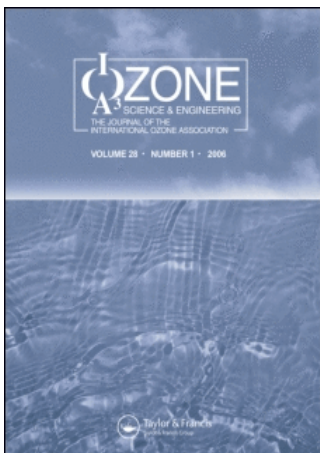


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# The Effect of Ozone on Cold Water Coagulation

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*The application of pre-coagulation ozone in drinking water treatment to provide primary disinfection, has an impact on coagulation and flocculation, and needs to be evaluated further for cold water temperatures, especially when accompanied by episodes of high alkalinity and dissolved organic carbon (DOC). Ozone application to raw water, prior to the addition of coagulants and coagulant aides, was shown to reduce coagulant and coagulant aide doses, and improve settled and filtered water turbidity. The impact on particle count was also noticeable, filtered water particle count was reduced after the application of pre-coagulation ozonation. Pilot-scale experiments were conducted at the Walkerton Clean Water Centre, Walkerton, Ontario, Canada, to investigate the effect of pre-coagulation ozonation, on filtered water turbidity, particle count, and filter performance, during periods when water temperatures could be lower than 5°C.*

**Keywords** Ozone, Coagulation, Cold water temperature

## INTRODUCTION

The drinking water treatment industry is facing increasing demands for improvement of finished water quality and optimization of removal of the cysts and oocysts of *Giardia* and *Cryptosporidium*. The chemically assisted filtration process generally includes chemical mixing, coagulation, flocculation, sedimentation and rapid gravity filtration. Aluminum salts are often used as primary coagulants. Cationic and anionic polymers are most commonly used as flocculation aids. The coagulants and polymers are used to destabilize the generally negatively charged colloidal particles, which allow aggregation to occur via chemical and van der Waals interactions.

The resulting particles are filtered out when the water passes through dual- or mixed-media granular filters.

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Changes in alkalinity, color, and turbidity affect coagulation and the properties and rate of settling of resulting floc particles. Temperature affects efficiency by influencing the rate of chemical reactions and the viscosity of water, thereby affecting the particle settling velocity and the filter backwash rate. The lower the temperature of the water, the more difficult it is to treat the water.

The application of pre-coagulation ozone in drinking water treatment to provide primary disinfection, has an impact on coagulation and flocculation, and needs to be evaluated further for cold water temperatures, especially when accompanied by episodes of high alkalinity and dissolved organic carbon (DOC).

The use of different coagulants, coagulant-aides to investigate improvement of flocculation and coagulation in cold water temperatures is a matter of high importance for the drinking water industry, especially in Canada and the United States, where water temperatures can be lower than 5°C for several months.

Ozone application to raw water, prior to the addition of coagulants and coagulant aides, has shown to reduce coagulant and coagulant aide doses, and improve settled and filtered water turbidity. The impact on particle count was also noticeable, filtered water particle count was reduced after the application of pre-coagulation ozonation.

Pre-coagulation ozonation offers potential benefits related to improved particle destabilization and aggregation. Improved filtered water quality, longer filter runs and potentially reduced coagulant dosages may be possible (Anderson et al., 1996). The benefits would appear, however, to be restricted by raw water character. Chang and Singer (1991) conducted a study to investigate raw water characteristics which would promote ozone-induced coagulation. Optimal ozone-induced particle destabilization was found to occur in waters with hardness-to-total organic carbon (TOC) ratios >25 mg CaCO<sub>3</sub>/mg C, and ozone doses of about 0.4–0.8 mg O<sub>3</sub>/mg C. This

study involves Lake Huron water, which could be interpreted for many Great Lakes source water users.

The study by Metropolitan Water District of Southern California (MWD) on pre-coagulation ozonation, found that particle destabilization occurred at ozone dosages of 1.0–4.0 mg/L (Paode et al. 1995). However, these authors found that particle aggregation (as indicated by electrophoretic mobility) was observed only at lower ozone dosages (<2.0 mg/L). Aluminum sulfate (Alum) and ferrous sulfate were used as primary coagulants in that study and a coagulant aid (Catfloc T at a constant dose of 1.5 mg/L with alum and 0.5 mg/L with ferrous sulfate) was used. At higher dosages, ozone appeared to break up and disperse colloidal aggregates. At ozone dosages less than 2.0 mg/L it was found that, for California State Project water and Colorado River water, pre-coagulation ozone (and pre-coagulation ozone/hydrogen peroxide) improved flocculation efficiency and particle removal through filtration. The ferrous sulfate provided better results than alum on all preoxidized waters. Paode et al. (1995), indicated that alum dose could be reduced with the application of pre-coagulation ozone (2.5 mg/L O<sub>3</sub> resulted in a savings of 5 mg/L alum, which was 50% of the alum dose being applied).

The work conducted by Becker et al. (1995) indicated that when alum was used as the sole coagulant in a synthetic water, pre-coagulation ozone did not induce microfloculation. However, when alum was used in conjunction with a cationic polymer (Catfloc T), ozone-induced particle destabilization and aggregation occurred. These authors also noted a negative effect on particle aggregation at high ozone dosages (dosages not specified).

The pilot-scale experiments conducted in Windsor, Ontario, Canada, indicated that ozone-induced coagulation and flocculation is possible at the Windsor Water Treatment Centre. Settled water turbidity was always lower on the side of the pilot plant where pre-coagulation ozone was applied. Dual-media (anthracite/sand) filter performance for turbidity was consistently better when pre-coagulation ozone was applied prior to coagulation. The experiments indicated the potential importance of particle counting as a tool to monitor filter performance and to optimize treatment processes. The project provided additional information to assist with considerations involving the possible implementation of pre-coagulation ozonation in the Water Treatment Centre in Windsor (Jasim et al., 1998). Pre-coagulation ozonation was successfully implemented in Windsor, Ontario in 2001.

## BACKGROUND

In October 2004, the Ontario government established the Walkerton Clean Water Centre to help the government take practical actions to ensure clean water for all Ontarians. To fulfill this mandate, the Centre works to

continuously advance the - training and education of Ontario's drinking water systems operators and owners, especially those serving rural and remote communities.

The Walkerton Clean Water Centre works with the Ministry of the Environment and different stakeholders to identify and prioritize drinking water research needs that the Centre could sponsor independently or in partnership with other agencies. The Walkerton Clean Water Centre opened a comprehensive Technology Demonstration facility dedicated to train operators of the drinking water systems in Ontario. The facility comprises of a state-of-the-art pilot plant to demonstrate conventional and leading-edge water treatment technologies

Raw water used for this experiment was delivered from Lake Huron. Generally, Lake Huron water quality has small range in variation of key water quality parameters, low values of turbidity (except for occasional spikes), dissolved organic carbon (DOC) 2–3 mg/L, and moderate alkalinity 90–100 mg/L (as CaCO<sub>3</sub>).

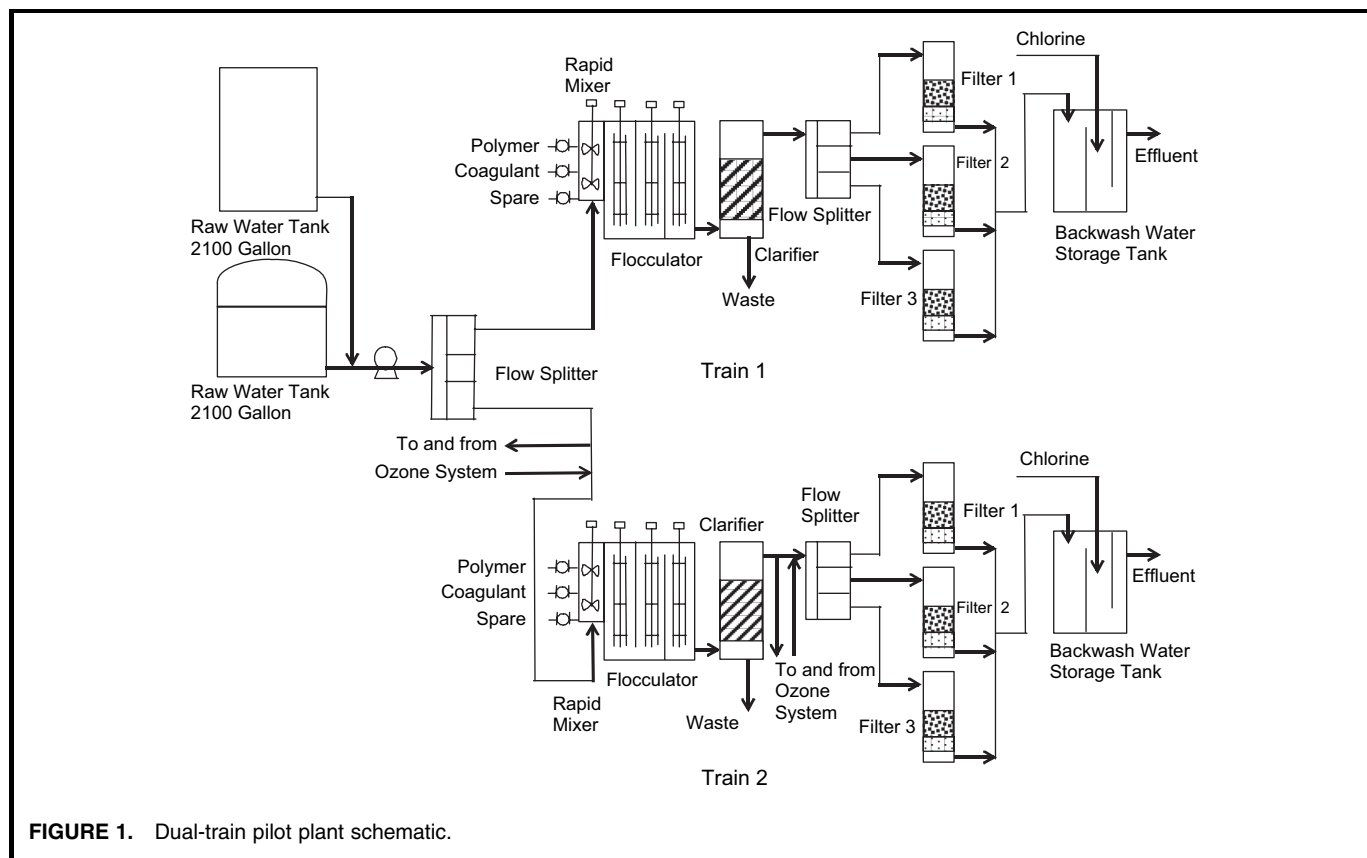
## MATERIALS AND EXPERIMENTAL PROCEDURES

### Pilot-Plant Description

The dual train pilot plant was supplied by Corix Water Systems (Langley, BC, Canada), formerly Terasen Water Inc. It is a completely automatic gravity flow system that consists of 2 process trains (Train 1 and Train 2) each rated to treat up to 15.0 L/min (Figure 1). The feed water to the pilot plant is contained in 2 above-ground tanks of 4000 liters each.

Each train consists of rapid mixing with provision to inject 3 chemicals using Masterflex C-77521-50 drive with C-77200-60 Pump Head (Cole Parmer, Vernon Hills, Illinois, USA), mechanical flocculation with 3 flocculation cells (10–30 minutes total detention time), plate settlers with 75 minutes' detention time (25.62 LPM/m<sup>2</sup> average), 3 filter columns (15 cm diameter), one backwash water tank and one baffled chlorine contact tank with 2 chambers, equipped with Masterflex C-77521-50 Drive with C-77390-00 pump head for chlorine injection. For each train, the first filter column contains sand and anthracite, the second column contains sand and granulated activated carbon and the third column is a spare column for future use. Train 1 is equipped with a Chemtrac Streaming Current Controller Model SCC 3500XRD (supplied by Chemtrac Systems Inc., Norcross, GA, USA), for coagulant dosage optimization.

The ozone system with a capacity of 8 L/min is incorporated to Train 2 of the pilot plant. The ozone process is connected to the pilot plant to allow either ozonation of the water prior to coagulation or filtration. The water is pumped to the ozone system at the top inlet port of the first glass column and then flows by gravity throughout the system. The water flows downward in the first column and upward in the second. The ozone gas is injected at the



bottom of the first column. The second column is equipped with 14 baffles and 4 sample ports located at different heights. The off gas from the system is collected at the top of each column and directed to a heated ozone destruct unit prior to be released to the air outside the building.

Unless otherwise stated, the data were collected using online sensors and transmitters and a Supervisory Control and Data Acquisition system (SCADA). The SCADA system was developed by Dakins Engineering Group Ltd. (Mississauga, Ontario, Canada) using iFix software (distributed by GE Fanuc Canada, Mississauga, Ontario, Canada).

The total flow to the pilot plant is controlled using a MAS Ball Valve with Keystone EPI-3 electric actuator (Tyco, Seattle, WA, USA) and measured using ABB Meg Flow Meter ABB 000402713/X017. The flow to each train is measured using ABB Meg flow Meter 000401781/X013. The effluent flow of each filter is measured using SeaMetrics EM101 Meg flow Meter (SeaMetrics, Kent, WA, USA). Headloss and water levels were determined with an assembly of Marshall Town pressure gauge and Wika C-10 Pressure Transmitter (Wika, Klingenberg, Germany). Turbidity was measured using Hach 1720E Low Range Turbidimeter (Hach Company, Loveland, CO, USA). pH and temperature were determined using ABB AP303/21020000 pH

Sensor, ABB pH Transmitter Model AX466/6/0/0/0, and ABB pH Transmitter/Temperature Model AX466/6/0/0/0 (Supplied by ABB Inc., Reno, Nevada, USA).

The ozone is produced by a Pacific Ozone Generator Model SGC11 (Pacific Ozone Technology, Benicia, CA, USA). The ozone level of the gas leaving the generator is measured using an IN-USA Ozone Analyzer Model Mini-Hicon (IN USA Incorporated, Needham, MA, USA). The residual dissolved ozone, at the inlet (Port 1) and effluent line (Port 5) of the second glass column, is continuously monitored using a three way solenoid valve and an ATI Dissolved Ozone Monitor Model Q45H-2-2 (manufactured by ATI Analytical Technology, Inc., Collegeville, PA, US).

### Sampling and Analysis

Experiments were conducted on the pilot plant (Figure 1), located at the Walkerton Clean Water Centre, Walkerton, Ontario. Experiments were conducted during the period of February–March, 2007, when water temperatures were in the range of 3.0–7.0°C. Raw water was delivered from Lake Huron. Raw water quality is shown in Table 1.

Experiments were conducted including investigation of raw water quality change and the effect of low water temperatures on coagulation. Bench scale analyses were performed to establish raw water quality for each

**TABLE 1.** Raw Water Quality

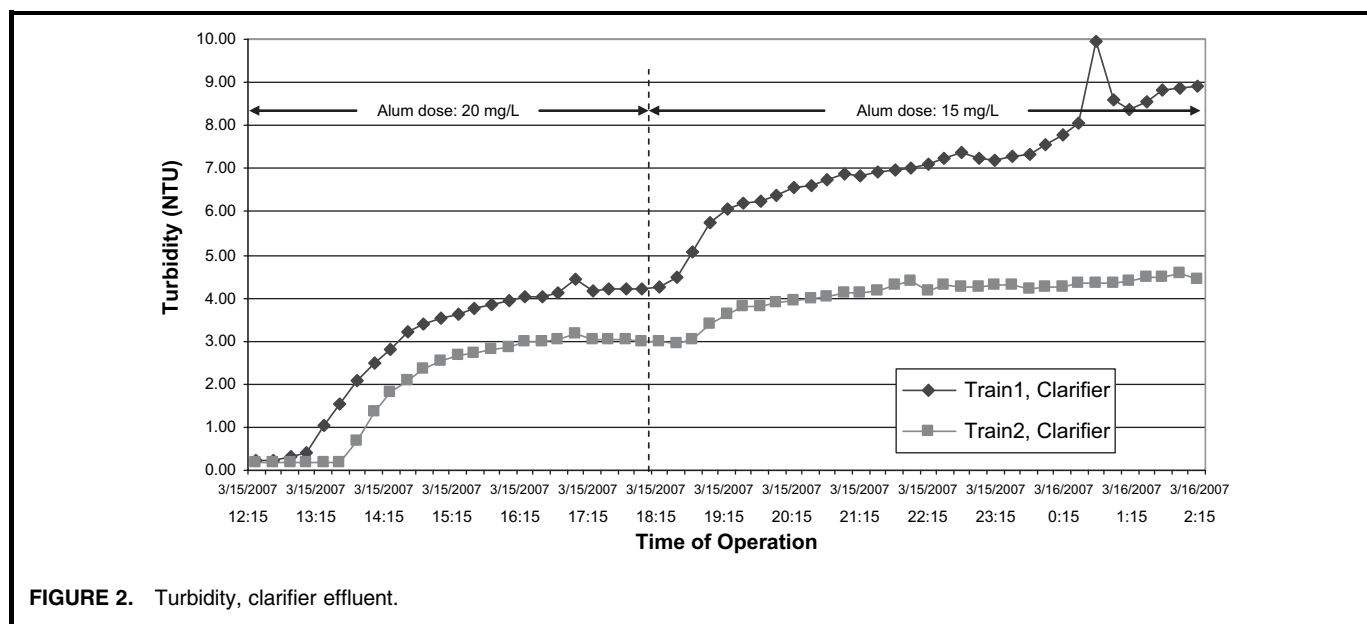
No. of Experiment	Date of Experiment	Temperature (°C)	Turbidity (NTU)	DOC (mg/L)	Alkalinity (mg/L as CaCO <sub>3</sub> )	pH	Apparent Colour TCU
Run1	2/15/2007	4.1	1.99		100	7.81	85
Run2	2/21/2007	4.7	0.83		100	7.98	4
Run3	2/27/2007	4.7	0.96	2	98	7.75	4
Run4	3/7/2007	3.8	0.88	2	95	7.97	95
Run5	3/15/2007	4.9	37.50	2	104	8.14	375
Run6	3/20/2007	4	14.00	27			
Run7	3/21/2007	4.3	9.06	24	98	8.20	66
Run8	3/28/2007	7.9	163.00	3	120	7.60	1135
Run9	4/5/2007	4.7	20.10	3	106	7.80	133
Run10	4/12/2007	7.2	21.60	3	102.8	7.90	165

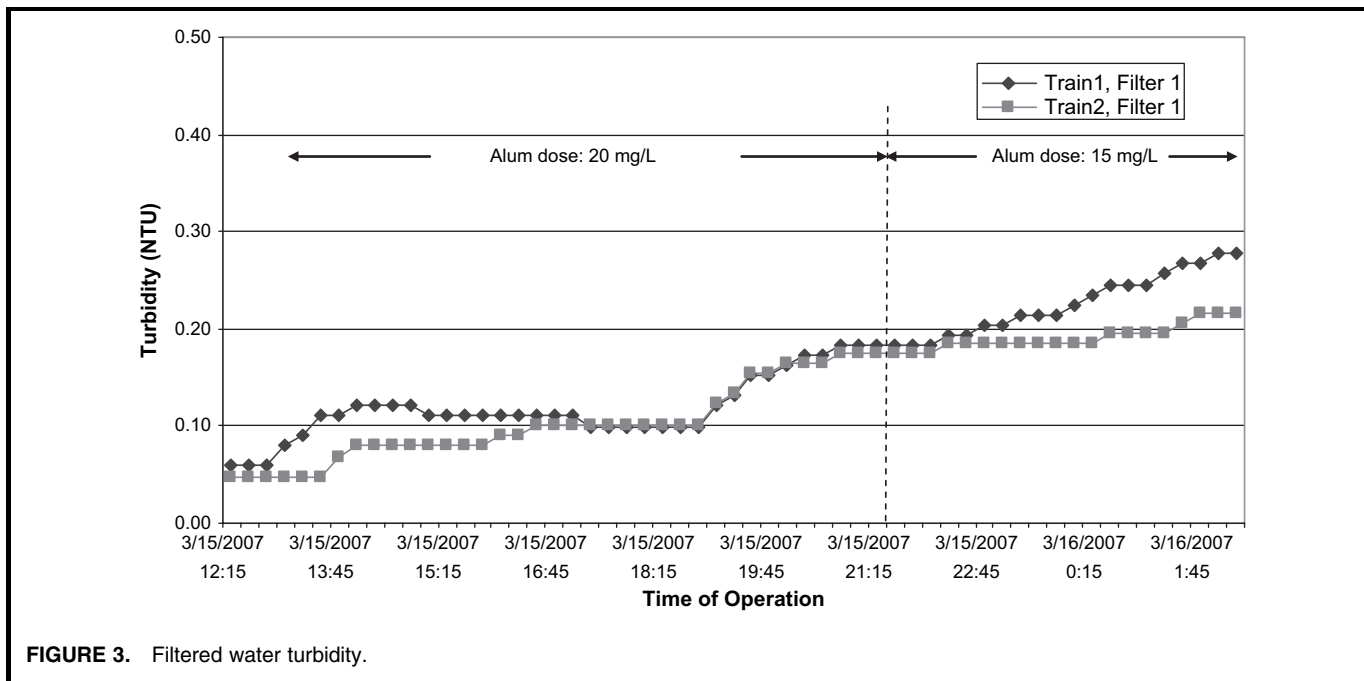
experiment. Raw water used in all the experiments was delivered to the Centre from Lake Huron. Three runs of the experiment were during a stormy weather (Runs 6, 7, and 8). Elevated water turbidity and dissolved organic carbon levels were observed during that time (Table 1). The coagulant, aluminum sulfate (Alum) and the coagulant aid (Magnafloc LT 22) were added to both sides of the pilot plant. Alum dosages ranged between 10–30 mg/L. Polymer dosage was 0.05 mg/L during all experiments.

Ozone was applied (pre-coagulation ozonation) on side 2 of the pilot plant only. Ozone dosages were 1.00–2.00 mg/L. Settled water turbidity was always lower on side 2 of the pilot plant, where pre-coagulation ozonation was employed compared to side 1 where no ozone was applied (Figure 2). Improved filter turbidities were observed on side 2 compared to that of side 1 (Figure 3).

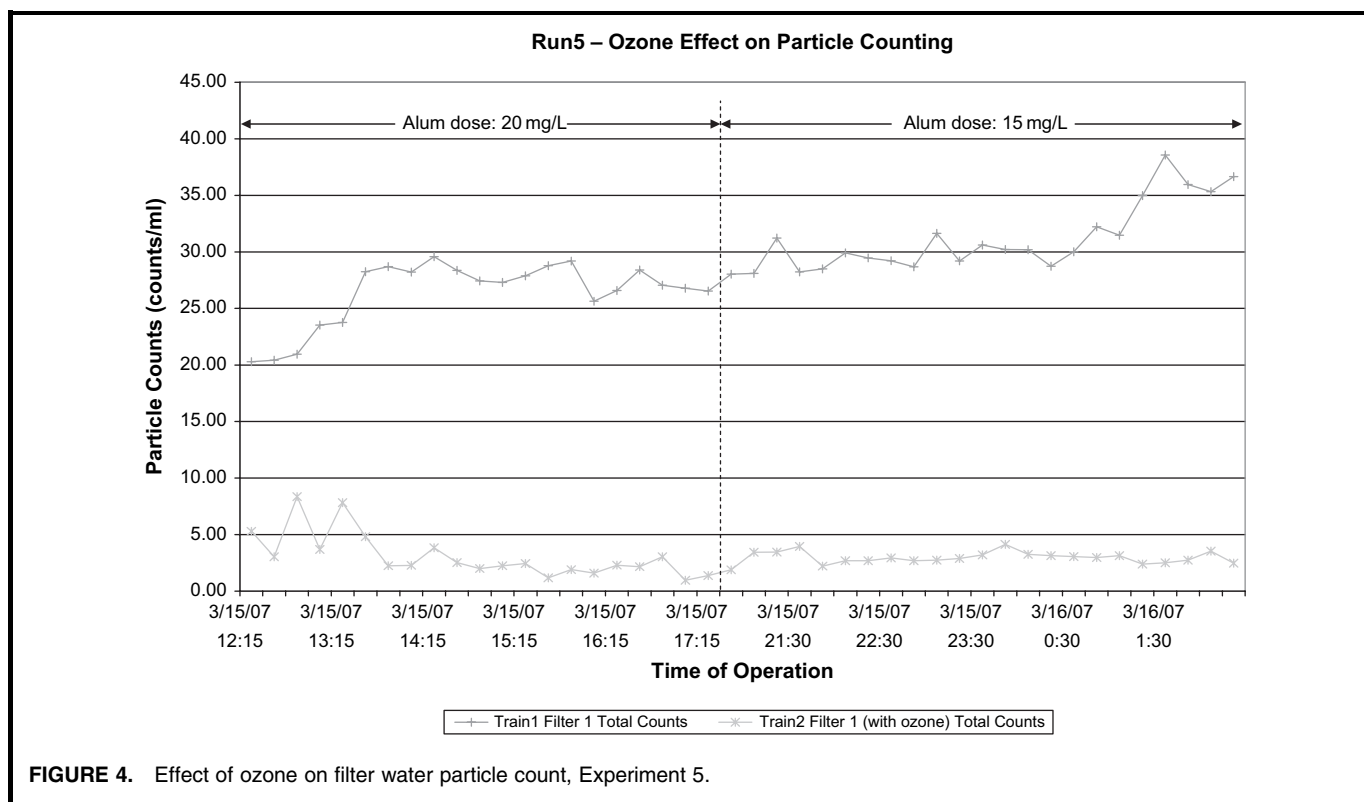
The use of particle counting in drinking water treatment optimization and monitoring continues to grow rapidly. Particle counting has been used successfully to evaluate treatment plant performance and to explore the relationship between particle counts and protozoan cysts and oocysts. Recording particle counts in a number of size ranges gives the operator a sense of the particle size distribution in the sample. Multiple size channels help to identify specific contaminants of concern, such as algal growth in the treatment process. Three or four size channels adequately fulfill these needs. Filtered water rarely contains particles greater than 20  $\mu\text{m}$ ; therefore, size ranges below 20  $\mu\text{m}$  provide the necessary data for process performance in the drinking water industry (Lewis et al., 1996; Lind, 1996).

Figures 4 and 5 illustrate the results for particle count analysis collected on March 7, 15 and 16, 2007. The total

**FIGURE 2.** Turbidity, clarifier effluent.



**FIGURE 3.** Filtered water turbidity.



**FIGURE 4.** Effect of ozone on filter water particle count, Experiment 5.

particle count indicated clearly that the effect of ozone application has a major effect on the reduced number of particle count for filtered water. Data for particle counts for both trains were collected on a 15 minute intervals. The use of pre-coagulation ozonation resulted in

improved particle removal, especially in the 2–3, 3–5, and 5–10  $\mu\text{m}$  size ranges, compared to the use of conventional treatment processes (Figure 6).

Figure 7 indicates a lower head loss for the filter on side 2, where pre-coagulation ozonation was applied.

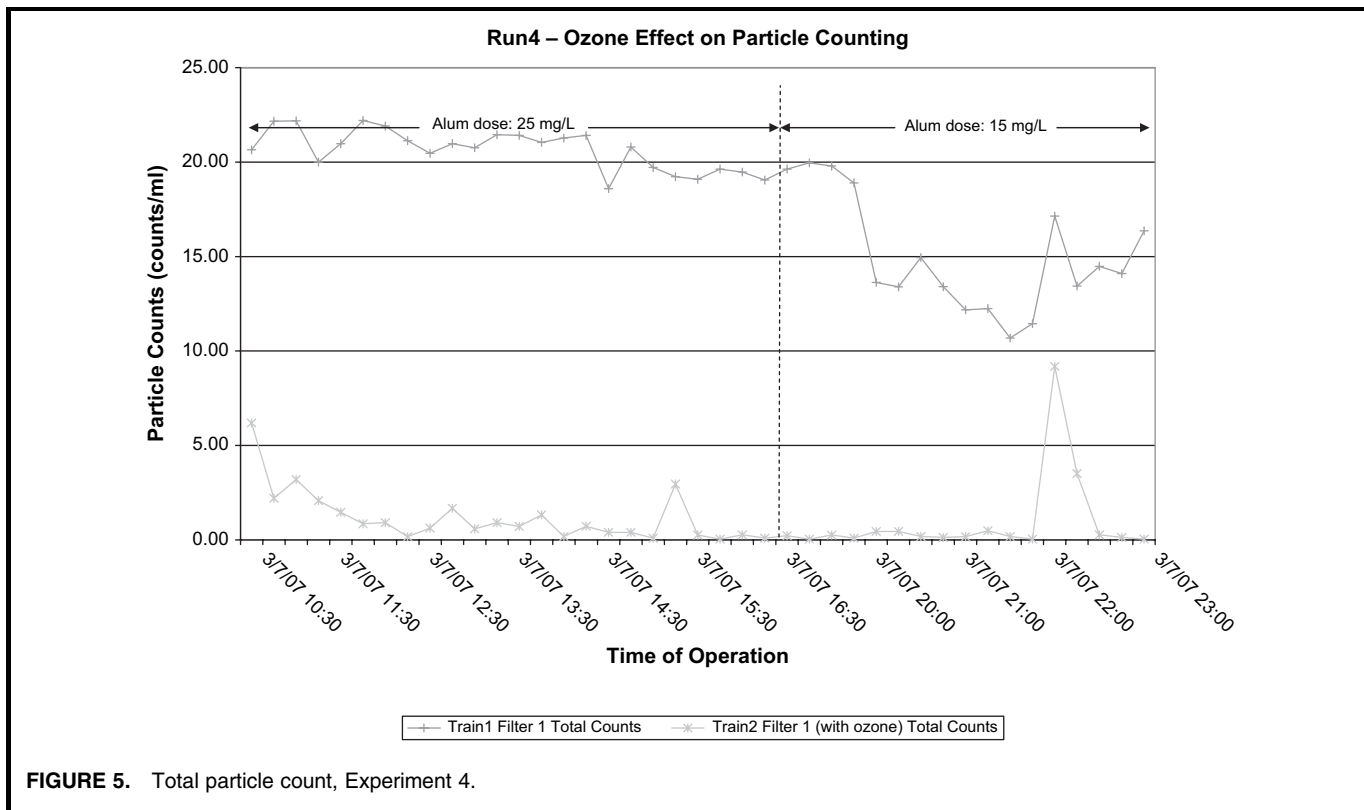


FIGURE 5. Total particle count, Experiment 4.

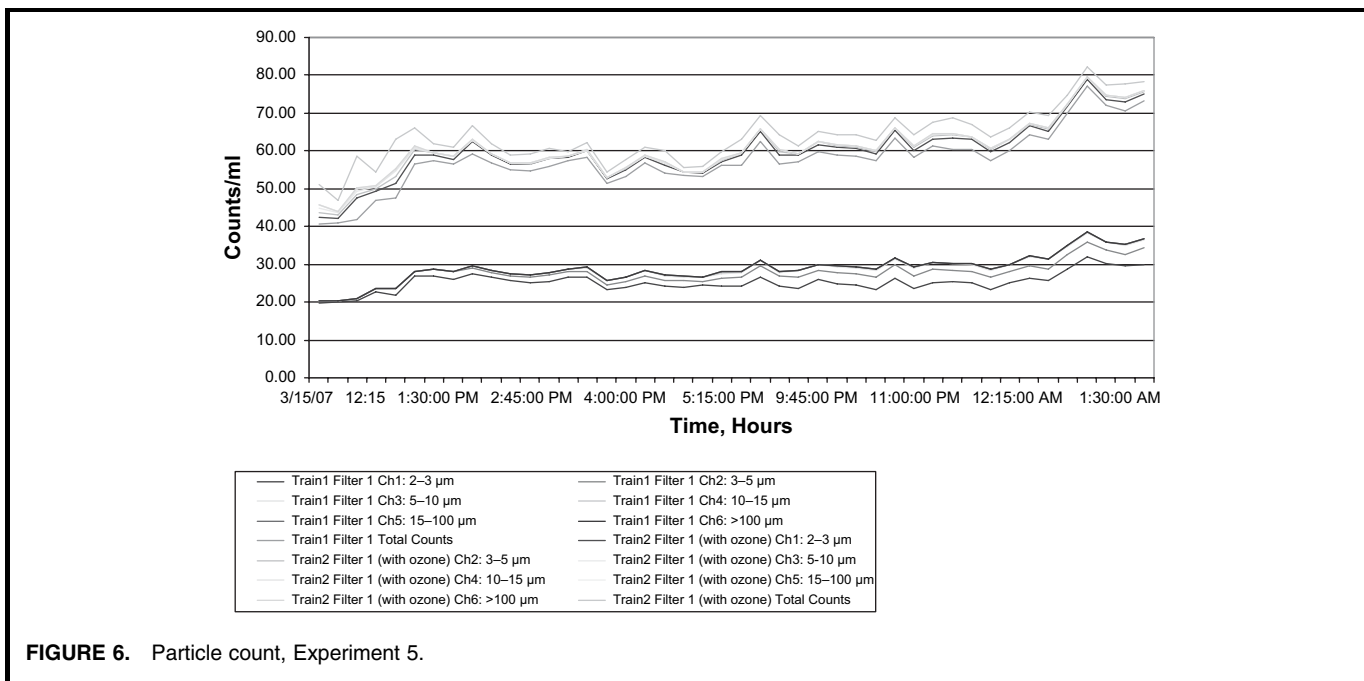


FIGURE 6. Particle count, Experiment 5.

That represents an important operational factor for water treatment operation when setting the parameters for filter backwash. Head loss increase is one of the parameters used to indicate the need to initiate a filter backwash.

The reduction of turbidity for sedimentation (Clarifier) effluent will have an important impact on filter run time. The current experiment did not allow for a continuous operation to achieve these findings due to the sever

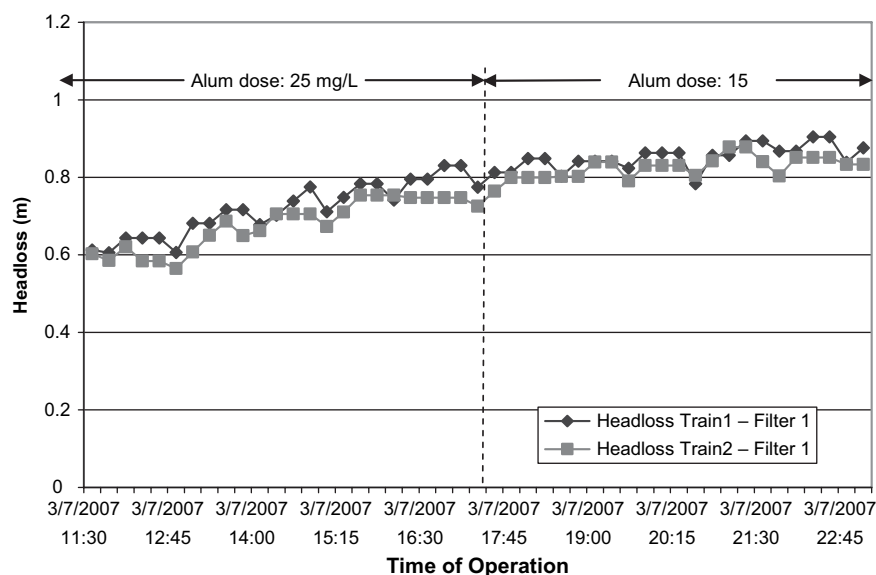


FIGURE 7. Filters head loss.

weather conditions which delayed the delivery of water from Lake Huron to the Centre. Future experiments will be able to obtain such information after the recent addition of another storage tank to provide longer operations for the pilot plant.

## CONCLUSION

Experiments conducted with a parallel train pilot plant at the Walkerton Clean Water Centre, Walkerton, indicated that ozone-induced coagulation and flocculation is possible for Great Lakes Water at cold water conditions, which is an important operational matter for many water treatment systems in Canada and the United States. Settled water turbidity was always lower on the side of the pilot plant where pre-coagulation ozone was applied. Dual-media (anthracite/sand) filter performance for turbidity was improved when pre-coagulation ozone was applied. In an effort to improve particle removal in drinking water treatment plants, utilities employing ozone may consider pre-coagulation ozonation to assist with particle removal. The use of pre-coagulation ozonation improved particle removal especially for size ranges of 2–3, 3–5  $\mu\text{m}$  and 5–10  $\mu\text{m}$ , compared to the non-ozonated side.

The experiments indicated the potential importance of particle counting as a tool to monitor filter performance and to optimize treatment processes. The project provided additional information to assist with considerations involving the advantages achieved using pre-coagulation ozonation for Great Lakes water at low temperatures.

## DISCLAIMER

The mention of commercial products does not constitute endorsement by the authors or funding agencies.

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