An innovative process for the treatment of high loaded surface waters for small communities

Patrick Niquette, Robert Hausler, Pierre Lahaye, and Maurice Lacasse

Abstract: Treatment trials have been realized with a new compact process in order to meet the drinking water regulation newly implemented in the province of Quebec. This process is especially designed for the supply of small communities. It combines complementary treatments operated by a centralized computer: ozonation, membrane filtration, and biological filtration, thus reducing operation to basic tasks. The process functioned very well for the period under review, in spite of extreme conditions met: cold water and constant fluctuation of the raw water quality. The process considerably lowers the contents of organic compounds (TOC, DOC, and color), the turbidity, the chlorine demand, and the concentrations of trihalomethane precursors present in the raw water. For this specific application, the backwash wastewaters may be mixed and discharged directly into a river nearby.

Key words: drinking water, small communities, ozonation, membrane filtration, biological activated carbon, turbidity, trihalomethane precursors, TOC.

Résumé : Des essais de traitement ont été réalisés dans le cadre de l'accréditation d'un nouveau procédé par le Comité sur les technologies de traitement en eau potable du gouvernement du Québec. Le procédé testé est compact et il est conçu spécialement pour alimenter les petites communautés. Il combine différentes étapes de traitement complémentaires (ozonation, filtration sur membrane et filtration biologique) et commandés par un système de contrôle automatique. Le procédé a très bien fonctionné pendant la période de suivi, malgré les conditions extrêmes rencontrées : eaux froides et fluctuation constante de la qualité de l'eau brute à traiter. Le procédé abaisse considérablement les teneurs de composés organiques (COT, COD et couleur vraie), la demande en chlore, les concentrations de précurseurs de trihalométhanes (SDS-THM) et la turbidité présentes dans l'eau brute. Dans le cas expérimenté, les eaux de lavage du tamis, des membranes et des unités de filtration peuvent être mélangées et rejetées directement dans le milieu environnant.

Mots clés : eau potable, petites communautés, ozonation, membrane, traitement biologique, turbidité, précurseurs de trihalomethane, COT.

Introduction

Stricter regulations concerning drinking water quality have been implemented in Canada. Small communities need to upgrade their existing drinking water treatment plants in order to respond to these new regulations. They necessitate compact treatment plants efficient and easy to operate. Premanufactured compact treatment plants are easily transported in a shipping container, which minimize construction costs, and they do not necessitate large on-site infrastructures.

In the province of Quebec, the new regulation requires that the treated water has trihalomethane levels below 80 μg/L, that turbidity of the treated water is low (below 0.1 nephelometric turbidity units, NTU, for membrane treated water) and that high removal of pathogen microorganisms occurs (the treated water must not contain pathogen organisms or indicator organisms of a fecal contamination, such as fecal coliforms, *Escherichia coli*, enterococcus bacteria, and coliphage viruses; Government of Quebec 2001). A new compact process must aim to meet this regulation. It has to combine complementary treatments removing particles, trihalomethane precursors, and microorganisms. The combination of ozone (inactivating pathogens and oxidizing trihalomethane precursors), membrane filtration (removing particles), and biological filtration (reducing chlorine demand and removing biodegradable organic matter) seems to be appropriate to achieve these objectives. The coupling of ozonation and biological activated carbon filtration is very effective to remove trihalomethane precursors (Niquette et al. 1999). The addition of a clarification step would help to remove pathogens and organic matter, but it needs the addition of coagulants and it produces sludge. Such a clarification step is not easy to operate in small communities where qualified staff is rare and, often, there is no municipal sewer where the clarification sludge may be disposed of.

The objective of the present study is to evaluate the combination of these processes. The government of Quebec requires that any new water treatment process equipment must undergo a 3 month pilot-scale trial. An official committee verifies their efficiency and, if the trial is successful, they issue an official

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P. Niquette[1] and R. Hausler. École de technologie supérieure, STation Expérimentale des Procédés Pilotes en Environnement (STEPPE-ÉTS), 1100, Notre-Dame West, Montreal, QC H3C 1K3, Canada.
P. Lahaye and M. Lacasse. Dagua inc. 1281, Industriel boulevard, Granby, QC J2J 2B8, Canada.

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[1]Corresponding author (e-mail: patrick.niquette@etsmtl.ca).

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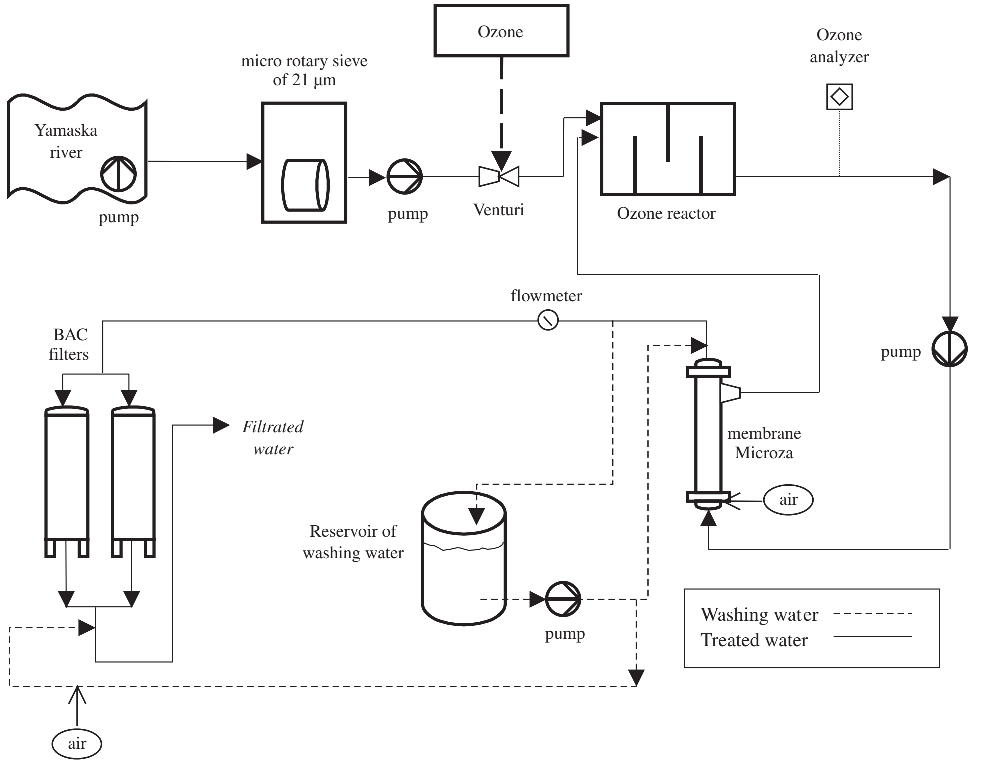
Fig. 1. Flow chart of the DaguaFlo UMF process.



accreditation. This accreditation enables the implementation of the full-scale treatment plant.

Materials and methods

A trial was conducted with the abovementioned compact treatment process. This trial was undertaken in the autumn and winter, from 17 October 2003 to 20 January 2004, when the raw water quality is fluctuating. The raw water quality was very unstable during the period in question. The raw water was pumped from the Yamaska River at the municipality of Farnham. This surface water is very contaminated by organic compounds, particles, and pathogenic microorganisms.

The process tested was the pilot plant version of the DaguaFlo UMF. It is very compact and it does not require coagulants. The flow schematic of the DaguaFlo UMF, pilot version, is shown in Fig. 1. The pilot plant is designed to treat 28 L/min (7.4 US gal/min) and it is automatically operated in a continuous mode, 24 h a day, 7 days a week. This process is composed of the following modules: micro rotary sieve of 21 μm, ozonation, ultra-micromembrane filtration, and biological activated carbon (BAC) filtration. A polyvinylidene fluoride (PVDF) venturi (Mazzei, model 978) insures ozone injection. An ozone residual concentration between 0.62 and 0.69 mg/L is maintained at the ozone contactor outlet, which has a detention time of 11.6 min. These conditions combined with the hydraulic efficiency of the ozonation contactor, which has four contact cells, insure a 3.09 log removal of *Giardia* cysts and a 6.67 log removal of viruses (MENV 2001).

The ultra-micromembrane is composed of inside-out PVDF capillary. The membrane was resistant to ozone and the presence of ozone on the membrane reduced the chemical backwashing frequency of the membrane. In fact, no chemical cleaning of the membrane was made during the 3 month trial because the transmembrane pressure of the membrane was stable (20 psig; 1 psi = 6894.76 Pa) and below the critical pressure (35 psig) recommended by the manufacturer. Only air–water backwashing was performed. The BAC filters had an empty bed contact time of 6.9 min. The adsorption capacity of the activated carbon (Calgon F400; effective size: 0.55–0.75 mm; uniformity coefficient: 1.9) had been saturated before the trial. The level of organic matter entering and exiting the BAC filter was followed with UV absorbance measurements during the start-up phase and the official study started when these levels were equivalent. Only adsorption can remove the organic UV absorbing compounds, which are double and triple bonded carbon compounds that autochthonous bacteria hardly remove. The industrial version of the process includes thereafter UV lamps insuring an additional 3 log removal of *Cryptosporidium* cysts and 3 log removal of *Giardia* cysts (to obtain the removal criteria of MENV 2001). This need for UV lamps would be eliminated if the government agrees with the latest tests with latex microspheres showing that the membrane is able to remove more than 5 log of these parasites. The industrial version also includes a chlorination step at the end of the process. So, the industrial system respects the disinfection regulation (*Ct*; *C* is disinfection concentration and *t* is effective contact time) for surface waters having a very strong contamination

Fig. 2. Configuration of a full-scale treatment plant (DaguaFlo UMF 150).

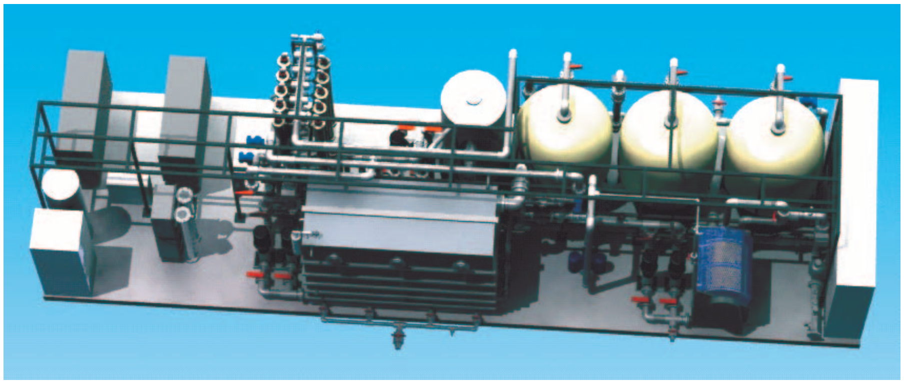


Table 1. Analyses made during the 3 month trial.

Parameters	Raw water	Water after membrane	Treated water	21 μm Sieve spent backwash waters	BAC filter spent backwash waters	Membrane spent backwash waters
pH (on-site)	13		13			13
Temperature (on-site)	13		13			13
Fecal coliforms	13		13			
Total coliforms	13		13			
HPC	13		13			
True color	13		13			
Total organic carbon	13		13			3
Dissolved organic carbon	13		13			3
Turbidity	13	13	13			3
Suspended solids				3	3	3
UV transmittance (254 nm)	13		13			
Ammonia	3		3			
Nitrites	3		3			
Nitrates and nitrites	3		3			
Chlorine demand	3		3			
Total alkalinity	6		6			
Calcium	6		6			
Total hardness	6		6			
Total iron	6		6			3
Total manganese	6		6			3
Dissolved solids	3		3			3
Suspended solids	3		3			3
Conductivity	3		3			
SDS-THM			3			
Bromates			3			
Bromides	3					

by pathogenic microorganisms (MENV 2001). This industrial version may serve small communities with a nominal drinking water production varying from 50 m^3/d to 4 900 m^3/d. Figure 2 shows an example of a full-scale plant in a container able to treat 820 m^3/d (150 US gal/min) and able to supply about 1800 persons.

The analytical parameters were measured by a professional laboratory according to standard methods (APHA et al. 1995). They include total organic carbon (TOC; Method # 5310 C: Persulfate-Ultraviolet Oxidation Method), dissolved organic carbon (DOC; Filtration on 0.45 μm followed by Method # 5310 C: Persulfate-Ultraviolet Oxidation Method), UV transmittance (Method # 5910 B: Spectrophotometric Method), true color (Method # 2120 C: Spectrophotometric Method), fecal coliforms (Method # 9222 D: Membrane Filter Procedure), total coliforms (Method # 9222 A: Membrane Filter Technique), heterotrophic plate counts (HPC; Method # 9215), total iron (acid digestion followed by Method # 3120 B: Induction Coupled Plasma Analysis), total manganese (acid digestion followed by Method # 3120 B: Induction Coupled Plasma Analysis),

Fig. 3. Concentrations of TOC in the raw water and in the treated water.

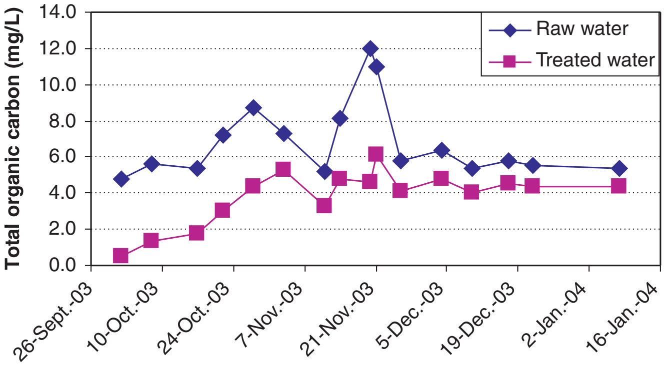


Fig. 4. Concentrations of DOC in the raw water and in the treated water.

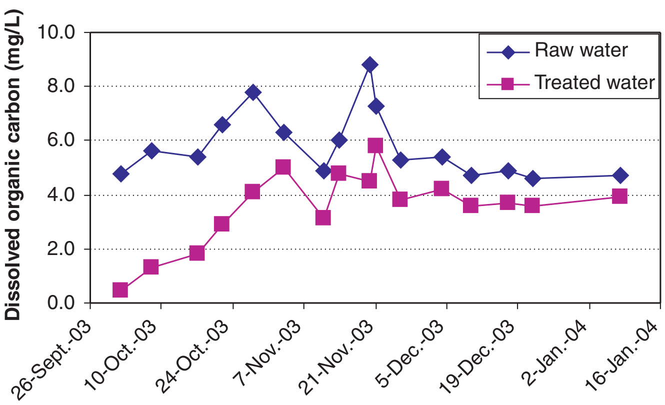


Fig. 5. True color measured in the raw water and in the treated water.

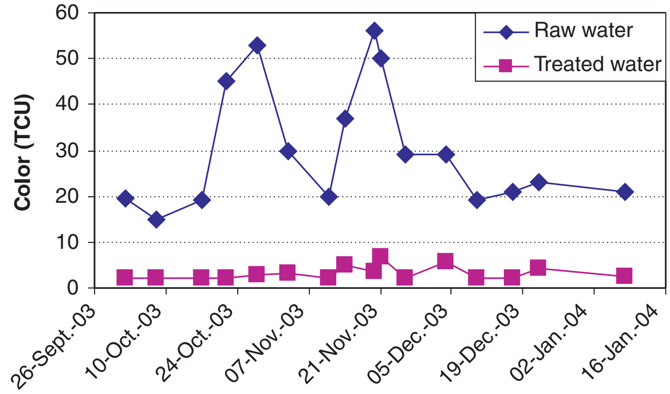
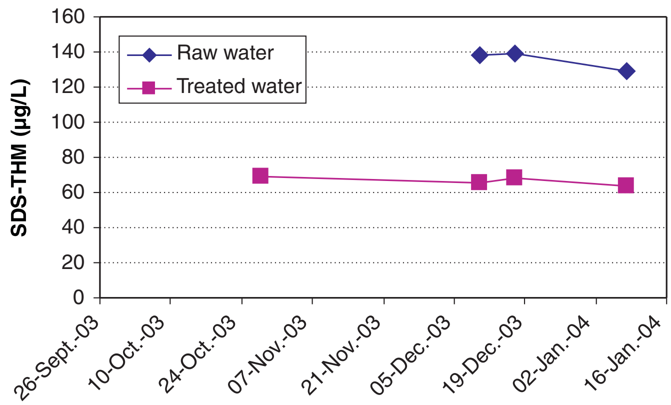


Fig. 6. Concentrations of SDS-THM measured in the raw water and in the treated water.



ammonia (Method # 4500-NH_3 D: Ammonia-Selective Electrode Method), nitrites (Method # 4500-NO_2^- B: Colorimetric Method), nitrates (Method # 4500-NO_3^- D: Nitrate Electrode Method), chlorine demand (Method # 2350 B: Chlorine demand based on a residual chlorine of 0.5±0.2 mg/L after 24 h), trihalomethanes formed in conditions of distribution (SDS-THM; Method # 5710 C with incubation at in situ pH and temperature, incubation time of 24±1 h; residual chlorine of 0.5±0.2 mg/L), total hardness (based on calcium and magnesium concentrations), calcium (acid digestion followed by Method # 3120 B: Induction Coupled Plasma Analysis), total alkalinity (Method # 2320 B: titration method), suspended solids (Method # 2540 D: total suspended solids dried at 103–105 °C), conductivity (Method # 2510), bromides (Method # 4500-Br^-: phenol red colorimetric method), and bromates (Method # 4110: Ion Chromatography). These parameters were measured with a frequency respecting the sampling protocol prescribed by the committee.

On-line parameters were also measured: turbidity (measured by three Wallace & Tiernan turbidimeters, model TMS 561), temperature (thermometer), pH (Hannah electrode), and ozone residual (Prominent, model OZE 3). The ozone electrode was calibrated using a colorimetric method (Hach, DR-2000). Table 1 summarizes the location of the samples taken and the results of the analyses performed during the 3 month trial.

Results and discussion

Parameters measured on the raw water and the treated water

The Daguaflo-UMF process functioned very well for the period under investigation, in spite of the extreme conditions encountered: cold water and constant fluctuation of the raw water quality, which was much degraded.

The process considerably lowers the content of organic compounds. The physical removal by the membrane (for the removal of particulate organic matter) and the combined action of the ozone contactor and the BAC (for the removal of biodegradable dissolved organic carbon) reduce many parameters linked to the organic content of the treated water: TOC, DOC, true color, SDS-THM, and UV Transmittance. The concentration profiles of TOC and COD are respectively shown in Figs. 3 and 4. Average removals of TOC and COD through the study where 38.5% and 31.4%, respectively. The true color of the treated water, shown in Fig. 5, was well below the aesthetic criteria of 15 true color units (TCU) prescribed by the Canadian recommendations (Government of Canada 2004). They were below the detection limit of the analytical method used (2.0 TCU). The concentrations of SDS-THM (Fig. 6) measured in the raw water, 135.5 μg/L, were reduced below the maximum regulated in the

Fig. 7. UV transmittance before and after the process.

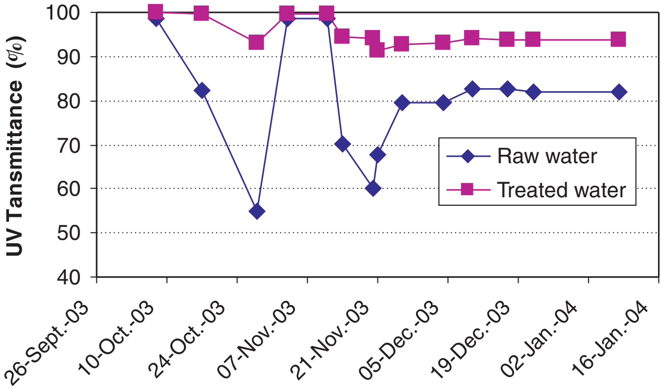


Fig. 8. Turbidity of the raw water.

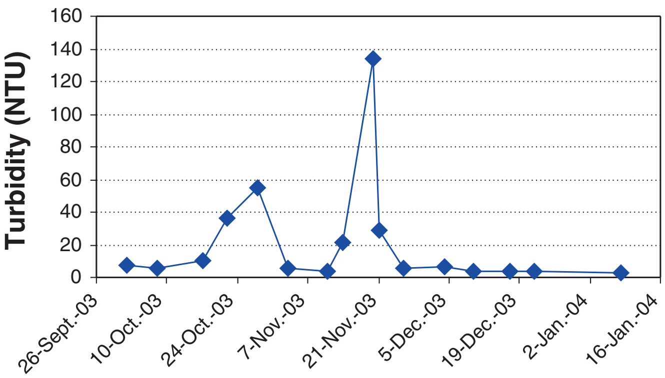


Fig. 9. Turbidity of the treated water.

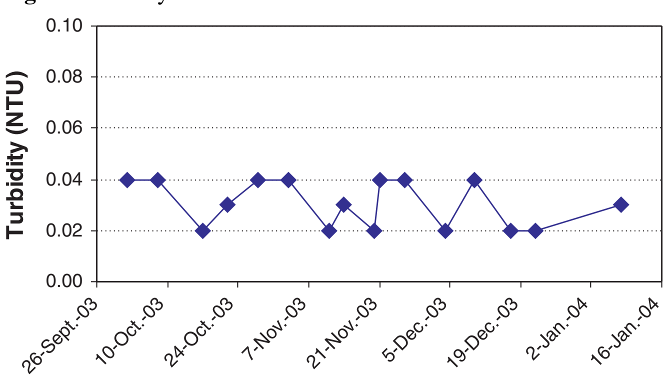


Fig. 10. Concentrations of total coliforms in the raw water.

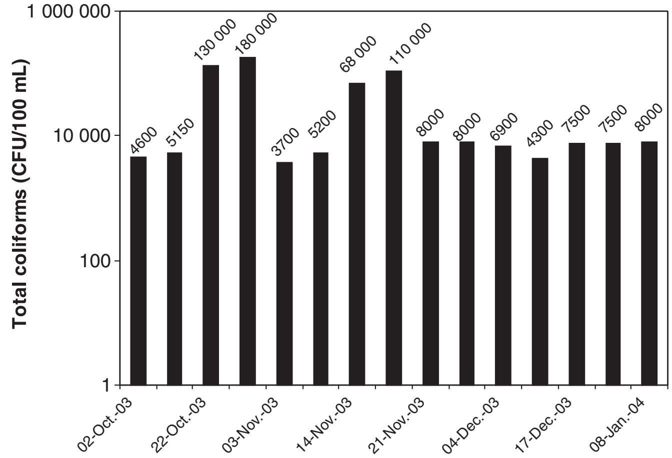
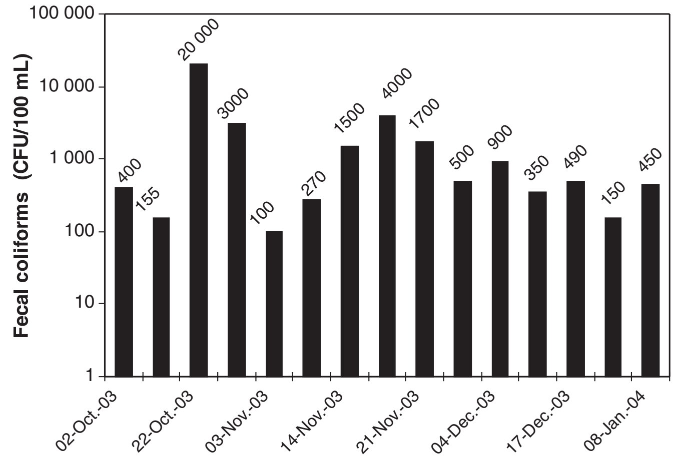


Fig. 11. Concentrations of fecal coliforms in the raw water.



province of Quebec, 80 μg/L (Government of Quebec 2001), and the maximum recommended by the government of Canada (2004), 100 μg/L. Another study undertaken with a similar process in similar conditions (results not shown) revealed that ozonation and BAC filtration considerably reduced the concentrations of SDS-THM in spite of the cold temperature of the treated water (Niquette 2003). Ultraviolet transmittance of the treated water increased with an average value of 88.9% after treatment (Fig. 7).

The turbidity of the raw water was considerably lowered by the process. Figure 8 shows the raw water turbidity and Fig. 9 illustrates the turbidity of the treated water. Even when the raw water turbidity reached 134 NTU, the membrane process constantly maintained turbidity below the 0.1 NTU prescribed for membrane filtration (Government of Quebec 2001) and treated water had a turbidity lower than 0.5 NTU (MENV 2001). This efficiency indicates that the membrane was working satisfactorily.

Bacteriological results showed that the use of the Daguaflo-UMF process followed by a final disinfection would meet the standards. In spite of the high levels of total coliforms (Fig. 10) and fecal coliforms (Fig. 11) detected in the raw water, no coliform was detected in the treated water. The high dose of ozone residual maintained in the ozone contactor, between 0.62 and 0.69 mg/L, is responsible for this efficiency.

No bromide was detected in the influent (below 0.1 mg/L) of the pilot process and no bromate was detected in the effluent. The bromate concentrations were below the detection limit of the analytical method used (2.0 μg/L), thus satisfying the maximum concentration of 10 μg/L (Government of Quebec 2001; Government of Canada 2004). Song et al. (1997) found that bromate ion formation is an important consideration for waters containing more than 0.10 mg/L bromide ion. The iron concentrations in treated water are very low (average of 0.03 mg/L).

Table 2. Suspended solids in the backwash wastewaters.

	Suspended solids (mg/L)
Mixed backwashing waters	10
Backwashing waters after a settling of 15 min	6
Backwashing waters after a settling of 30 min	4

Table 3. Official chart for the use of DaguaFlo UMF as a full-scale drinking water plant.

Measured parameters	Raw water
Turbidity (NTU) (95% of the samples)	<55
Turbidity (NTU) (maximum)	134
TOC (mg/L) (95% of the samples)	<8.7
TOC (mg/L) (maximum)	12
Color (TCU) (95% of the samples)	<53
Color (TCU) (maximum)	56
Bromides (μg/L) (maximum)	100
Other parameters measured at Farnham	
Fecal coliforms (CFU/100 mL) (maximum)	20 000
Temperature	2.0 to 9.2 °C
pH	6.9 to 7.6
Total alkalinity (mg/L $CaCO_3$)	39 to 50
SUVA (L mg^{-1} cm^{-1})	2.5 to 5.8

The pH (close to neutrality), total hardness, calcium concentration, total alkalinity, and conductivity remained at stable values before and after treatment. The average concentrations of iron, ammonia, and nitrites were very low in the treatment effluent (corresponding average of 0.03 mg Fe/L, 0.07 mg NH_4-N/L and 0.02 mg NO_3-N/L). The measured temperatures of the raw water were very cold, between 2.0 °C and 9.2 °C. The biological filtration was thus functioning at it lowest capacity. The combined concentration of nitrates and nitrites of 0.89 mg/L was well below the regulated levels of 10 mg/L in Quebec (Government of Quebec 2001) and 45 mg/L in Canada (Government of Canada 2004). Except for one measurement on 28 October, manganese concentrations were below the aesthetic standard of 0.05 mg/L as set by the Government of Canada (2004). The Mn concentration of 0.063 mg/L measured in the effluent on 28 October is not a problem because the concentration of manganese measured in the raw water this day, 0.28 mg/L, is unusual for surface water. Iron and manganese removals could also be optimized by the adjustment of the ozone treatment that is transforming these metals into particles, which are removed by the following membrane filtration (Bellamy et al. 1991).

Parameters measured on the backwash wastewaters

The membrane, resisting ozone, did not require any chemical backwashing. The industrial version of the process will be equipped with a peroxide feed in case chemical cleaning would be necessary. The backwash wastewaters of the micro rotary sieve and of the membrane could be mixed in a settling pond (in the case of an industrial process), where the residual ozone will be dissipated and where the suspended matter will settle. This mixing will attenuate the impact of the discharge and small concentrations of suspended solids are thus released into the environment. A mixing test was carried out on the proportional mixture of the backwash wastewaters of the micro rotary sieve and the backwash wastewaters of the membrane (see Table 2). Their combination meets the maximum level for suspended solids, 20 mg/L (MENV 2001), that could be released directly in the environment. The spent backwash waters of the BAC filters satisfies this maximum limit, with an average load of suspended solids of 6 mg/L and a maximum load of 12 mg/L.

Conclusion

The official Quebec committee judged that the quality of the results obtained at the time of the process trial validated its use as a full-scale drinking water treatment. The application of the process remains limited to all the raw waters having characteristics that correspond to the obligatory parameters summarized in Table 3. The values of these regulated parameters were met during this study.

The high UV transmittance of the treated water (Fig. 7) and the low iron concentrations in the treated water facilitates the use of an UV lamp as post-disinfection of the treatment. The removal of coliforms obtained during this study showed that the ozonation step already inactivated pathogen microorganisms.

In spite of a turbidity peak reaching 134 NTU in the raw water, the water treated by the membrane had a turbidity (average of 0.03 NTU) lower than the standard of 0.1 NTU prescribed for membrane filtration (Government of Quebec 2001) and the treated water had a turbidity lower than 0.5 NTU (MENV 2001). No bromate was detected in the effluent of the pilot process, thus the standard of 10 μg/L was met (Government of Quebec 2001; Government of Canada 2004). Regardless of the cold temperature of the treated water (minimum of 2.0 °C), the biological activity in the activated carbon filter and the ozone contactor considerably reduced the concentrations of precursors of trihalomethanes. As for the other measured physicochemical parameters, the membrane process preceded by an ozonization removes iron and manganese present in the raw water without demineralizing the treated water. In fact, the alkalinity, the conductivity, the calcium concentration, and the hardness of the raw water were unchanged. The nitrite concentrations and the concentrations of nitrites and nitrates were clearly below the regulated levels.

Concerning the backwash wastewaters from this process, they could be mixed in a settling pit before disposal. The possible use of such a pit in future applications has to be determined by additional pilot tests. The amount of suspended solids present in the backwash wastewaters would determine if these backwash wastewaters could be released into a river or, at best, in a nearby sewer, which is often not available in rural communities.

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