to their concentration. Therefore, UV absorbance at 254 nm (UV₂₅₄) wavelength is a surrogate of natural organic matter (Edzwald and Tobiason, 1999; EPA, 1999). The effect of coagulation and clarification on UV₂₅₄ was similar to DOC reduction (Figure 4).

Specific ultraviolet absorbance (SUVA) can be calculated from the raw water's UV₂₅₄ and DOC and can act as a guideline to estimate the expected DOC removals using enhanced coagulation of alum (Edzwald and Tobiason, 1999; EPA, 1999).

$$SUVA = \frac{UV_{254} (cm^{-1})}{DOC (\frac{mg}{L})} \times \frac{100 cm}{1 m}$$

The SUVA value of the community's raw water is 4.81 - 4.90 L/mg•m. Raw water SUVA values above 4 indicate that the organics are not only highly hydrophobic with high molecular weights, but are also more easily removed by enhanced coagulation (Edzwald and Tobiason, 1999; EPA, 1999). Alum is expected to remove > 50% of DOC from the raw water (Edzwald and Tobiason, 1999; EPA, 1999).

Additionally, the relationship of DOC and alkalinity of the source water can also estimate DOC removal (EPA, 1999). Provided the raw water has DOC of 8.64 – 8.86 mg/L and

alkalinity of 62 - 66 mg/L of CaCO₃, the percentage of DOC removal is estimated to be between 40 - 50% with enhanced coagulation (EPA, 1999).

These predictive tools support the results in this study, because 49 - 64% of DOC removal was achieved from all coagulants at 60 mg/L.

Specifically, select clarified samples were collected for SDS testing for TTHMs and HAA₅, as indicated with red symbols (Figure 3). Specifically, TTHMs and HAA₅ were tested on samples dosed with PAS-8 (60 mg/L and 80 mg/L for both DAF and conventional) and ALS (40 mg/L and 60 mg/L for DAF and 50 mg/L and 60 mg/L for conventional) (Figure 3, 8, 9).

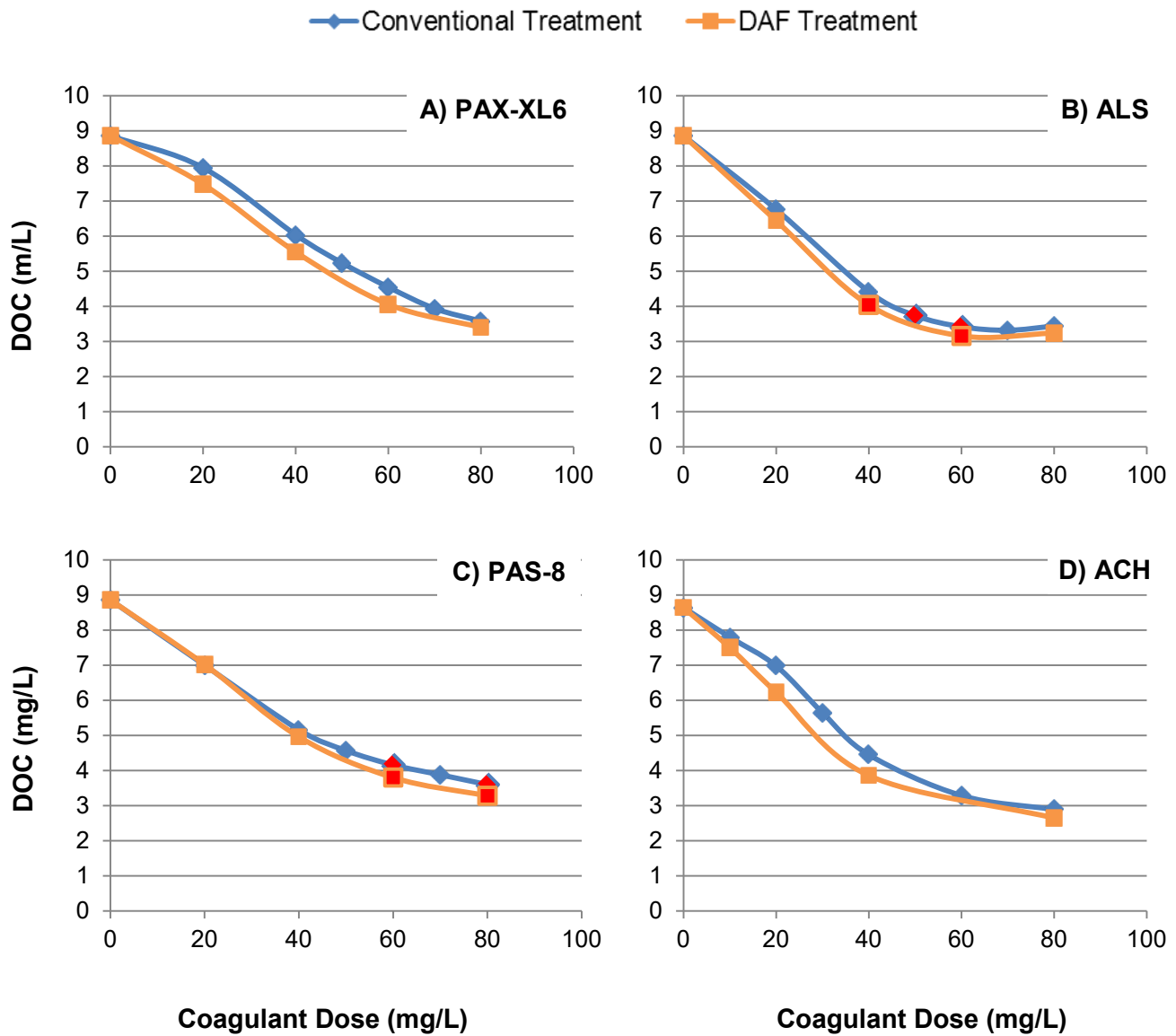


Figure 3. Dissolved organic carbon (DOC) from conventional and DAF jar test using (A) PAX-XL6, (B) ALS, (C) PAS-8 or (D) ACH. Note. Red symbols indicate which samples were collected for the simulated distribution system to measure TTHMs and HAA₅.

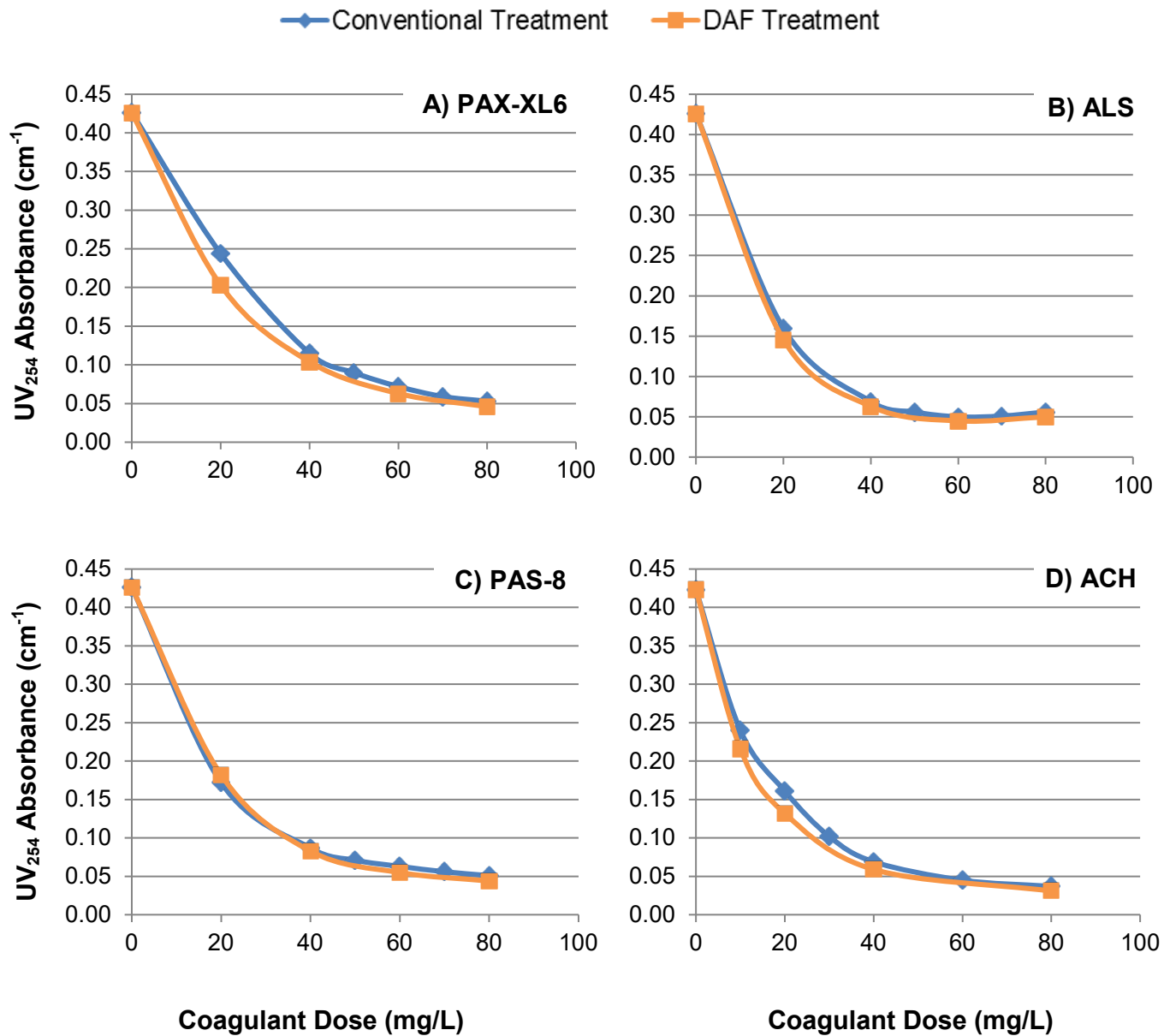


Figure 4. UV₂₅₄ absorbance (cm⁻¹) from conventional and DAF jar test using (A) PAX-XL6, (B) ALS, (C) PAS-8 or (D) ACH.

3.1.4. True Colour

True colour is the measure of yellow colouring from filtered water, which can be used as an indicator of dissolved organic matter. Coagulant dosages of 40 mg/L and greater removed approximately 90% of true colour, regardless of the type of coagulant and the type of jar test (Figure 5).

With the consideration of DOC, UV_{254} and true colour, the optimal coagulant dosage to control organics is 40 - 60 mg/L of ALS and 60 - 80 mg/L of PAX-XL6, PAS-8 or ACH, for both conventional and DAF.

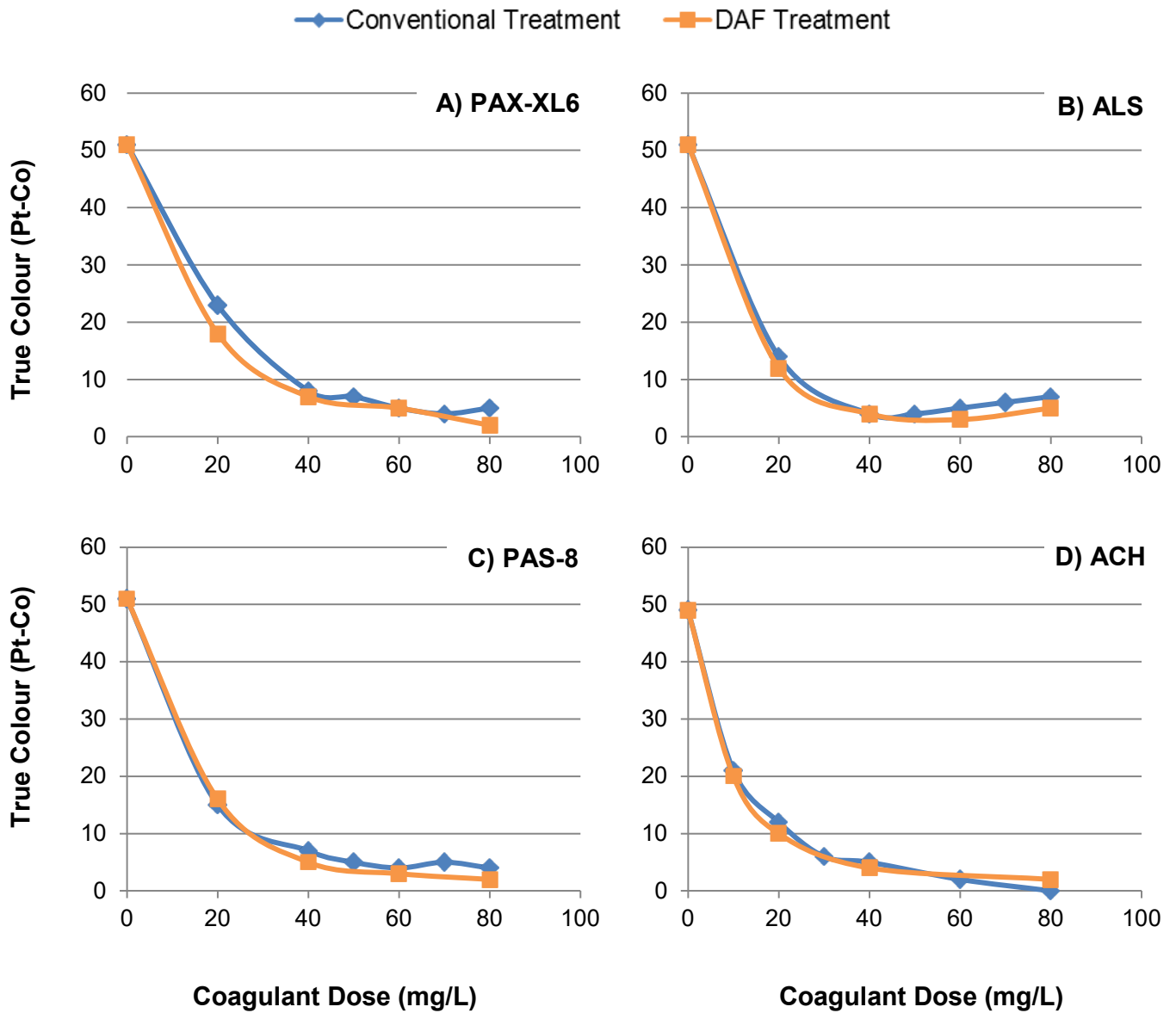


Figure 5. True colour (mg/L Pt-Co) from conventional and DAF jar test using (A) PAX-XL6, (B) ALS, (C) PAS-8 or (D) ACH.

3.1.5. Alkalinity

Alkalinity is necessary for proper coagulation because alkalinity assists the formation of floc (MECP, 2006b). This study showed that any addition of coagulant reduced alkalinity (Figure 6). When comparing the high dosages of coagulant, 80 mg/L of ALS consumed the most alkalinity (93% and 89% of alkalinity consumed for conventional and DAF jar tests, respectively). ACH consumed the least alkalinity (Figure 6). With the exception of 80 mg/L of ALS, all other dosages of each coagulant consumed more alkalinity in DAF jar tests, compared to conventional jar tests (Figure 6).

In general, organic removal by enhanced coagulation is more effective when raw water has low alkalinity and high total organic carbon (EPA, 1999). Therefore, the higher alkalinity and lower organics, the more difficult it is to remove organics by enhanced coagulation (EPA, 1999). Because the community's raw water has high organics (i.e. DOC, UV_{254} , true colour) and low alkalinity, the jar tests showed good DOC removal (Figure 3-6).

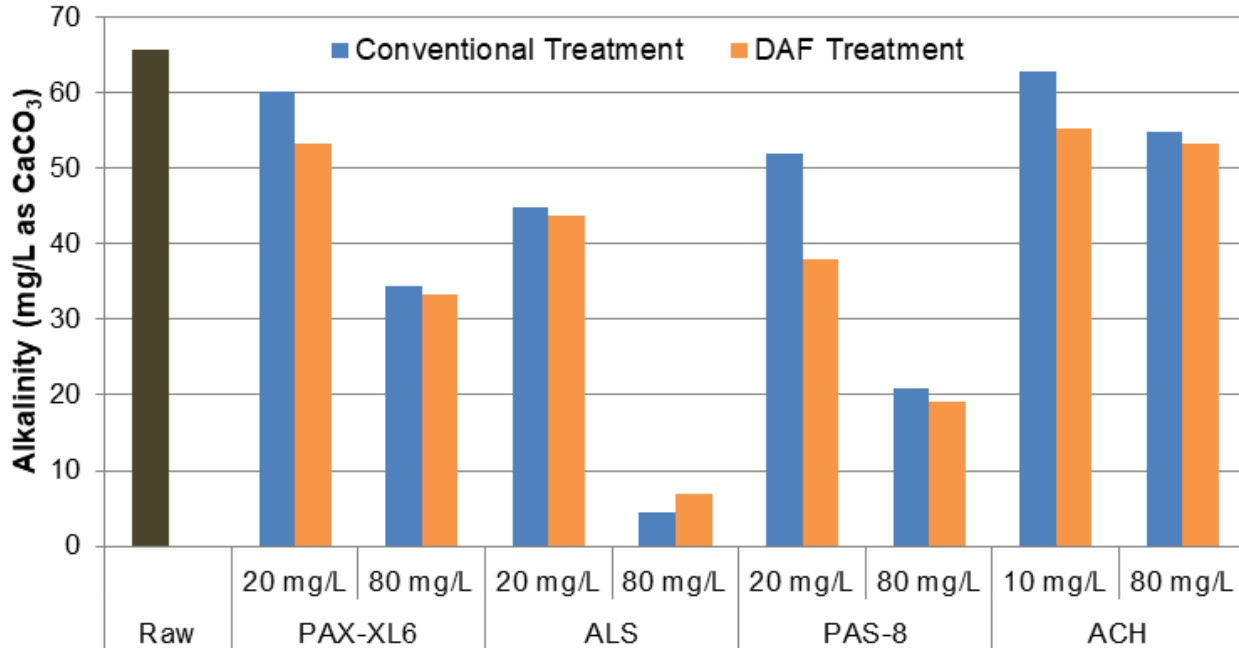


Figure 6. Alkalinity (mg/L CaCO₃) from conventional and DAF jar test from selected dosages of coagulants

3.1.6. Dissolved Aluminum

All coagulants in this project are aluminum-based; therefore, monitoring the aluminum residuals of the jar tests is an operational indicator of optimized coagulation. The aluminum residuals were tested from the filtered samples, which represents the finished water after filtration of a pilot or full-scale system. It is evident that 80 mg/L of ALS was an overdose of coagulation; however, all remaining coagulants were below the operational guideline of 0.1 mg/L (Figure 7). Conventional jar tests had consistently higher dissolved aluminum, compared to DAF jar tests, at the same coagulant dosages (Figure 7).

The optimal dosage for turbidity removal was determined at 40 mg/L PAX-XL6 and 60 mg/L PAX-XL6 from conventional and DAF processes, respectively. Whereas, the optimal dosage for organic removal was determined at 40 - 60 mg/L ALS and 60 - 80 mg/L PAX-XL6, PAS-8 and ACH, for both conventional and DAF processes. Aluminum residuals for these optimal dosages are below the operational guideline of 0.1 mg/L. Additional precaution may be needed for ALS when it is used at its optimized dosage of 60 mg/L, as the aluminum residuals are close to the operational guideline (Figure 7).

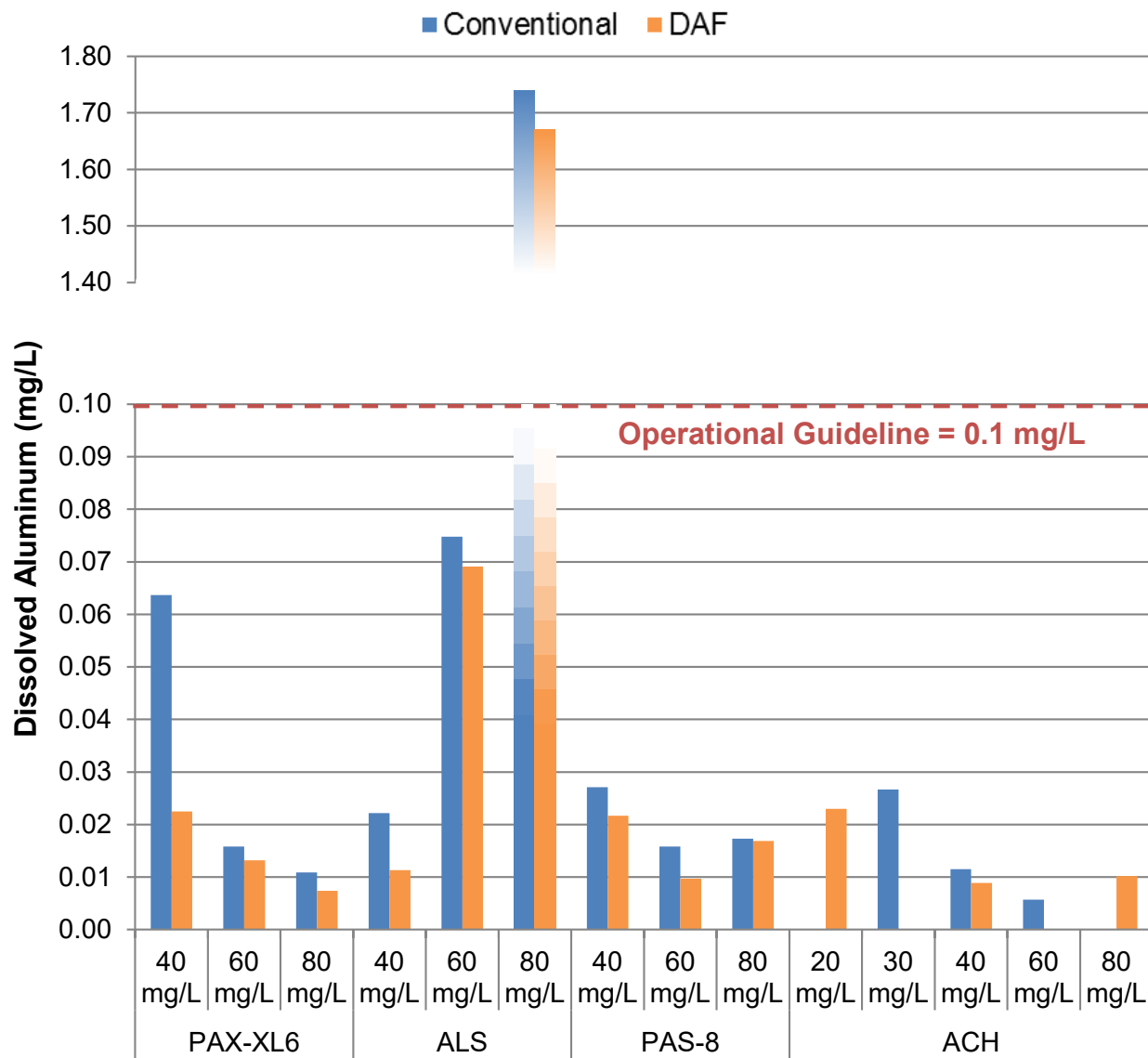


Figure 7. Dissolved aluminum (mg/L) from conventional and DAF jar test using PAX-XL6, ALS, PAS-8 or ACH.

3.2 Simulated Distribution System – TTHMs and HAA₅ Tests

Water samples from ALS and PAS-8 jar tests were selected for SDS testing to determine the concentrations of TTHMs and HAA₅. The majority of the TTHMs were chloroforms, which is commonly the most concentrated TTHM found in drinking water (Health Canada, 2006). The majority of the HAA₅ were dichloroacetic acid and trichloroacetic acid. Samples were dosed at 7.07 mg/L of sodium hypochlorite and had free chlorine residuals of 2.34 – 3.84 mg/L and 1.78 – 3.32 mg/L after 3 and 5 days of contact time, respectively.

Compared to conventional jar tests, DAF jar tests had consistently higher TTHMs and HAA₅ after 3 days and 5 days of contact time for all ALS and PAS-8 dosages, with the exception of 80 mg/L of PAS-8 (Figure 8-9). It is noted that the water samples selected for the SDS test were unfiltered; however, the samples for organic precursors (as indicated by DOC, UV₂₅₄ and true colour) were filtered using a 0.45 µm filter paper and did not show a drastic difference between conventional and DAF processes. Filtration may not only reduce TTHMs and HAA₅ concentrations, but filtered water samples may also result in a smaller difference of organic precursors and TTHMs and HAA₅ between conventional and DAF.

Samples from conventional jar test using 50 mg/L and 60 mg/L of ALS and 80 mg/L of PAS-8 had TTHMs levels measured below the maximum acceptable concentration (MAC) of 100 µg/L after 3 days of contact time, however, the TTHMs levels increased above 100 µg/L after 5 days of contact time (Figure 8). All HAA₅ results were above the MAC of 80 µg/L (Figure 9). Among all tested samples, 80 mg/L of PAS-8 resulted in the lowest HAA₅ concentration for conventional and DAF after 3 days and 5 days of contact time (Figure 9).

Provided that the free chlorine residual remained moderately high (2.34 – 3.84 mg/L after 3 days and 1.78 – 3.32 mg/L after 5 days of contact time), a lower chlorine dosage may be used to reduce TTHMs and HAA₅. Additionally, the samples were stored at room temperature to maximize the DBPs formation; however, TTHMs and HAA₅ formation would also be reduced if they were stored at colder temperatures and if the water samples were filtered.

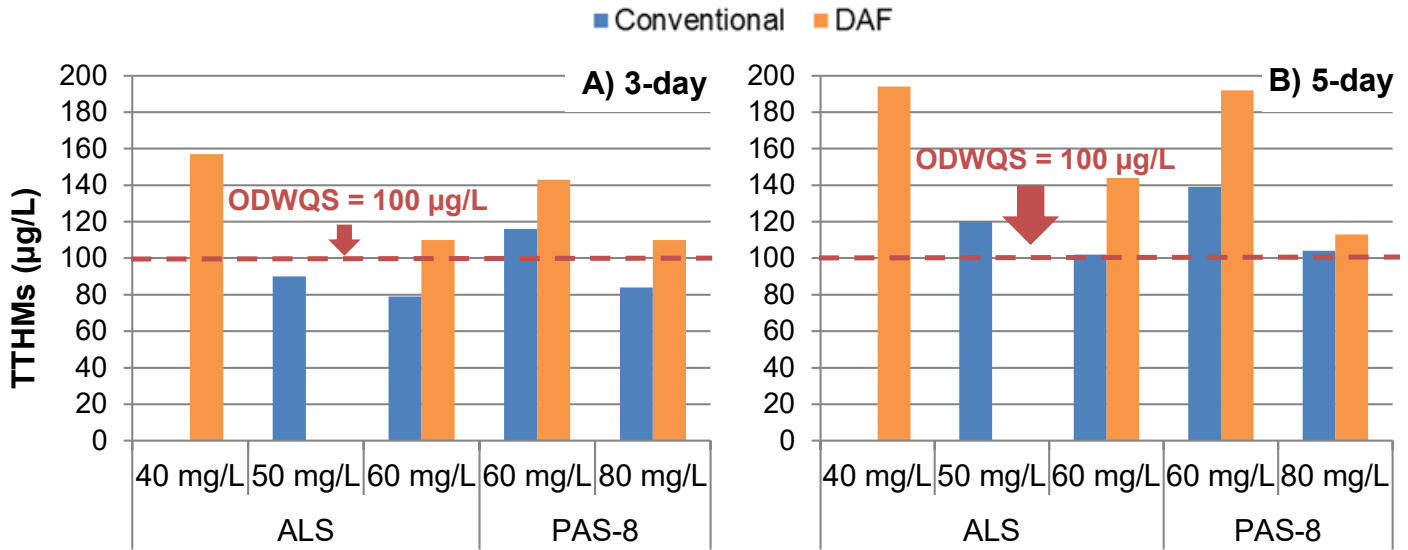


Figure 8. Total trihalomethanes (TTHMs) from conventional and DAF jar tests using selected dosages of ALS and PAS-8 after (A) 3 days and (B) 5 days of chlorine contact time. **Note:** Ontario Drinking Water Quality Standard (ODWQS) (O. Reg. 169/03) and Health Canada

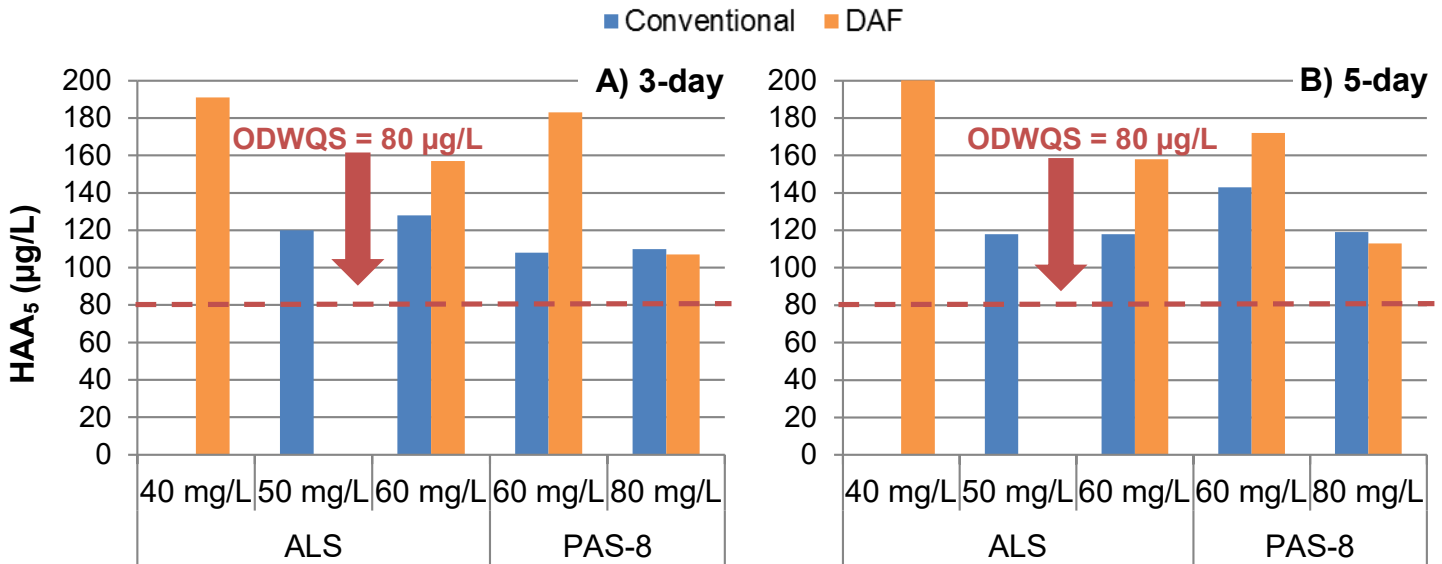


Figure 9. Haloacetic Acids (HAA₅) from conventional and DAF jar test using selected dosages of ALS and PAS-8 after (A) 3 days and (B) 5 days of chlorine contact time. **Note:** Health Canada Guidelines for Canadian Drinking Water established a MAC of 80 µg/L HAA₅ as a RAA of quarterly samples.

4. Conclusions

Overall, conventional jar tests achieved higher turbidity removal than DAF jar tests using PAX-XL6. However, conventional and DAF jar test results had similar DOC, UV_{254} and true colour trends. To measure DOC, UV_{254} and true colour, the clarified water was filtered using 0.45 μm filter paper. On a full-scale system, filtration after clarification may reduce TTHMs and HAA_5 .

When comparing coagulants, turbidity removal was optimal at 40 mg/L PAX-XL6 and 60 mg/L PAX-XL6 from conventional and DAF, respectively. The optimal coagulant dosage to achieve DOC removal with minimal TTHMs and HAA_5 formation was 60 mg/L ALS and 80 mg/L PAS-8, for both conventional and DAF jar tests.

It was found that TTHMs and HAA_5 were above the maximum acceptable concentration; however a lower chlorine dosage and colder contact time conditions could have reduced the disinfection by-products.

5. References

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