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Pilot Testing Project Report:

Reducing Arsenic in the Shakespeare Drinking Water System

Walkerton Clean Water Centre

Research & Technology

February 9, 2022

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Executive Summary

Background

The Village of Shakespeare, a part of the Municipality of Perth East in Perth County, Ontario, receives drinking water from the Shakespeare Drinking Water System which has 130 connections serving a population of approximately 260. The rated capacity of the system is 545.76 m^3/day. The system includes two wells (Well 1 and Well 2), six pressure tanks, a chlorine injection system and a chlorine contact tank.

The village's raw water has arsenic concentrations ranging from 11 µg/L to 15 µg/L (n=12), with an average concentration of 13.9 µg/L (n=16) in treated water. The maximum allowable concentration (MAC) of 10 µg/L for arsenic was introduced on January 1st, 2018 (MECP, 2018), reduced from the previous MAC of 25 µg/L. Therefore, since the MAC was lowered, additional treatment or optimization was required to provide greater arsenic reduction.

Objectives

The objectives of this pilot testing project were:

1) To reduce arsenic to less than 5 µg/L in the finished water.
2) To reduce iron to less than 0.3 mg/L in the finished water.
3) To establish the impact of different chlorine dosages on iron oxidation and filterability through jar testing and pilot testing.
4) To establish the impact of chlorine and ferric chloride dosages on arsenic oxidation and filterability.

Approach

Jar Test 1 was conducted as a bench scale test to find the optimum chlorine dose for oxidizing arsenic and assessing its filterability. Jar Test 2 was then conducted to find an optimum ferric chloride dosage and to determine if it's addition would enhance arsenic reduction.

Pilot testing was then initiated using the chlorinated well water. This was fed through a pilot treatment system that split into three separate trains. The flow of chlorinated water was simultaneously subjected to a train of cartridge filters, a train of pressure filters housing engineered media, and a train consisting of a pressurized sand filter, with and without a contact tank. A total of 6 experiments were conducted under differing conditions.

Key Findings

The following conclusions were made from this study:

- When ≥1 mg/L sodium hypochlorite was dosed followed by filtration, arsenic was reduced ≥75%.
- The addition of ferric chloride to chlorinated water, up to 5 mg/L, continued to reduce arsenic levels.
- Iron could be reduced to ≤0.02 mg/L when filtration followed chlorination.
- A series of cartridge filters (10, 5 and 1 µm size) reduced the average arsenic level to 4.76 µg/L at a flow rate of 10 L/min.
- Depth cartridge filtration (50-5 µm) followed by a cartridge filter series (1 and 0.35 µm) reduced arsenic to 2.5 µg/L at a 10 L/min flow rate and 2.75 µg/L at a 20 L/min flow rate.
- Filtration with Omni-SORB™ and SORB 33® in series lowered arsenic levels <0.10 µg/L in all experiments (n=6).
- Ferric chloride addition at 2.5 mg/L followed by sand pressure filtration reduced arsenic to an average level of 0.16 µg/L when a static mixer was used.

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1.0 Introduction

The village of Shakespeare, a part of Township of Perth East, receives drinking water from the Shakespeare Drinking Water System which has 130 connections serving a population of approximately 260. The rated capacity of the system is 545.76 m^3/day. The system includes two wells (Wells 1 and 2), six pressure tanks, a chlorine injection system and a chlorine contact tank.

The village's raw water has arsenic concentrations ranging from 11 µg/L to 15 µg/L (n=12), with an average concentration of 13.9 µg/L (n=16) in treated water, as per information received from the engineering consultant, B. M. Ross and Associates Limited, in Goderich, Ontario. The current maximum allowable concentration (MAC) for arsenic is 10 µg/L and was introduced on January 1st, 2018 (MECP, 2018); reduced from the previous MAC of 25 µg/L. Therefore, additional treatment is required for arsenic reduction to comply with the regulation.

Iron is commonly present in groundwater as a result of mineral deposits and chemically reducing underground conditions. The groundwater supply contained iron levels of 0.63 - 0.66 mg/L in July 2020. As per Ontario's aesthetic objective (AO), iron concentrations should be ≤0.3 mg/L (MECP, 2018). Excessive levels of iron may impart colour to water and fixtures, impart bitter tastes and promote the growth of iron bacteria in pipes.

2.0 Objectives

The objectives of this project are:

1) To reduce arsenic to less than 5 µg/L in the finished water.
2) To reduce iron to less than 0.3 mg/L in the finished water.
3) To establish the impact of different chlorine dosages on iron oxidation and filterability through jar testing and pilot testing.
4) To establish the impact of chlorine and ferric chloride dosages on arsenic oxidation and filterability.

3.0 Materials and Methods

3.1 On-site Jar Testing

3.1.1. Jar Tests

Two jar tests (Table 1) were conducted on-site.

- Jar Test 1 – was conducted to find an optimum dose of chlorine to oxidize arsenic and iron and compare it with the system's current chlorine dose.
- Jar Test 2 – was conducted with the system's current chlorine dose with the addition of ferric chloride to investigate any enhanced reduction of arsenic.

Table 1: Jar Test Conditions

Jar Test	Chemical Addition (mg/L)	Conditions	Time (minutes)	Remarks
1	Chlorine (1, 2, 3, 4, 5 and 6)	Rapid mixing	1	Filterability of oxidized particles will be observed when filtering through a 0.45 µm filter
		Flocculation	15	
		Sedimentation	30	
2	Chlorine (4.1)	Rapid mixing	1	Performed using Shakespeare system's current chlorine dose
		Flocculation	15	
	Ferric chloride (1.0, 2.0, 2.5, 3.0, 4.0 and 5.0)	Rapid mixing	1	Filterability of oxidized particles will be observed when filtering through a 0.45 µm filter
		Flocculation	20	
		Sedimentation	30	

3.1.2 Sampling and Analysis

In each jar test, grab samples were collected from jars after the sedimentation stage. Arsenic and iron analysis were conducted on both filtered (0.45 µm pore size) and unfiltered samples. Arsenic analysis was conducted externally by an accredited laboratory. Other water quality parameters such as turbidity, pH, alkalinity, true and apparent colour, dissolved organic carbon (DOC), ultraviolet (UV) absorbance, free chlorine and iron analysis were conducted by WCWC on-site and at the Centre.

3.2 On-site Pilot Testing

3.2.1 Set-up

Chlorinated water was fed to a custom designed and fabricated pilot plant through a pressure tank and backflow preventer. The chlorinated water flow was directed simultaneously into three different trains and a total of 6 experiments were run under different conditions.

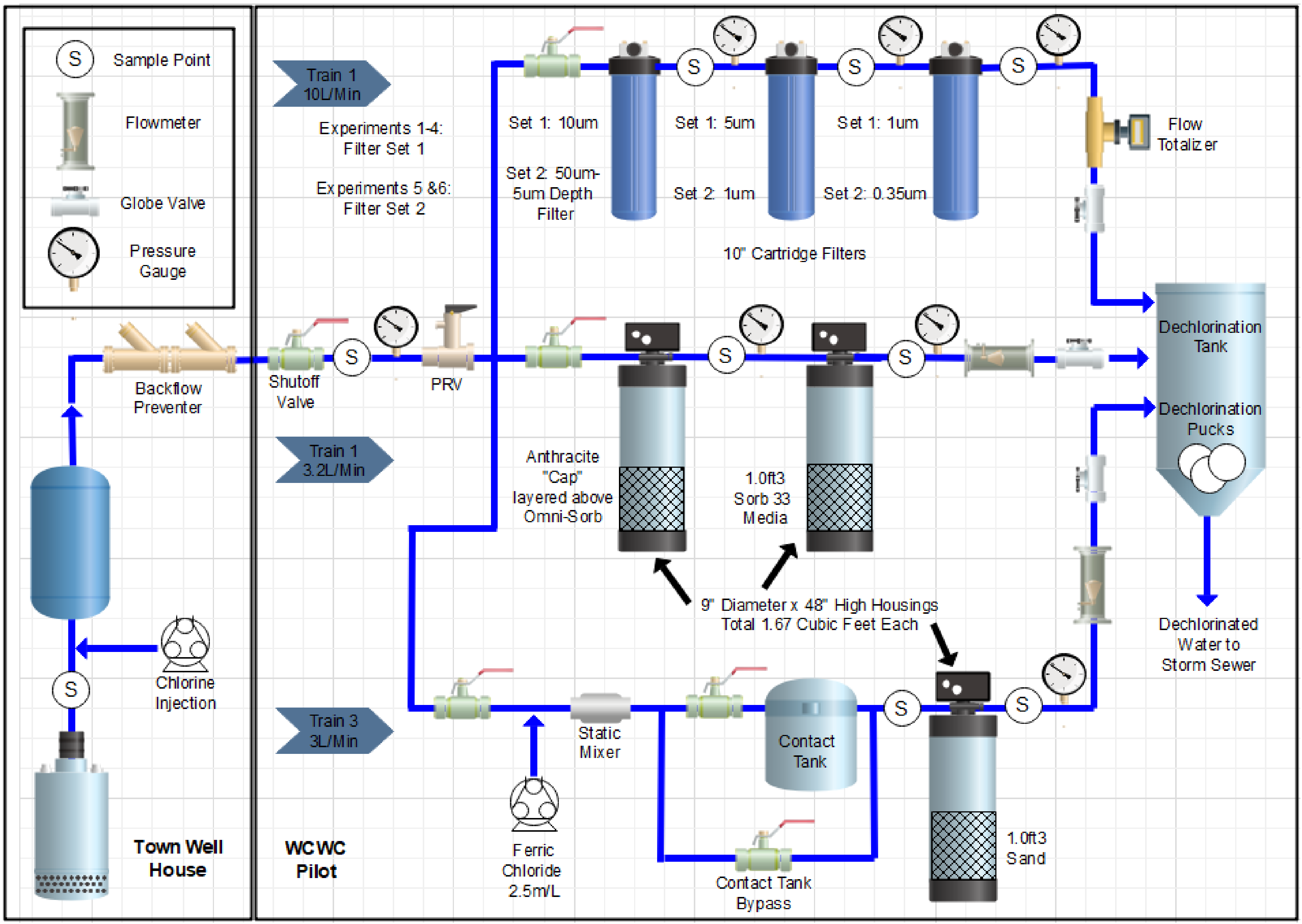
1) Train 1 was operated using two set ups:
   a) Nominal cartridge filters with pore sizes of 10 µm, 5 µm and 1 µm in series
   - Experiments 1 and 2 were run at a flow rate of 10 L/min
   - Experiments 3 and 4 were run at a flow rate of 20 L/min
   b) Cartridge filters with pore sizes of 50-5 µm (depth filter), 5 µm (nominal cartridge filter) and 0.35 µm (nominal cartridge filter) in series.
   - Experiment 5 was run at a flow rate of 10 L/min
   - Experiment 6 was run at a flow rate of 20 L/min
2) Train 2 was operated as follows:

Pressure filter filled with Omni-SORB™ media with an anthracite cap followed by a pressure filter filled with SORB 33® media flowrate at a flow rate of 3 L/min.

3) Train 3 was operated as follows:

Ferric chloride dosing at 2.5 mg/L with static mixer and contact tank followed by a pressure filter filled with mono sand at a flow rate of 3 L/min.

   a) Experiments 1 and 2 were run bypassing both the static mixer and the contact tank
   b) Experiments 3 and 4 were run with a static mixer, bypassing the contact tank
   c) Experiments 5 and 6 were run with the static mixer, followed by the contact tank



S Sample Point
Flowmeter
Globe Valve
Pressure Gauge
Train 1 10L/Min
Experiments 1-4: Filter Set 1
Experiments 5 &6: Filter Set 2
Set 1: 10um
Set 2: 50um-5um Depth Filter
Set 1: 5um
Set 2: 1um
Set 1: 1um
Set 2: 0.35um
10" Cartridge Filters
Flow Totalizer
Backflow Preventer
Shutoff Valve
PRV
Train 1 3.2L/Min
Anthracite "Cap" layered above Omni-Sorb
1.0ft3 Sorb 33 Media
Dechlorination Tank
Dechlorination Pucks
9" Diameter x 48" High Housings
Total 1.67 Cubic Feet Each
Dechlorinated Water to Storm Sewer
Chlorine Injection
Train 3 3L/Min
Static Mixer
Contact Tank
Contact Tank Bypass
Ferric Chloride 2.5m/L
1.0ft3 Sand
Town Well House
WCWC Pilot

3.2.2. Monitoring and Sampling

General water quality parameters such as turbidity, pH, alkalinity, colour (true and apparent), UV absorbance at 254 nm, DOC, chlorine and iron were analyzed in-house by the Walkerton Clean Water Centre. Samples for arsenic were sent to an external lab for analysis.

4.0 Results and Discussion

4.1 On-site Jar Testing

4.1.1 Jar Test 1 – Arsenic and Iron Reduction

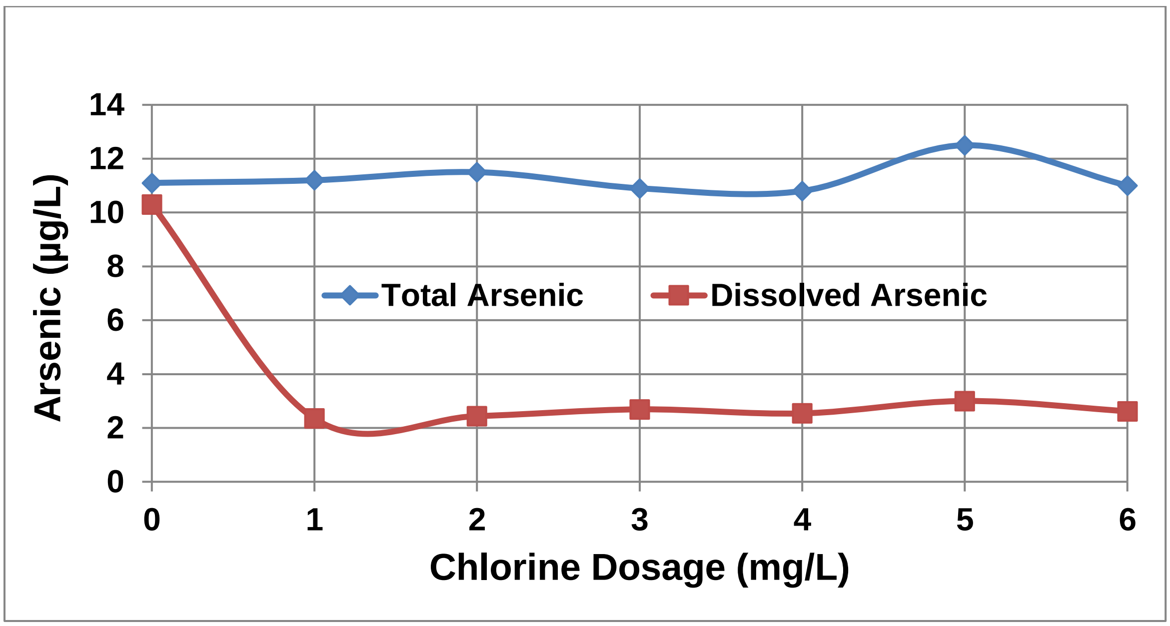


Figure 1. Arsenic levels observed during Jar Test 1.

Total arsenic and dissolved arsenic in raw water were 11.1 and 10.3 µg/L, respectively, which shows that 93% of the arsenic concentration was in dissolved (III) form which needs to be oxidized and filtered for removal. When 1 - 6 mg/L of chlorine was added, total arsenic levels ranged from 10.8 - 12.5 µg/L indicating that there was no reduction of total arsenic. However, when the samples were filtered, dissolved arsenic levels were 2.35 - 2.70 µg/L (76 - 79% reduction) which was significantly lower than the Ontario MAC of 10 µg/L (MECP, 2018).

Overall, chlorination followed by filtration reduced arsenic levels down to 2.70 µg/L (greater than 75% reduction) based on Jar Test 1 results. Although the optimized dose of chlorine was determined to be 1 mg/L for arsenic reduction based on Jar Test 1 results, Jar Test 2 was conducted using a 4.1 mg/L chlorine dose to mimic the Shakespeare water system's current operations.

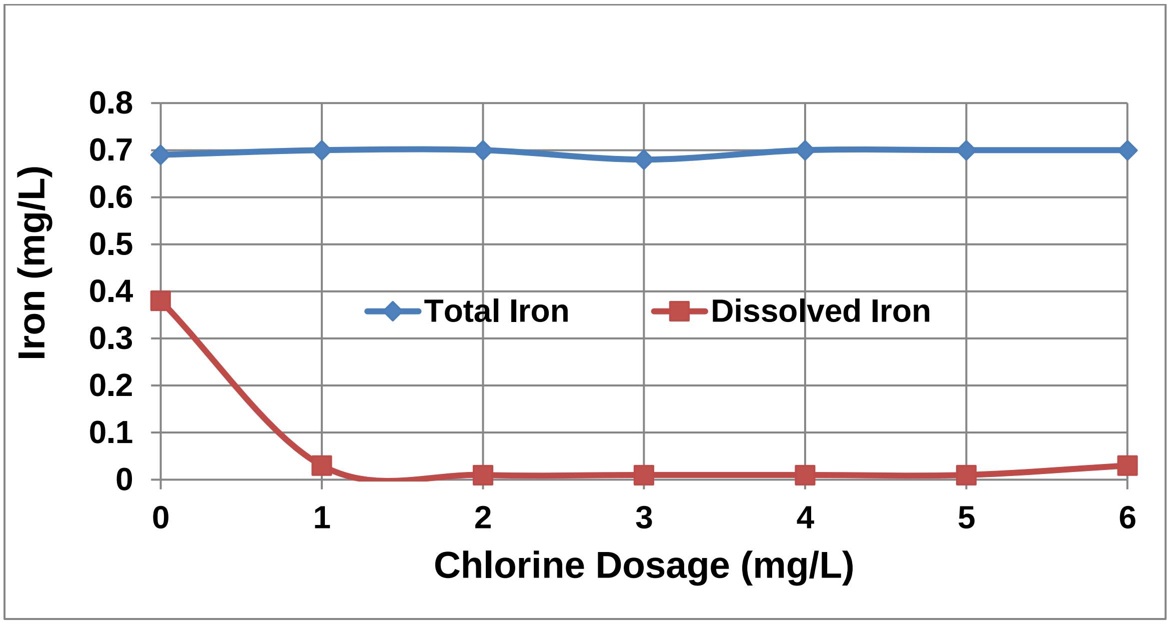


Figure 2. Iron levels observed during Jar Test 1.

Raw water iron concentrations were 0.69 and 0.38 mg/L, for total and dissolved iron respectively. This indicates that 55% of the iron was in dissolved form. Total iron levels remained at 0.68 - 0.70 mg/L when 1 - 6 mg/L of chlorine was added in Jar Test 1 but dissolved iron levels were reduced to 0.03 mg/L or lower after filtration. These results demonstrate that iron needs to be filtered out to comply with Ontario's AO of < 0.3 mg/L iron in treated water (MECP, 2006).

4.1.2 Jar Test 2 - Arsenic and Iron Reduction

One of the proposed treatment options for the Shakespeare system was the addition of 2.55 mg/L of $FeCl_3$ followed by pressure sand filtration. Jar Test 2 was conducted on-site to determine whether the addition of chlorine and $FeCl_3$ would further reduce arsenic levels. Figure 3 shows the arsenic levels observed in Jar Test 2.

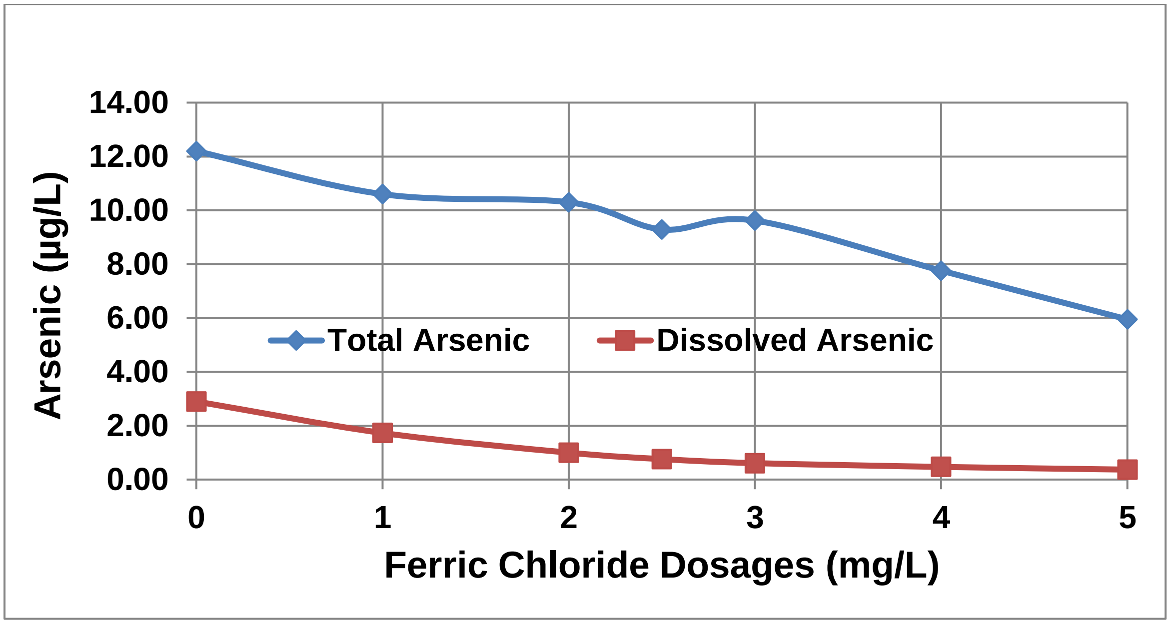


Figure 3. Arsenic levels observed during Jar Test 2.

Total and dissolved arsenic concentrations in chlorinated raw water were 12.2 and 2.9 µg/L, respectively. The total arsenic level increased by 1 µg/L when compared to the water quality analysis of Jar Test 1, indicating that the level of arsenic in the raw water fluctuates. The dissolved arsenic level decreased to 2.9 µg/L after 1 minute of rapid mixing, 35 minutes of flocculation and 30 minutes of settling time despite not adding any $FeCl_3$. When 1 - 5 mg/L of $FeCl_3$ was dosed with 20 minutes of flocculation time and 30 minutes of settling, the total and dissolved arsenic linearly decreased to 5.95 µg/L (51%) and 0.37 µg/L (97%), respectively. Overall, the addition of $FeCl_3$ to chlorinated water reduced total and dissolved arsenic levels up to the maximum dose 5 mg/L. Figure 4 presents total and dissolved iron levels observed in Jar Test 2.

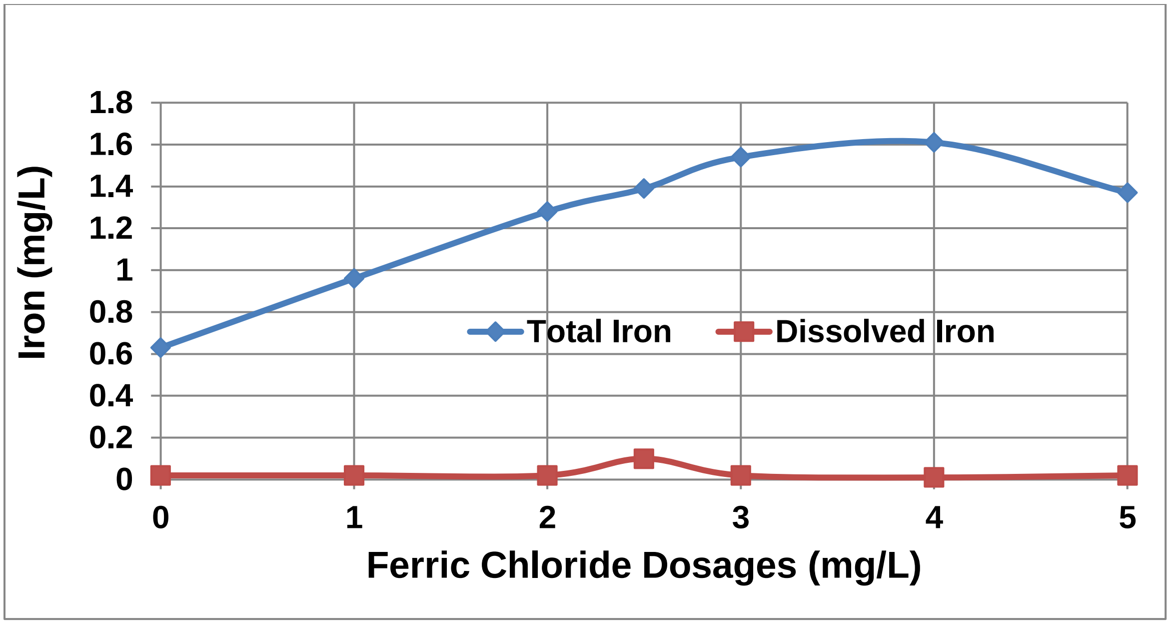


Figure 4. Iron levels observed during Jar Test 2.

The total iron level in raw water increased from 0.63 mg/L to 1.61 mg/L when dosed 4 mg/L with $FeCl_3$ in Jar Test 2 because $FeCl_3$ contains iron. Dissolved iron was measured at ≤0.02 mg/L in all ferric chloride doses, except for 2.5 mg/L $FeCl_3$, which is significantly lower than Ontario's AO of 0.3 mg/L (MECP, 2006).

4.2 On-site Pilot Testing

4.2.1 Reduction of Arsenic by Cartridge Filtration

Figure 5 presents arsenic levels sampled from the pilot system using cartridge filters during Experiments 1-4.

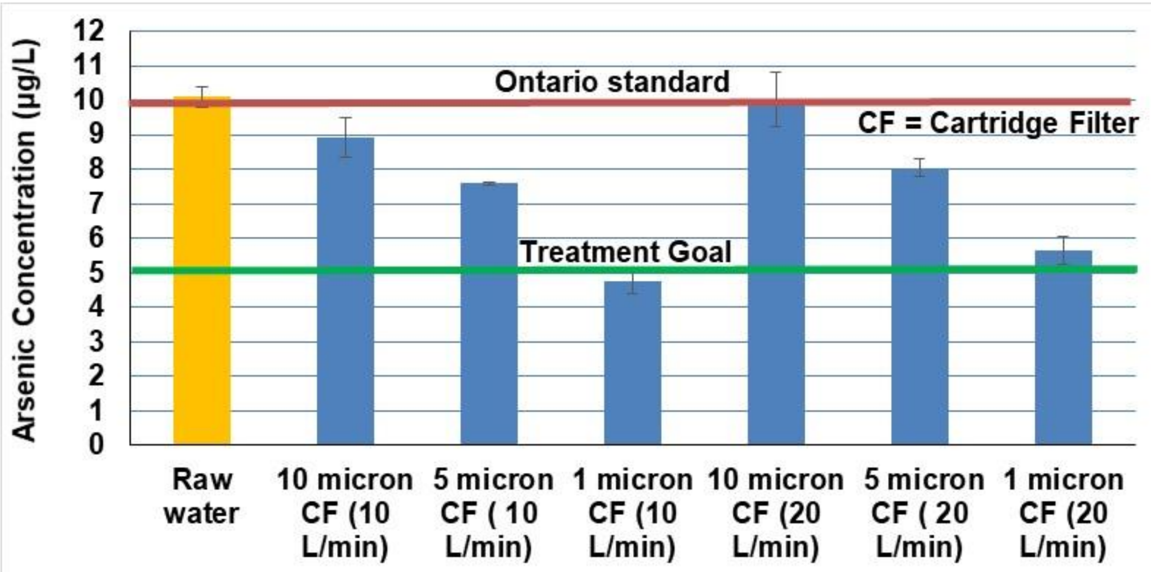


Figure 5. Arsenic levels for cartridge filters in Experiments 1-4.

The average arsenic level in treated water obtained from samples taken following the 1 µm cartridge filters was 4.76 µg/L at the flow rate of 10 L/min in Experiments 1 and 3. The average treated water arsenic level was reduced under 5 µg/L under 10 L/min flow rate conditions achieving the treatment goal (Experiments 1 and 3). However, when the flow rate was adjusted to 20 L/min, the treatment goal was slightly surpassed with an average arsenic level of 5.66 µg/L (Experiments 2 and 4).

When comparing the on-site pilot to Jar Test 1 results, they showed that filtration was more effective in a controlled laboratory setting than it was in the pilot system as the arsenic levels were reduced to 2.35 - 2.70 µg/L during jar testing.

Figure 6 shows the arsenic levels in treated water sampled from a depth filter followed by cartridge filters were used in Experiments 5-6.

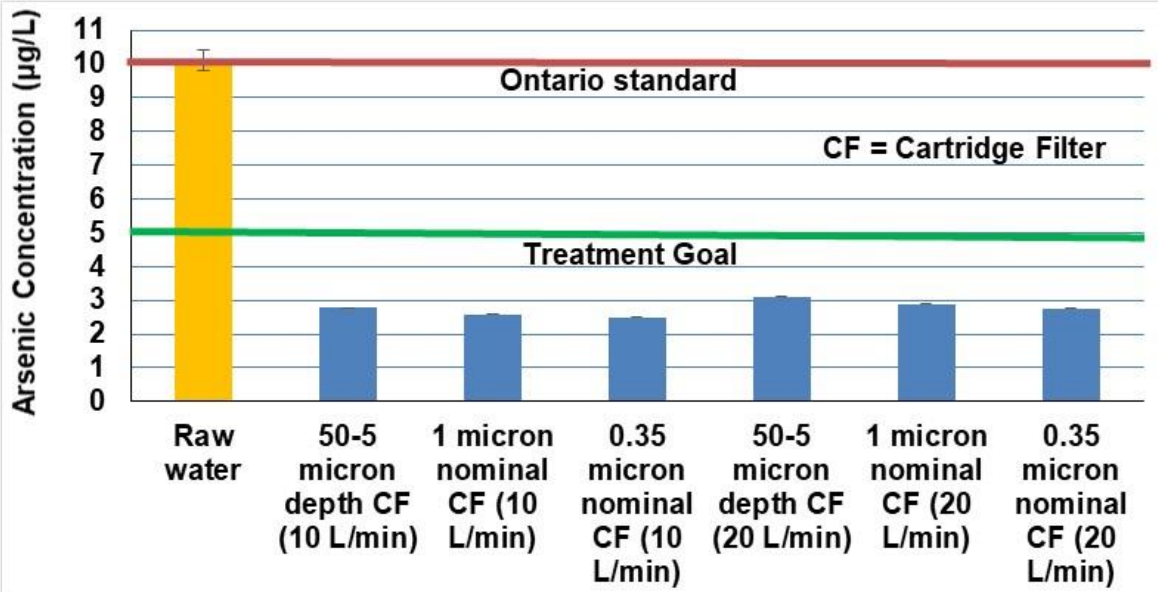


Figure 6. Arsenic levels for depth and cartridge filters in Experiments 5-6.

The average treated water arsenic level was found to be 2.5 µg/L at a 10 L/min flow rate. These results were lower than observed when using the cartridge filtration train (Experiments 1-4) which was attributed to the design of the depth filter employed in these pilot runs (Experiments 5-6). When the flow was increased to 20 L/min, the treated water arsenic levels were increased to 2.75 µg/L, but all results from Experiments 5-6 achieved the desired treatment goal for arsenic reduction.

4.2.2 Reduction of Arsenic by Omni-SORBTM and SORB 33®

In all experiments (n=6), Omni-SORB™ and SORB 33® lowered treated water arsenic levels to < 0.10 µg/L. In this treatment train, Omni-SORB™ alone removed arsenic to a non-detectable level. Based on these results, SORB 33® would only need to be considered as an optional polishing filter for the treatment of arsenic.

4.2.3 Reduction of Arsenic by Ferric Chloride followed by Sand Filtration

Figure 7 presents arsenic reduction results obtained when dosing 2.5 mg/L ferric chloride followed by sand filtration, which reduced average arsenic levels to 0.16 µg/L in the treated water in Experiments 3-6. A static mixer was used in Experiments 3-4 and bypassed the contact tank, while the contact tank was used in Experiments 5-6. Results showed that the arsenic reduction was greater when just the ststic mixer was used without the contact tank (Experiments 3-4) but both sets of experiments resulted in reducing arsenic below the treatment goal.

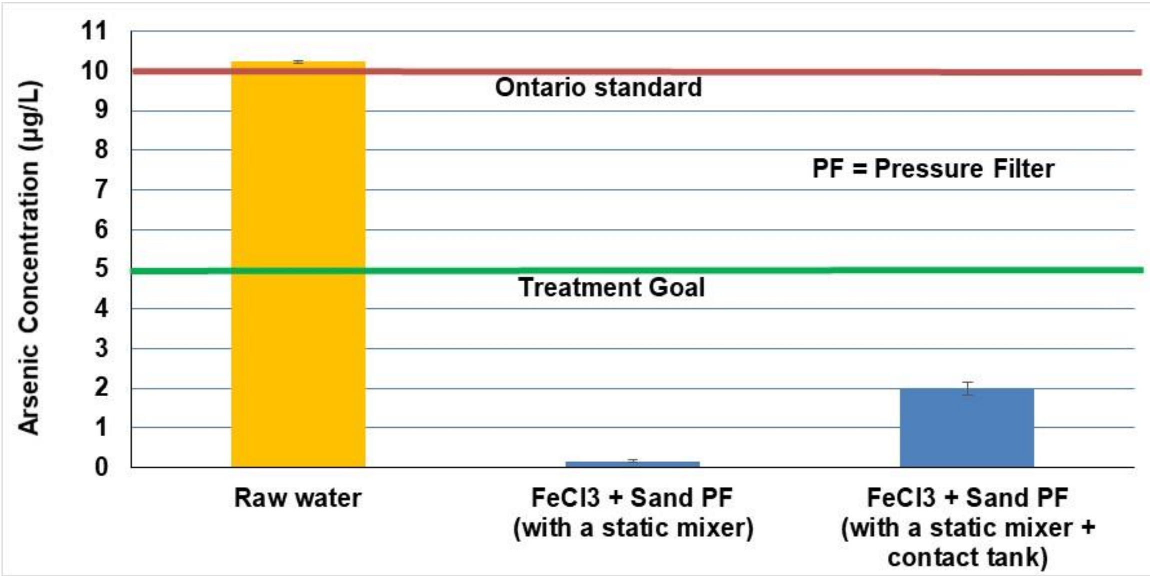


Figure 7. Arsenic levels for ferric chloride addition followed by sand filtration in Experiments 3-6.

4.2.4 Reduction of Iron by Treatment Trains

In Experiments 1-4, when cartridge filters of 10, 5 and 1 µm in series at a flow rate of 10 L/min were used, the iron concentration was reduced from 0.63 mg/L in raw water to 0.19 mg/L, meeting Ontario's AO (Figure 8). When the flow was increased to 20 L/min, the iron reduction was not as effective and was more variable.

In Experiments 5-6, when using a 50-5 µm depth filter, 1 and 0.35 µm cartridge filters in series at both 10 L/min and 20 L/min flow rates, the treated water iron levels were reduced to ≤ 0.02 mg/L (Figure 8). The additional effectiveness of these experiments compared to that of Experiments 1-4 appears to be due to the depth filter design and the lower pore size of cartridge filters used.

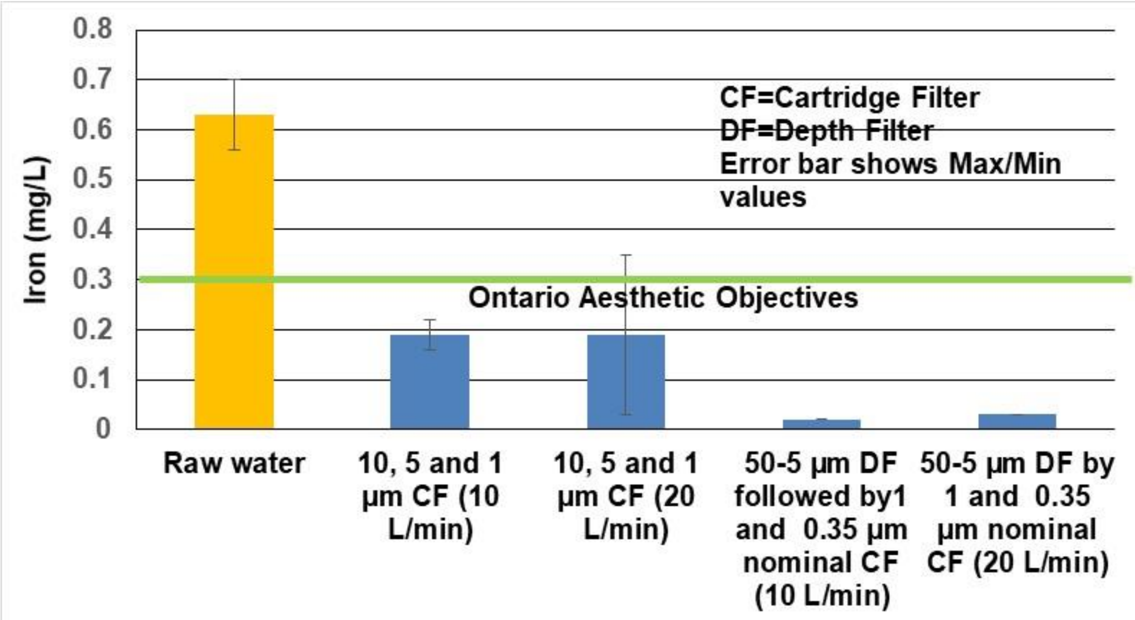


Figure 8. Iron levels for cartridge and depth filters

Omni-SORB™ and SORB 33® consistently reduced treated water iron levels to ≤0.03 mg/L in all experiments conducted.

The ferric chloride addition at a dose of 2.5 mg/L followed by sand filtration also reduced treated water iron levels to ≤0.02 in all experiments except for in Experiment 6, where the treated iron level was measured at 0.31 mg/L.

5.0 Limitations

Omni-SORB™ and SORB 33® were found to be effective at reducing arsenic concentrations to lower than the analysis method's detectable limit. However, the performance of the media may decline over time and necessary action will be needed at that time (Jasim et al., 2020).

Investigation into the life cycle and maintenance of the filters used in this pilot study was outside of the scope of the project and not considered.

6.0 Conclusions

The following conclusions were made from this study:

- When ≥1 mg/L sodium hypochlorite was dosed followed by filtration, arsenic was reduced ≥75%.
- The addition of ferric chloride to chlorinated water, up to 5 mg/L, continued to reduce arsenic levels.
- Iron could be reduced to ≤0.02 mg/L when filtration followed chlorination.
- A series of cartridge filters (10, 5 and 1 µm size) reduced the average arsenic level to 4.76 µg/L at a flow rate of 10 L/min.
- Depth cartridge filtration (50-5 µm) followed by a cartridge filter series (1 and 0.35 µm) reduced arsenic to 2.5 µg/L at a 10 L/min flow rate and 2.75 µg/L at a 20 L/min flow rate.
- Filtration with Omni-SORB™ alone, and Omni-SORB™ and SORB 33® in series, lowered arsenic levels <0.10 µg/L in all experiments (n=6).
- Ferric chloride addition at 2.5 mg/L followed by sand pressure filtration reduced arsenic to an average level of 0.16 µg/L when a static mixer was used.

7.0 References

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