Development of a Full-Cycle Water Remediation Process

L. Yerushalmi* and B. Seyhi**

* Dagua Technologies Inc., 1010 Ste. Catherine Street West, # 730, Montreal, Canada, H3B 5L1
(E-mail: *lyerushalmi@dagua.com*)

** Centre des technologies de l'eau (CTE), Montreal, Canada
E-mail : (*bseyhi@cteau.com*)

Abstract
The development of a full-cycle water remediation process, transforming wastewaters into fresh water is presented. The developed water remediation process treated the effluent of a full-scale wastewater treatment plant by ozonation and ultrafiltration membrane processes. The wastewater treatment process reduced the organic and inorganic content of wastewater and clarified the effluent. The treated effluent was subjected to chemical softening process before passing through the ozonation and ultrafiltration membrane processes to remove or reduce the concentrations of remaining contaminants, including colour, turbidity, suspended solids, iron and pathogenic substances. The full-cycle water remediation process produced an advanced treatment capability in providing a significant source of fresh water for a variety of end-uses in municipal, industrial or agricultural operations or drinking water.

Keywords
Full-cycle water remediation; fresh water; ozonation; membrane ultrafiltration

INTRODUCTION

Wastewater reclamation and reuse, materialized by the advanced treatment of effluents emerging from wastewater treatment plants, provides a significant source of fresh water for a variety of end-use, including irrigation, industrial processes, aquifer recharge, or drinking water (Niquette et al. 2007; Mirza, 2014). The importance of water treatment is increasing at a higher rate than anticipated due to the rising demands of economic development, urbanization, agricultural and industrial expansion, along with insufficient supply of freshwater, poor quality of existing freshwater resources, inadequate water distribution and climate change. A more efficient use of water resources including water reuse practices will provide an important source of fresh water, directly addressing the existing water stress. The developed full-cycle water remediation system transformed the effluent of the full-scale municipal wastewater treatment plant in Farnham, Canada, by using the DaguaFlo technology, a drinking water treatment technology that combines ozonation and ultrafiltration membrane processes (Yerushalmi, 2014). Ozonation degrades dissolved organic compounds, oxidizes inorganic substances and disinfects water by killing the pathogenic substances. The follow-up membrane ultrafiltration process further removes the suspended and colloidal particles and improves the turbidity and colour of water. The combined use of these processes is also efficient in the removal of emerging contaminants such as pharmaceutical compounds, hormones and antibiotics that are commonly found in surface waters and resist degradation by the conventional biological and physical-chemical treatment processes (De la Cruz et al., 2012).

METHODOLOGY

Process description

The full-cycle water remediation process used the DaguaFlo technology that contains ozonation and ultrafiltration membrane processes to transform the effluent of a municipal wastewater treatment plant (WWTP) into drinking water. The WWTP plant, located in Farnham, Canada, consists of a grit removal unit for the removal of solid objects and particulate matter, followed by an oxidation ditch for the removal of biodegradable organic matter by biological processes, and finally a clarifier for the separation of solids from liquid and production of a clear and well-treated effluent. The Farnham WWTP is designed for the mean wastewater flow rate of 10,750 m^3/d and the mean BOD_5 of 1,530 kg/d. The effluent of this treatment plant has a BOD_5 concentration of 14 mg/L and a total hardness of about 200 mg/L (as $CaCO_3$).

The effluent from the Farnham WWTP passed through a chemical softening process for the removal of water hardness before entering the DaguaFlo technology for the production of fresh water. The DaguaFlo technology consists of a pre-filtration unit, an ozone injection system containing a venturi injector, a reaction chamber for proper disinfection and oxidation of contaminants, and ultrafiltration membranes for complete decontamination and production of drinking water that emerges downstream of the membranes. The schematic diagram of the full-cycle water remediation process is presented in Figure 1.1.

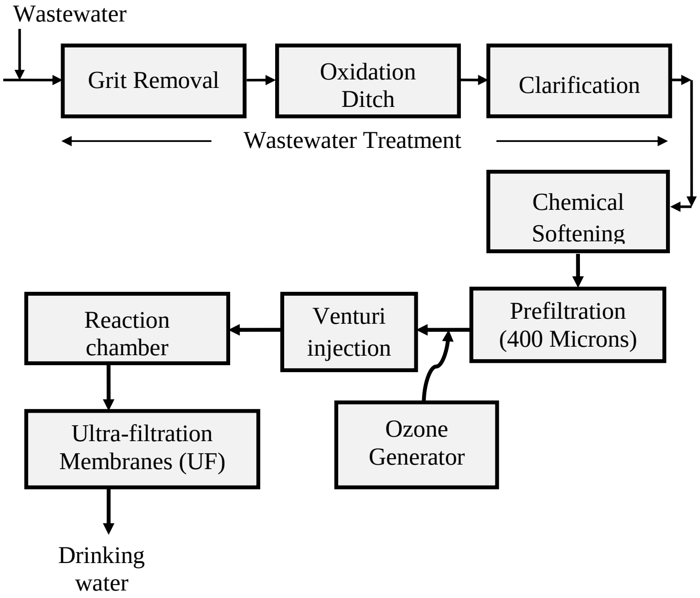

Figure 1.1. Schematic diagram of the full-cycle water remediation process

Chemical softening process

Water hardness is commonly present as calcium and magnesium salts. The softening process used chemical precipitation to reduce the water hardness to values below 30 mg/L. The removal of hardness is recommended as it will prevent scaling in the pipes and equipment and inside the membranes that may cause damage to the equipment and membranes and deteriorate their function and their useful life.

The optimum operating conditions for the softening of water were obtained by conducting laboratory experiments in 2000 mL flasks at 1000 mL working volume. Calcium hydroxide

($Ca(OH)_2$) at concentrations of 0.05 to 0.9 g/L, sodium hydroxide (NaOH) (30%) and sodium carbonate ($NaCO_3$) at concentrations of 0.2 g/L to 10 g/L were examined for the softening of water at pH values ranging from 9 to 11.

Operation setup and conditions

The reported full-cycle water remediation operation was conducted in a pilot-plant unit that has a treatment capacity of 100 m^3/day and uses the DaguaFlo technology for the production of drinking water from surface waters (Figure 1.2). The operation of this pilot plant has been demonstrated and reported before (Niquette et al., 2007).

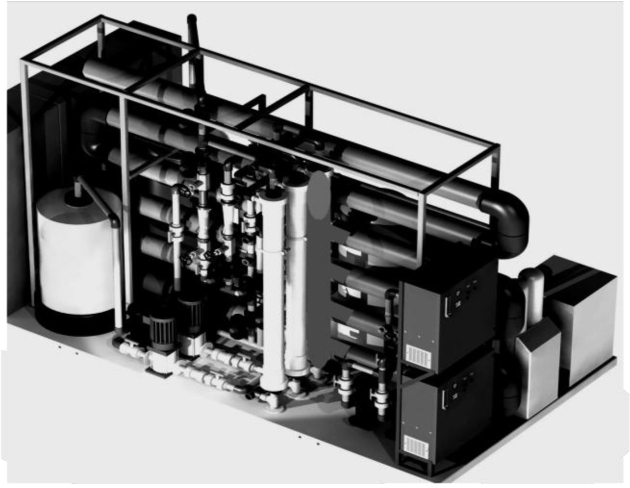

Figure 1.2. Pilot-scale installation (100 m^3/d) of the DaguaFlo technology for the transformation of wastewater effluent into drinking water

In the present study, the pilot plant was modified to accommodate for the removal of water hardness by chemical precipitation. During the operation, water initially passed through a prefiltration unit that contained a rotary sieve with a pore size of 400 microns to remove solid objects and particulate matter from the water and for initial water clarification. Water then passed through a cylindrical tank (150 m^3) equipped with dosing pumps for the addition of softening chemicals at optimum concentrations. After the removal of hardness, water was injected with ozone by a venturi injector (Mazzei, California, USA) for high mass transfer and efficient dissolution of ozone in water. Ozone was generated from air by using a Pinnacle Plasma QuadBlock® ozone generator (Florida, USA), producing 8-10% ozone (w/w). Ozone is used for the disinfection and chemical oxidation of contaminants. As a powerful natural disinfectant gas, more active than chlorine, ozone removes pathogenic substances including viruses, bacteria and *Giardia* and *Cryptosporidium* protozoa. As a powerful oxidant, ozone oxidizes organic and inorganic contaminants, promotes coagulation of suspended and colloidal particles, and removes taste, colour and smell that are referred to as organoleptic properties of water, and improves water clarification. Ozone also removes or reduces the concentrations of trace contaminants that result from industrial and pharmaceutical operations and gasoline additives, and reduces the content of iron and manganese in water. The ozonated water passed through a reaction chamber with a retention time of 5 minutes for proper disinfection and oxidation of contaminants. The water emerging from the reaction chamber passed through a degassing unit for gas-liquid separation and removal of non-dissolved gases from the water. The gas-saturated water passed through the ultrafiltration membrane for the removal of colloidal and suspended particles and further improvements to the turbidity and colour of water, resulting in the production of drinking water. One ultrafiltration (UF) membrane module containing polyvinylidene difluoride (PVDF) hollow fiber membranes (Memstar, Singapore) was used in this process. The UF membrane had an active membrane surface of 40 m^2, pore size of <0.1 micron and operated at a filtration flux of 40-50 $L/m^2/h$. The operating pressure of the treatment process was maintained at 30-40 psi.

Membrane cleaning and fouling prevention mechanism

The DaguaFlo technology benefits from the generation of microbubbles and their use to prevent membrane fouling, contributing to the continuous cleaning of membranes without using chemicals. Microbubbles are generated due to the transmembrane pressure gradient that transforms the dissolved gases into microbubbles when the gas-saturated water passes through the membranes. The microbubbles contribute to the continuous cleaning of membranes and prevention of their clogging by several physical-chemical mechanisms including scrubbing and self-collapse that creates pressure waves, contributing to the detachment of deposits (Agrawal et al., 2012). In addition to oxygen and nitrogen, the microbubbles also contain ozone that will be decomposed and produce OH radicals, promoting the oxidation of organic matter and enhancing the destabilization of colloidal particles, further preventing the attachment of fouling material to the membrane capillaries.

The effect of continuous membrane cleaning and fouling prevention mechanism has been demonstrated by the maintenance of transmembrane pressure (TMP) below the critical membrane pressure of 35 psi during full-scale operations of the DaguaFlo technology. A schematic diagram of the Dagua technology is presented in Figure 1.3.

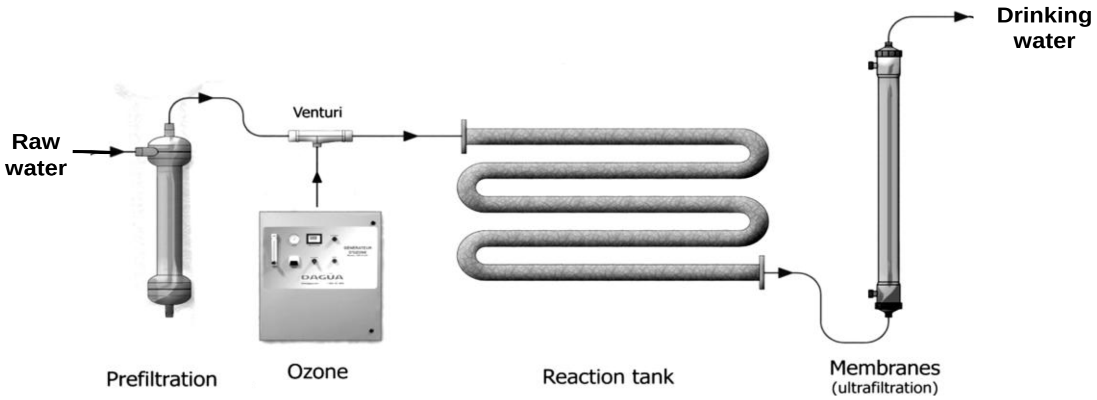

Figure 1.3. Schematic diagram of the Dagua drinking water treatment technology

RESULTS AND DISCUSSION

Removal of water hardness

The results of hardness removal tests from the effluent of wastewater treatment plant are presented in Figure 2.1. Using calcium hydroxide (lime) alone at 0.2 g/L, the maximum removal of hardness was 35.7%. The addition of $NaCO_3$ at 2 g/L in the presence of lime at 0.2 g/L improved the hardness removal efficiency to 79.7%, while the use of NaOH alone, raising the water pH to 11, produced a removal efficiency of 70%. The highest reduction of hardness below 30 mg/L, representing 89% removal efficiency, was obtained when a combination of lime (0.2 g/L) and NaOH was used at pH 11.

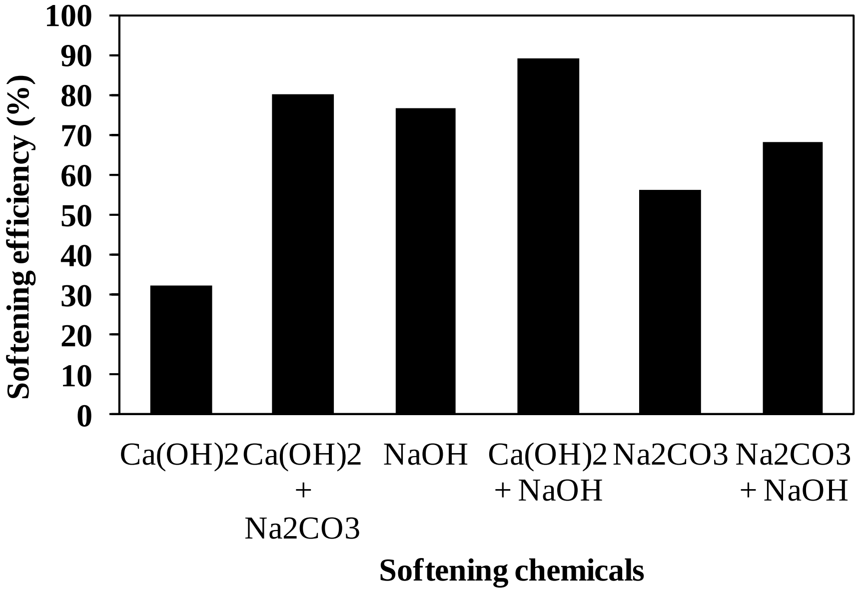

Figure 2.1. Water softening efficiency in response to the softening chemicals

Removal of turbidity and pathogens

During the pilot-scale operation, the removal of turbidity at the efficiency of 97% was achieved consistently by the UF membrane (Figure 2.2), producing a final turbidity of 0.2 NTU in the treated water, while the true colour completely disappeared from around 10 TCU to <1 TCU (Table 1).

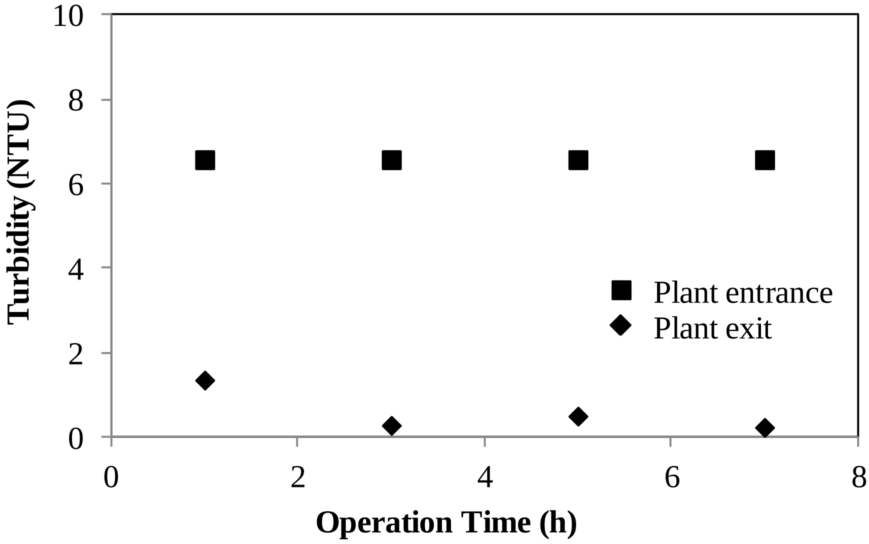

Figure 2.2. Removal of turbidity by the Dagua technology

The fecal *coliform* and *E.coli* bacteria, representing pathogenic substances, were completely removed during the ozonation process from an initial value of 5900 CFU/100 mL fecal *coliform* and 5500 CFU/100 mL *E. coli* (Table 1). Ozonation also reduced the iron concentration in water from 0.8 mg/L to <0.3 mg/L.

A steady transmembrane pressure (TMP) was maintained during the entire operation of the treatment process.

Table 1. Removal of pathogens and colour by the Dagua technology

Parameter	Value (plant entrance)	Value (plant exit)
Coliform bacteria (CFU/100 mL)	5900	<10
E. coli (CFU/100 mL)	5500	0
Colour (TCU)	10	<1

CONCLUSIONS

The developed full-cycle water remediation process used ozonation and ultrafiltration membrane processes to transform the effluent of a wastewater treatment plant into fresh water. The developed water remediation process provides a dependable source of water for industrial and agricultural use, and offers important environmental benefits by reducing the diversion of water from sensitive ecosystems, decreasing wastewater discharges and preventing pollution.

REFERENCES

1. Agarwal, A., Xu, H., Ng W.J. and Liu, Y. (2012) Biofilm detachment by self-collapsing air microbubbles: a potential chemical-free cleaning technology for membrane Biofouling. *J. Mat. Chem.* **22**, 2203-2207.
2. De la Cruz, N., Giménez, J., Esplugas, S., Grandjean, D., De Alencastro, L. and Pulgarin, C. (2012) Degradation of 32 emergent contaminants by UV and neutral photo-fenton in domestic wastewater effluent previously treated by activated sludge. *Wat. Res.* **46**(6), 1947-1957.
3. Misra, A.K. (2014) Climate change and challenges of water and food security, *Int. J. Sustainable Built Environ.* **3**(1), 153-165.
4. Niquette, P., Hausler, R., Lahaye, P. and Lacasse, M. (2007) An innovative process for the treatment of high loaded surface waters. *Environ. Eng. Sci.* **6**, 139-145.
5. Van Der Bruggen, B., Vandecasteele, C., Van Gestel, T., Doyen, W. and Leysen, R. (2003) A review of pressure-driven membrane processes in wastewater treatment and drinking water production, *Environ. Prog.* **22**(1), 46-56.
6. Yerushalmi L. (2014) Drinking water treatment using the combined ozonation and membrane ultrafiltration processes. *Proc. of the International Ozone Association,* Montreal, Canada, 23-27 August.