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Development of a full-cycle water remediation process

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Abstract

A full-cycle water remediation process has been developed by expanding the capacity of an existing water treatment technology that uses combined ozonation and ultrafiltration membrane processes. The developed water reclamation process treated the effluent of a full-scale wastewater treatment plant in Canada that uses biological treatment processes to treat municipal wastewater, and reduced the colour, turbidity, suspended solids, iron and pathogen content of the effluent. The removal of hardness from the wastewater effluent was accomplished by the precipitation process. The use of lime (0.2 g/L) in the presence of NaOH operating at pH 11 showed the best results, reducing the water hardness by 89.1%. The advanced treatment capability of ozonation (8–10% w/w) and polyvinylidene fluoride (PVDF) hollow fiber ultrafiltration (UF) membrane produced a reliable source of water for municipal, industrial and agricultural use. The developed process offers important environmental benefits by reducing the diversion of water from sensitive ecosystems, decreasing wastewater discharge and preventing pollution.

Key words: membrane ultrafiltration, ozonation, wastewater reclamation, wastewater reuse

INTRODUCTION

Water scarcity is a global problem which is growing rapidly and affects economic development, expansion of industrial and agricultural activities and human health. The population under water scarcity increased from 0.24 billion (14% of the global population) in the 1900s to 3.8 billion (58%) in the 2000s (Kummu *et al.* 2016). By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under conditions of water stress (UN-Water 2007).

Wastewater reclamation and reuse, materialized by the advanced treatment of wastewater treatment plants' effluent, provides a significant source of fresh water for a variety of end uses, including municipal activities, irrigation, industrial processes, aquifer recharge, and drinking water (Angelakis & Bontoux 2001; Friedler 2001; Vourch *et al.* 2008; Yi *et al.* 2011; Jaramillo & Restrepo 2017). 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 (Misra 2014). A more efficient use of water resources including water reuse practices will provide an important source of fresh water for potable and non-potable applications, directly addressing the existing water stress.

In addition to providing a clean and reliable source of water for municipal, industrial and agricultural use, wastewater recycling coupled with water conservation will contribute to waste management and pollution prevention, supporting the sustainable management of vital water resources. Recycled water can also be used to create or enhance wetlands and riparian habitats. Moreover, wastewater reclamation and water reuse deliver cost benefits compared to seawater desalination, since the lower salinity of wastewater reduces energy consumption for reuse compared to seawater desalination (Madwar & Tarazi 2003; Cartwright 2013). The city of San Diego is currently studying the feasibility of recycling wastewater from the Point Loma Wastewater Treatment plant for drinking (Ghernaout 2018). Jaramillo & Restrepo (2017) reviewed the effects of wastewater reuse in agriculture and stated that the use of treated wastewater in agriculture benefits human health, the environment and the economy. In particular, the use of treated wastewater as an alternative irrigation source in agriculture reduces the pressure on valuable water resources since agriculture is the greatest global water user, consuming 70% of available water (Pedrero *et al.* 2010; Jaramillo & Restrepo 2017).

Wastewater reclamation systems usually use a combination of physical and chemical processes for removing contaminants from the treated effluent of wastewater treatment plants, depending on the type and concentration of contaminants and the target application of the treated water. These processes include coagulation, flocculation and chemical precipitation, as well as carbon adsorption, media filtration, membrane filtration, advanced oxidation processes and disinfection (Friedler 2001; Casani *et al.* 2005). Non-potable water use, which is currently the main application of reclaimed water, commonly employs conventional reclamation systems that rely on chemical processes. The produced water can be used in applications such as fire fighting, street washing, toilet flushing, irrigation of parks and golf courses, process water for selected industrial applications, artificial lakes, and hydraulic fracturing (California Department of Water Resources 2004; Levine & Asano 2004).

The advanced treatment of tertiary-treated effluent from wastewater treatment plants by advanced water treatment technologies that rely on various combinations of membrane bioreactors (MBR), microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), advanced oxidation processes (AOP) and ozone or UV disinfection can produce highly-purified water for industrial applications such as manufacturing semi-conductors or drinking water that conforms to rigorous standards for potable water. The use of membrane-based systems during full-cycle water remediation processes is gaining momentum since they produce an effluent with superior quality compared to conventional systems that rely on chemical processes (Wintgens *et al.* 2005). Besides, chemical processes use a great amount of chemicals and produce a large volume of metallic waste that needs careful handling and treatment. The use of membrane technologies will reduce the number of unit operations and the complexity of the process, while improving the reliability and consistency of treatment operation compared to conventional systems (Cartwright 2013). Membrane-based systems offer automatic operation and a greater potential to remove added contaminants. Additionally, they are capable of adapting to changes in operating conditions. The improved reliability, reduced complexity and the lower number of unit operations make the membrane-based systems economically viable, environmentally sustainable and more cost-effective compared to conventional water reclamation systems. Among the membrane technologies, MF, UF and RO have gained more attention due to their superior performance and reliability and improved economics. These technologies have been used in water reuse applications including artificial groundwater recharge, indirect and direct potable reuse as well as for industrial process water production (Levine & Asano 2004; Xu *et al.* 2010). Mavrov & Bélières (2000) showed that NF and low-pressure RO followed by UV disinfection produced drinking water from chiller shower water in the meat processing industry and from wash water in bottle-washing machines. Since 2003, Singapore has been producing NEWater, which is reclaimed water used for both direct non-potable use (DNPU) and indirect potable use (IPU) by employing advanced membrane processes including MF and RO followed by UV disinfection (Wintgens *et al.* 2005; Lafforgue & Lenouvel 2015).

The combined use of ozonation and membrane processes in reclamation and reuse of wastewater has also been reported. Pre-ozonation has often been used to reduce the fouling and clogging of membranes through the decomposition of organic contaminants in water. Seo *et al.* (2001) used ozonation and hollow fiber UF membrane for the reclamation of domestic laundry wastewater, and showed that the reclaimed water could be used for rinsing purposes, while ozone injection reduced membrane fouling. Similarly, Fujioka *et al.* (2018) used ozonated water flushing during the reclamation of secondary wastewater effluent by a ceramic NF membrane and reported improved performance of the membrane due to the fouling mitigation effects of surface flushing with ozonated water. The combination of ozonation and UF membrane processes removes water contaminants, including the pathogens. Wang *et al.* (2005) showed that membrane ultrafiltration effectively removed coliforms and CoxB3 virus, used as a virological tracer, and a higher removal of both pathogens was obtained when ozone was applied.

The present study explored the development of a wastewater reclamation system by expanding the capacity of an existing water treatment technology called DaguaFlo that combines ozonation and UF membrane processes (Niquette *et al.* 2007; Yerushalmi 2014). Ozonation degrades dissolved organic compounds, oxidizes inorganic substances and disinfects water by killing the pathogens. The follow-up UF process removes the suspended and colloidal particles and improves the turbidity and colour of water. The combined use of these processes has also been shown to be efficient in the removal of emerging contaminants such as pharmaceutical compounds, hormones and antibiotics that are commonly found in the effluent of wastewater treatment plants and surface waters and resist degradation by the conventional biological and physical-chemical treatment processes (Acero *et al.* 2015). The application of the developed reclamation process in the removal of contaminants and treatment of effluent of the full-scale municipal wastewater treatment plant in Farnham, Canada, is presented.

METHODOLOGY

Process description

The developed wastewater reclamation process used the unique combination of ozonation and UF membrane processes in the DaguaFlo technology for the advanced treatment of effluent from a full-scale municipal wastewater treatment plant (WWTP). 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 water parameters in the effluent of this WWTP are as follows: BOD_5, 3–10 mg/L; total Kjeldahl nitrogen (TKN), 1.3–4 mg/L; ammonia-nitrogen (NH_4^+-N), 0.1–2 mg/L; total phosphorus, 0.1–0.4 mg/L; total suspended solids (TSS), 2–20 mg/L; and iron, 0.3–2 mg/L.

The effluent of the wastewater treatment plant passed through a chemical softening process for the removal of water hardness before entering the DaguaFlo technology for the removal of the remaining water contaminants. 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, a degassing unit for the removal of un-dissolved gases from water, and UF membranes. The schematic diagram of the full-cycle water remediation process is presented in Figure 1.

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 40 mg $CaCO_3$/L. The removal of hardness is recommended as it prevents scaling in the pipes and equipment and inside the

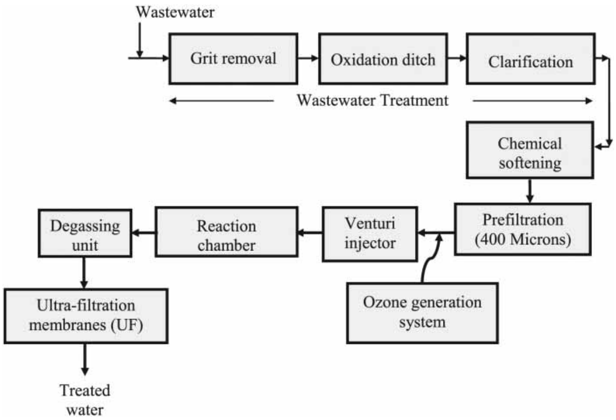

Figure 1 | Schematic diagram of the full-cycle water remediation process.

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 at the research laboratories of the Centre des technologies de l'eau (CTE) in Longueuil, Canada. The laboratory tests used 2,000 mL flasks at 1,000 mL working volume. Calcium hydroxide ($Ca(OH)_2$) at concentrations of 0.05–0.9 g/L, sodium hydroxide (NaOH) (30%) and sodium carbonate ($NaCO_3$) at concentrations of 0.2 g/L–10 g/L were examined for the softening of water at pH values ranging from 9 to 11. The water softening tests were conducted at least three times at each examined condition. The average values are reported here.

Operation setup and conditions

The reported wastewater reclamation operation was conducted in a pilot-plant unit of the DaguaFlo technology in Farnham, Canada. The effluent from the Farnham wastewater treatment plant was collected at the outlet port of this full-scale plant and was transported to the pilot installation by a tanker truck. The pilot plant has a treatment capacity of 100 m^3/day and is equipped with a prefiltration unit, an ozone generation system and hollow fiber PVDF membranes (Figure 2). The operation of this pilot plant has been demonstrated during the treatment of surface water as reported before (Niquette *et al.* 2007).

The DaguaFlo technology uses a prefiltration unit consisting of a rotary sieve with pore size of 400 microns to remove solid objects and particulate matter from the water and for initial water clarification. Water is then injected with ozone by a venturi injector (Mazzei, California, USA) for high mass

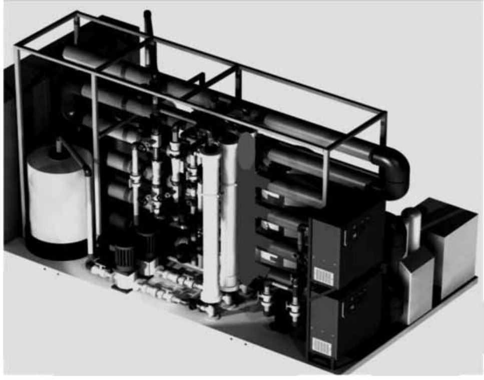

Figure 2 | Pilot-scale installation (100 m^3/d) of the DaguaFlo technology.

transfer and efficient dissolution of ozone in water. Ozone is used for the disinfection and chemical oxidation of contaminants. As a powerful natural disinfectant gas, more active than chlorine, ozone removes pathogens 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 oxidizes iron and manganese in water, which promotes their precipitation. The ozonated water passes through a reaction chamber (reactor) with a retention time of 4–6 minutes for proper disinfection and oxidation of contaminants. The water emerging from the reaction chamber passes through a degassing unit for gas-liquid separation and removal of un-dissolved gases from the water. The gas-saturated water, which still contains residual ozone at concentrations below 0.5 mg/L, enters the UF membranes for the removal of colloidal and suspended particles and precipitation of metals, and improvements to the turbidity and colour of water. A schematic diagram of the DaguaFlo technology is presented in Figure 3.

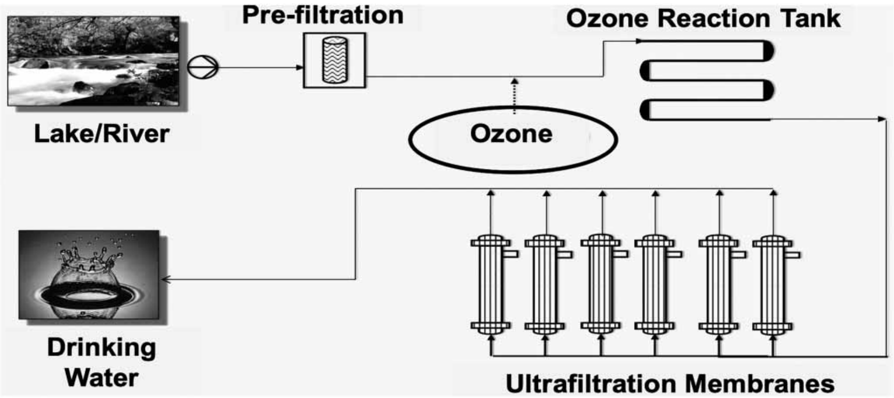

Figure 3 | Schematic diagram of the DaguaFlo drinking water treatment technology.

The pilot plant of the DaguaFlo technology that was used in the present study was modified to accommodate the removal of water hardness by chemical precipitation. A cylindrical tank equipped with dosing pumps for the addition of softening chemicals was installed upstream of the prefiltration unit. Ozone was generated from air by using a Pinnacle Plasma QuadBlock® ozone generator (Florida, USA), producing 8–10% ozone (w/w). The ozone dose was 12–15 g/h. One UF membrane module containing polyvinylidene fluoride (PVDF) hollow fiber membrane (Memstar, Singapore) was used in this process. The UF membrane had an active membrane surface of 40 m^2, pore size of 0.01–0.1 micron and operated at a filtration flux of 40–50 $L/m^2/h$. The employed hollow fiber membrane has anti-oxidation/ozone resistance properties. The operating pressure of the treatment process was maintained at 30–40 psi. The residual ozone in the gas phase emitting from the membrane module was destroyed before releasing the gas to the atmosphere.

Sampling and analytical methods

Throughout the duration of the operation, water samples were taken from the treatment system every 2 hours from a sampling port after the ozone reactor and from the membrane permeate. The water samples were stored in sealed containers, kept at 4 °C, and were delivered within 4 hours to an accredited laboratory (EnvironX) in Longueuil, Canada. All samples were analyzed for water parameters by using established analytical methods approved by the Quebec Ministry of Environment (2019).

The analyses for total coliform and *E.coli* bacteria were conducted by membrane filtration methods MA. 700 – Col 1.0 and MA. 700 – Ec.BCIG 1.0, respectively. These methods consist of collecting, identifying, and counting the bacteria on the surface of a sterile filter membrane. The enumeration of total coliforms consisted of filtering 100 mL of the diluted liquid sample through a sterile membrane with a porosity of 0.45 μm, followed by incubation for 24 ± 2 hours at 35 ± 0.5 °C on the m-Endo medium containing lactose. Under these conditions, coliforms produced metallic green colonies that were counted. For the enumeration of *E. coli* bacteria, incubation following membrane filtration was carried out on mFC-BCIG agar at 44.5 ± 0.2 °C. Under these conditions, *E. coli* bacteria form blue colonies. The metals were analyzed by mass spectrometry (ICP-MS) method MA. 203 – Mét.R.P. 1.0, color was analyzed by the UV-visible spectrophotometry with platinum-cobalt method MA. 103 – Col. 2.0, and turbidity was analyzed by nephelometric method MA. 103 – Tur. 1.0.

Membrane cleaning and fouling prevention mechanism

The DaguaFlo technology benefits from the generation and use of microbubbles 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 through several physical-chemical mechanisms including scrubbing and self-collapse that creates pressure waves, contributing to the detachment of deposits (Agarwal *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 operation of the DaguaFlo technology (Yerushalmi 2014).

RESULTS

Removal of water hardness

The results of hardness removal tests are presented in Figure 4. The total hardness of samples used in these tests was in the range of 190–304 mg $CaCO_3$/L. 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 to 33 mg

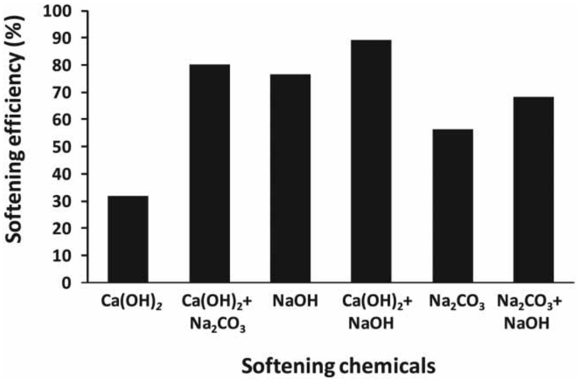

Figure 4 | Water softening efficiency in response to the softening chemicals.

$CaCO_3$/L from an initial value of 304 mg $CaCO_3$/L, representing 89.1% removal efficiency, was obtained when a combination of lime (0.2 g/L) and NaOH was used at pH 11.

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 5(a)), producing a final turbidity of 0.2 NTU in the treated water, while the true colour disappeared from 10 ± 3 TCU to <1 TCU (Table 1). Although the turbidity in the effluent of the WWTP used as the influent stream in the present study was relatively low (6–7 NTU), the results of full-scale operation of the DaguaFlo technology have shown that the combined use of ozonation and UF membranes in this technology produces treated water with turbidity levels below 0.5 NTU, even if the influent stream has high turbidity (>100 NTU). An example of the turbidity removal from polluted river waters in Canada by the DaguaFlo technology is presented in Figure 5(b).

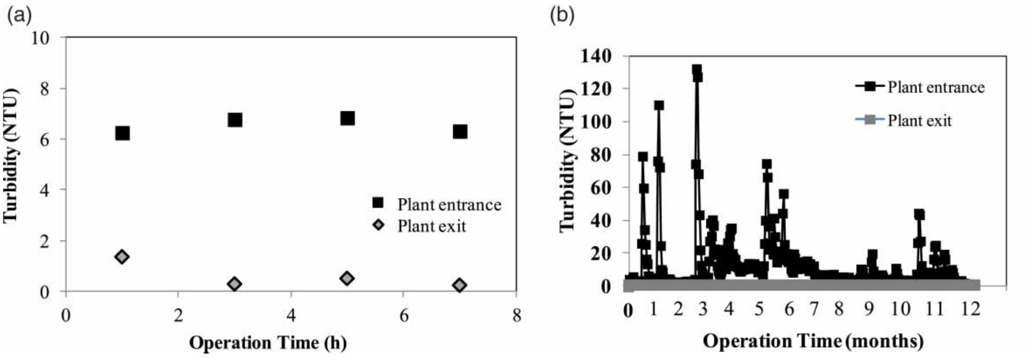

Figure 5 | (a) Removal of turbidity by the DaguaFlo technology, (a) in the pilot-plant study; (b) from a polluted river in Canada during full-scale operation.

Table 1 | Removal of pathogens and colour

Parameter	Value (plant entrance)	Value (plant exit)
Coliform bacteria (CFU/100 mL)	5,900 ± 180	<10
E. coli (CFU/100 mL)	5,500 ± 200	<10
Colour (TCU)	10 ± 3	<1

The fecal *coliform* and *E. coli* bacteria, representing pathogens, were removed after the ozonation process from an initial value of 5,900 ± 180 CFU/100 mL fecal coliform and 5,500 ± 200 CFU/100 mL *E. coli* (Table 1) to less than 10 CFU/100 mL. Although the removal of viruses, *Cryptosporidium* and *Giradia* protozoa was not monitored in this study, the operation results of full-scale Dagua plants using ozonation and UF membranes showed average log removals of 11.2, 3.3 and 5.6 for viruses, *Cryptosporidium* and *Giardia*, respectively.

Ozonation also oxidized iron and reduced its concentration in the water from 0.8 mg/L to <0.3 mg/L. The transmembrane pressure (TMP) was monitored to ensure that it remains below the critical pressure of 35 psi during the entire duration of this study.

The water loss during this process was approximately 15% of the influent flow rate. The major component of the operating cost in the DaguaFlo technology is electricity consumption. The electricity consumption of this technology ranges from 1.4 to 0.5 kWh/(m^3 treated water) for the water production capacity of 100 m^3/d to 5,000 m^3/d, respectively. These values refer to the consumption of electricity for the air compressor, oxygen generator, ozone generator, ozone pumping unit, ozone generator cooling system and the ozone destruction unit.

DISCUSSION

Membrane filtration systems are recognized as key technologies in advanced water reuse systems as they offer reliable performance and a superior quality of treated water compared to conventional technologies. The use of ozone in water treatment applications is also gaining attention because of its effective disinfection and chemical oxidation capacity, and its strength in the removal of micro-pollutants that result from pharmaceutical or industrial operations. Esplugas *et al.* (2007) investigated the application of advanced oxidation processes (AOP) and ozonation to remove micro-pollutants including endocrine disrupting chemicals (EDCs), pharmaceuticals and personal care products (PPCPs) in water, and reported successful results with the use of ozonation.

Despite their reliable performance, the application of membrane technologies in wastewater reclamation processes has faced challenges as the membranes are prone to clogging and need adequate pretreatment and regular chemical cleaning. The disposal of membrane concentrate is also an important issue that needs careful planning, and adds to the operating costs. As mentioned by Xu *et al.* (2010), membrane fouling is a key impediment for successful application of membrane processes that controls the range, type, and the economics of membrane applications. Therefore, pre-treatment processes such as ozonation, coagulation and flocculation, chemical precipitation, media filtration and carbon adsorption are often used before membrane filtration processes in wastewater reclamation systems for direct and indirect potable reuse applications. The use of pre-treatment processes is essential to ensure adequate removal of contaminating substances that may contribute to frequent fouling and clogging of membranes, and to maintain their consistent and high permeability.

A complex treatment train including pre-ozonation, coagulation, dual media filtration, main ozonation, biological activated carbon adsorption and a two-stage granular activated carbon adsorption as well as UF prior to chlorine disinfection is applied for reclamation of the secondary effluent (21,000 m^3/d) from a municipal wastewater treatment plant in Windhoek, Namibia, to drinking water quality level (Wintgens *et al.* 2005; Lafforgue & Lenouvel 2015). The Water Reclamation and Management Scheme (WRAMS) at the Sydney Olympic Park in Australia produces reclaimed water for non-potable applications by the advanced treatment of effluent from the sewage treatment plant at the capacity of 2 ML/d that treats the sewage collected from within the site, supplemented where necessary by storm water and with sewage from outside the area, by sequencing batch reactor (SBR) followed by UV. The effluent of this plant is treated by membrane filtration (MF). RO is then employed to treat 30% of the reclaimed water, reducing the total dissolved solids (TDS) concentration to below 500 mg/L, followed by chlorine disinfection before distribution (Wintgens *et al.* 2005). These examples show that existing reclamation systems use numerous physical and chemical treatment processes for the removal of organic and inorganic contaminants, and production of highly purified water.

The present study demonstrated the application of DaguaFlo technology, a patented water treatment technology that uses combined ozonation and UF membrane processes, in wastewater reclamation without relying on coagulation, flocculation, carbon adsorption or media filtration as the pre-treatment processes. Because of the presence of hardness in the wastewater treatment plant effluent that was used as the influent in this study, a chemical precipitation process was added to the train of treatment processes for the softening of water. The developed technology removes or reduces the concentration of water pollutants including turbidity, color, suspended solids, dissolved organic compounds, and pathogens. The removal of hardness is not necessary in many water reclamation applications as the required level of hardness in the treated water depends on the target use of water and the local standards. Nevertheless, chemical precipitation processes may be used as pre-treatment to membrane filtration processes for additional water clarification, and to reduce the concentration of metals and phosphorus in water. The continuous cleaning of membranes by the generated microbubbles that contain residual ozone prevents membrane fouling and clogging, contributing to their continuous cleaning without using chemical compounds, while permitting the disposal of membrane concentrate into the surface waters. The continuous cleaning of membranes by the generated microbubbles eliminates the need for frequent backwashing and use of chemicals, thus supporting long-term operation of membranes and preventing the generation of chemical waste sludge. The full-scale plants of the DaguaFlo technology conduct acid/base cleaning of membranes (using citric acid and sodium hydroxide) on an infrequent basis, once every 12–18 months, as opposed to conventional membrane-based treatment technologies that need frequent use of acid/base for membrane cleaning and de-clogging (Yerushalmi 2014).

The operating cost of the developed reclamation process depends on the required level of pre-treatment, the method of ozone generation, and the local cost of electricity ($/kWh). Ozone can be generated from concentrated oxygen or from oxygen in the air. The generation of ozone from concentrated oxygen eliminates the need for additional concentration of oxygen by an oxygen generator, as concentrated oxygen is directly fed to the ozone generator from a liquid oxygen tank. This method has lower electricity consumption, but it requires the supply of oxygen from a liquid oxygen tank. For the generation of ozone from air, an oxygen generator is used to concentrate oxygen from air and supply it to the ozone generator. This method of ozone generation eliminates the need for the supply of liquid oxygen by an external tank, but it requires the supply of an oxygen generator and will need additional electricity for increasing the oxygen concentration in the gas phase. The use of microbubbles for membrane cleaning in the DaguaFlo technology substantially reduces typical operating costs associated with the operation of membrane technologies by eliminating the need for expensive and hazardous chemicals for continuous membrane backwashing, and the costs associated with wastewater management. The developed reclamation technology can be configured for remote surveillance through an Internet-based connection, accessing a sophisticated process interface.

The developed water remediation process offers a dependable solution for wastewater reclamation that uses a lower number of unit operations, a smaller footprint, automated monitoring and control systems and the possibility of operation without the use of chemicals. The treated water emerging from the developed reclamation system can be used for a variety of non-potable and potable applications, depending on the local standards and regulations. The components of the developed reclamation system can be placed in a mobile container for treatment operations up to 1,000 m^3/d, facilitating the use of this system in remote areas. The relatively good quality of the effluent from the Farnham WWTP that was used as the influent in this study prevents the recognition of the developed reclamation process as a universal method to produce purified water conforming to rigorous potable or non-potable standards from the effluents of wastewater treatment plants with different qualities. More studies with effluent of a variety of municipal and industrial wastewater treatment plants are needed to optimize the operating parameters of this process, to determine the potential production of oxidation by-products, and to establish its capacity and limitations in wastewater reclamation.

CONCLUSIONS

The effluent of a wastewater treatment plant (WWTP) was reclaimed by using a unique design of ozonation and UF membrane processes in a patented technology called DaguaFlo. The developed reclamation system does not rely on physical-chemical processes for the pre-treatment of the WWTP effluent since it benefits from the continuous generation and use of microbubbles that contain residual ozone to prevent the fouling and clogging of membranes and to support the maintenance of a high flux through the membranes. The developed system used chemical precipitation as a pre-treatment process to reduce the water hardness. However, this process may be eliminated if the reduction of water hardness in not needed, or it may be included in the treatment system for additional water clarification or for the reduction of metals and phosphorus concentrations in water. The reclaimed water can be used in a variety of industrial, agricultural and municipal operations. The possible discharge of generated wastewater to the environment, along with a reduced number of unit operations and lower maintenance and control requirements compared to the conventions systems highlight the economic and environmental benefits of the developed reclamation system.

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