An evaluation of MBR and conventional pretreatment for reverse osmosis for water reclamation

J. Xu, F. C. Kent and K. Farahbakhsh

ABSTRACT

Two wastewater polishing systems were compared in terms of their ability to protect downstream reverse osmosis (RO) processes. A conventional full-scale wastewater treatment system with primary and secondary treatment followed by rotating biological contactors (RBC) and sand filtration were compared in a side-by-side study with a pilot-scale membrane bioreactor (MBR). Effluent from the two pretreatment trains was sent to two identical RO pilot systems. The effluent water quality of the two systems was compared as well as the RO performance. The MBR pretreatment provided effluent with a turbidity (0.11 NTU) that was more than five times lower than that of the conventional system (0.58 NTU). The fouling rate of the RO system with MBR pretreatment was 50–67% of the value found for the RO system with conventional pretreatment and the difference in turbidity values was identified as the major source of this large difference. The RO effluent quality of both systems was excellent, with similar overall removals in both systems. The study emphasizes the importance of removing particulate matter for the prevention of RO fouling within water reclamation.

Key words | MBR, membrane bioreactor, membranes, reverse osmosis, sand filtration, water reclamation

J. Xu*
F. C. Kent (corresponding author)
K. Farahbakhsh
School of Engineering,
University of Guelph,
50 Stone Rd. E.,
Guelph, ON,
Canada N1G 2W1
E-mail: *fraskent@gmail.com*

*Present address:
GE Energy – Power & Water,
3239 Dundas St. W.,
Oakvile, ON,
Canada L6M 4B2

INTRODUCTION

The use of reverse osmosis (RO) for water reclamation has been applied throughout the world and the number of applications is increasing steadily (Qin *et al.* 2004). This is a result of fresh water shortages and the high energy consumption and cost of desalination using RO (Cote *et al.* 2004). Extensive pretreatment is required upstream of RO processes for the success of these systems due to their propensity for membrane fouling (del Pino & Durham 1999). In particular, particulate matter has a tendency to foul the spiral-wound modules that are generally used in RO processes. In recent years, several full-scale plants have implemented low-pressure membranes as a pretreatment for RO and researchers have identified this pretreatment option as ideal (Adham *et al.* 2001). Since the use of membrane processes is more costly than conventional treatment, it is important to understand the benefits in RO performance and thereby provide hard evidence of the overall economic benefit of the investment in membrane pretreatment. Polishing of secondary effluent using low-pressure membranes has been used extensively; however the more recent introduction of the membrane bioreactor (MBR) technology has provided another option for pretreatment of RO in water reclamation applications. An MBR system is used in place of a conventional plant and involves an activated sludge process that uses a membrane to separate and retain solids instead of a secondary clarifier. It has been suggested that MBR processes have the ability to provide enhanced removal over conventional systems (Qin *et al.* 2006). In this work, RO fouling and removal rates were measured and compared given pretreatment with a conventional wastewater treatment plant (WWTP) and an MBR. The conventional plant included extensive treatment using a rotating biological contactor and media filtration in addition to primary and secondary processes. The objective of this study was to compare the ability of this type

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of conventional treatment plant to provide pretreatment for RO compared with an MBR process.

METHODS

All experimental work was conducted at the City of Guelph Wastewater Treatment Plant in Guelph, Canada. Diagrams of the conventional pretreatment plant and MBR systems are shown in Figure 1. The effluent from this conventional plant was fed to a pilot-scale RO treatment unit. In parallel, the raw wastewater of the plant was fed to a pilot-scale MBR system whose permeate was sent to a second pilot-scale RO treatment unit. The feed, permeate and concentrate water quality of the RO systems were measured over time as the fouling of the two systems was monitored.

Pretreatments

Conventional wastewater treatment

The conventional treatment process in the WWTP consists of preliminary, primary, secondary, and tertiary unit processes. The preliminary treatment includes an in-plant pump station, bar screens and grit chambers to remove substances that may interfere with the downstream processes or be detrimental to the plant equipment. Ferrous chloride was added to the wastewater in order to facilitate phosphorus removal in the downstream clarification processes. The wastewater enters rectangular primary clarifiers and then flows into the secondary treatment consisting of plug flow activated sludge systems and secondary clarifiers. The tertiary treatment consists of rotating biological contactors (RBC) for nitrification and sand filtration for polishing. The final treatment steps for the wastewater are chlorine disinfection and dechlorination before discharging to the Speed River.

The effluent from the sand filters (after chlorination) was collected as the feed for one of the RO pilot systems. The free chlorine concentration was approximately 0.15 mg/L with a total chlorine concentration of about 0.45 mg/L. Because the chlorine tolerance limit of the RO membranes was 0.1 mg/L, dechlorination was necessary. Sodium metabisulfite ($Na_2S_2O_5$) was injected into the RO feed tank at a dosage rate of 2.4 mg/min to remove free chlorine.

Membrane bioreactor

The MBR pilot system with a capacity of 240 m^3/d was operated by GE Water & Process Technologies (Oakville, Canada) at the Guelph Wastewater Treatment Plant. The raw wastewater was pumped to a fine screen with openings of 0.75 mm and transferred to three aeration tanks followed by three membrane tanks for separation of sludge. Each membrane tank housed a ZeeWeed-500c membrane module (GE Water, Oakville, Canada). The coarse bubble

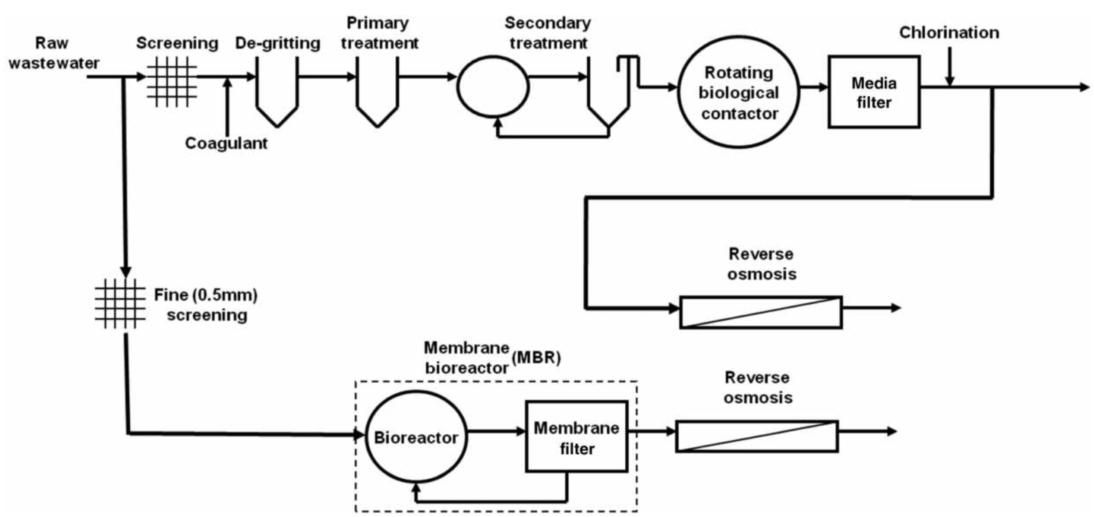

Figure 1 | Diagram of experimental set-up.

aeration in the membrane tank was used to reduce membrane fouling by providing turbulence on the membrane surfaces. In addition, a cyclic operating mode with 10 minutes permeation and 30 seconds relaxation was used to further help reduce membrane fouling. The MBR permeate was transferred into the RO feed tank and fed to the system by a centrifugal pump. Table 1 shows the MBR specifications and operating conditions for the duration of the study.

RO systems

Two RO pilots were provided by GE Water, Oakville, Canada. Each system consisted of a low-pressure feed pump, a 5 micron polypropylene cartridge filter, a high pressure process pump with 2 hp motor rated for 7 USGPM (26.5 L/min) at 260 psi (1,793 kPa), two 10 cm × 100 cm XLE-4040 RO membrane spiral-wound modules (provided by DOW/Filmtec, USA), a cleaning system and a solid state control system. The system was capable of producing up to 9.8 L/min of RO grade water based on a 25 °C feed water. The maximum operating pressure and temperature for the RO systems were 2,000 kPa and 35 °C, respectively. The systems are designed to automatically shut down when the feed pump pressure is lower than 200 kPa to protect the high pressure pump from cavitation. RO grade water produced by the RO modules was used to establish the baseline for flux and trans-membrane pressure (TMP) before starting the experiments. Table 2 shows the XLE-4040 RO membrane modules characteristics. Figure 2(a) and (b) show process flow diagrams of the MBR-RO and Conventional-RO systems, respectively.

Two RO membrane modules (XLE-4040, Dow-Filmtech, USA) were installed in each RO system and a preliminary study was conducted with the objective of optimizing system operation. Tap water was used to obtain the baseline for the permeate flux and TMP. The operating parameters including temperature, feed pressure, concentrate pressure, permeate pressure, concentrate flow rate and permeate flow rate were recorded daily. For the conventional pretreatment system, free chlorine concentration before and after dechlorination was tested to determine the effectiveness of the dechlorination procedure. During preliminary operation, both TMP increases and permeate flow decreases were observed due to membrane fouling. In order to monitor membrane fouling more accurately, permeate flux and system recovery rate were maintained at a constant value as the study continued. The variation of TMP was monitored by calibrated pressure transducers (Cole-Parmer, USA).

The change in pressure over time was recorded, indicating the extent of RO membrane fouling. Four new XLE-4040 RO membrane modules provided by DOW/Filmtec were used for the second set of experiments. RO grade water produced by the first set of RO membranes was filtered to establish the baseline condition of the new membrane modules. The system (containing two RO modules) was operated at a constant permeate flow of 9.45 L/min and reject flow of 26.46 L/min leading to an overall volumetric recovery of 26%. The increase in TMP was monitored and recorded over time to measure and compare the fouling rates of the two systems, thereby allowing a comparison of the impact of pretreatments on membrane fouling.

Table 1 | MBR system specifications and operating conditions

Wastewater treatment capacity	m^3/d	240
Fiber internal diameter	mm	0.9
Nominal pore size	μm	0.04
Total membrane area	m^2	209
Flux	$L/m^2/h$	26–48
Hydraulic retention time (HRT)	h	6
Solids retention time (SRT)	d	21
Average MLSS	g/L	12

Table 2 | RO system information

RO module	XLE-4040
Recommended module recovery rate	15%
Membrane type	Polyamide thin-film composite
Maximum operating pressure	600 psig (4,137 kPa)
Free chlorine tolerance	<0.1 ppm
Number of modules	2
Active area per module	87 (8.1) ft^2 (m^2)
System flux	20.6 (35) $gal/ft^2/d$ ($L/m^2/h$)
Average system recovery	24–26%

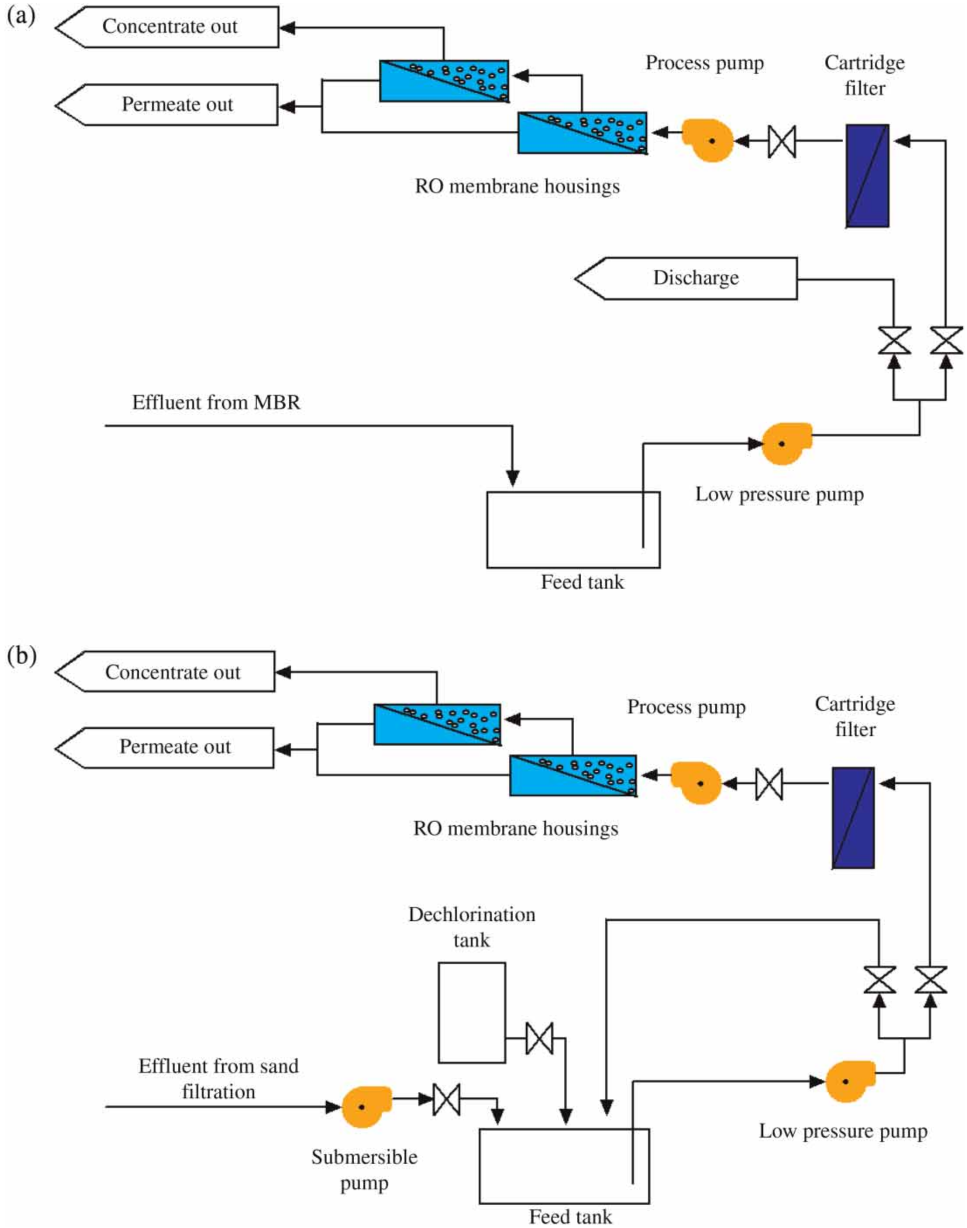

Figure 2 | Process flow diagram of the two parallel RO setups with (a) MBR pretreatment and (b) conventional pretreatment.

Analysis

Samples of feed, permeate and concentrate of the two RO systems were collected twice a week during the study period using 500-ml plastic and glass sampling bottles which were sterilized before sample collection. The glass containers were used to sample for chemical oxygen demand (COD) and total organic carbon (TOC) to reduce organic contamination from plastic. Sodium metabisulfite ($Na_2S_2O_5$) was added to samples of the sand filter effluent in order to negate the effect of residual chlorine on the total/fecal coliform tests. All the collected samples were transported to a laboratory at University of Guelph, Canada and were analyzed immediately or stored in the refrigerator for up to 24 hours prior to analysis.

Temperature and turbidity were tested immediately after sample collections in the field and the following parameters were analyzed in the laboratory at University of Guelph:

- pH
- Conductivity
- Total organic carbon (TOC)
- Chemical oxygen demand (COD)
- Total/fecal coliforms
- Cations (sodium, calcium, magnesium, ammonium)
- Anions (chloride, sulphate, nitrite, nitrate, phosphate)

The Fisher Scientific Accumet XL 60 meter was used to test the pH and conductivity. TOC was analyzed using a Shimadzu Total Organic Carbon Analyzer (TOC-V_{CSH}). The Reactor Digestion Method was used to determine COD values. The procedure has been adapted from the standard Hach procedure manual (HACH, USA). Total and fecal coliform detection was adapted according to the procedure outlined in the *Standard Methods* (APHA/AWWA/WEF 1998). The membrane filtration technique was used for both total and fecal coliform detection. Cations and anions-were analyzed using an ion chromatography (ICS-2000, Dionex Cooperation). Samples were injected into IC using an A40 auto sampler (ICS-2000, Dionex Cooperation). Peaks were analyzed by Chromeleon software.

Table 3 | Effluent water quality results from the MBR and conventional systems

Items	Conventional Mean	Conventional Standard deviation	MBR-RO Mean	MBR-RO Standard deviation
pH	7.91	0.15	7.68	0.16
Turbidity (NTU)	0.58	0.09	0.11	0.03
Conductivity (μs/cm)	2,200	200	2,450	210
TOC (mg/L)	9.9	2.2	7.1	2.2
Ammonium (mg/L)	0.09	0.03	0.03	0.02
Nitrite (mg/L)	0.04	0.02	0.07	0.03
Nitrate (mg/L)	6.8	1.2	6.6	1.1
Sulphate (mg/L)	166	23	166	18
Total phosphate	0.04	0.02	1.0	0.4
Calcium (mg/L)	125	27	158	32
Magnesium (mg/L)	38.9	6.8	47.9	9.4
Hardness as $CaCO_3$ (mg/L)	474	N/A	595	N/A
Sodium (mg/L)	302	56	382	70
Chloride (mg/L)	481	60	636	96
COD (mg/L)	22.8	10.3	20.9	8.7
Total coliforms (CFU/100 ml)	267	202	509	243
Fecal coliforms (CFU/100 ml)	99	63	84	57.2

RESULTS AND DISCUSSION

The evaluation of conventional and MBR pretreatment methods for RO was conducted through a comparison of effluent water quality from the two pretreatments and a comparison of fouling rates for the two RO systems that received effluent from these systems as feed. Based on these two sources of information, further discussion is provided regarding the mechanisms of fouling at hand. In addition, the removal rates for both RO processes are presented.

Pretreated water quality results

Table 3 shows the effluent water quality results from the MBR system and the conventional system. Significant differences in several analytes were found including turbidity, conductivity, ammonium, phosphate, total hardness and chloride. The differences in water quality were likely caused by inherent differences in these two processes. Within the MBR train, the raw wastewater was exposed to an activated sludge process followed by membrane separation while in the conventional train it was treated with coagulation, clarification, an activated sludge bioreactor, secondary clarification, a fixed film bioreactor, media filtration and chlorination. It is interesting to note that although many more processes were used in the conventional treatment train, the turbidity of the effluent (0.58 NTU) was still significantly higher than that of the MBR effluent (0.11 NTU). Despite the inability of the conventional process to provide effluent with turbidity values as low as the MBR effluent, it was found that the phosphate, chloride and conductivity values were significantly lower than those in the MBR effluent. This may have been a result of the coagulant addition in the conventional process as it is designed to remove phosphorus and may have led to the removal of additional ions, such as chloride, thereby causing a reduced conductivity. Not only did the MBR provide a lower turbidity than the conventional process for the downstream RO systems, but it also resulted in lower ammonium, indicating that more complete nitrification occurred in the MBR process. This may have been a result of the higher SRT in the MBR process since SRT has an important impact on the nitrification process.

RO fouling results

The RO systems were operated between 13 and 43 days depending on the fouling rate. The systems cannot tolerate pressures in excess of approximately 2,000 kPa and therefore the experimental runs were terminated once a threshold pressure was reached. Figures 3 and 4 show the results of two different fouling runs that were conducted concurrently. In both runs the fouling rate, or rate of change of TMP for the given flux was higher for the RO that had conventional pretreatment (Conventional-RO). The TMP for the Conventional-RO increased from 1,586 to 2,048 kPa within 13 days during the first run. For the RO with MBR pretreatment (MBR-RO) the same increase in TMP took 19 days. These are equivalent to fouling rates of 35.9 and 24.1 kPa/d for the Conventional-RO and MBR-RO systems, respectively. It is important to note that the modules used for this run had previously been operated to commission the equipment, although both membrane systems had undergone similar historical operation and thus had the same initial permeability.

For the second run, new modules were installed and the same test was repeated. Once again the Conventional-RO had a higher fouling rate of 29.6 kPa/day, compared to the MBR-RO which had a fouling rate of 15.9 kPa/day, a value that is close to half the fouling rate of the Conventional-RO.

These results suggest that the MBR pretreatment provided feed that had less of a tendency to foul the RO membranes used in this study. The cause of the difference in fouling between these two RO systems can be found in the feed water quality data. Reverse osmosis fouling has been divided into four different categories based on different fouling mechanisms: Particulate fouling, scaling, organic fouling and biofouling (Ghayeni *et al.* 1998; Vrouwenvelder *et al.* 2006). A discussion of these four fouling mechanisms and the water quality parameters they are associated with is given below.

Particulate fouling

Particulate fouling is a common problem in spiral-wound elements due to the concentrate spacers provided to promote turbulent flow. The higher turbidity of the conventional effluent (0.58 NTU) suggests that it would

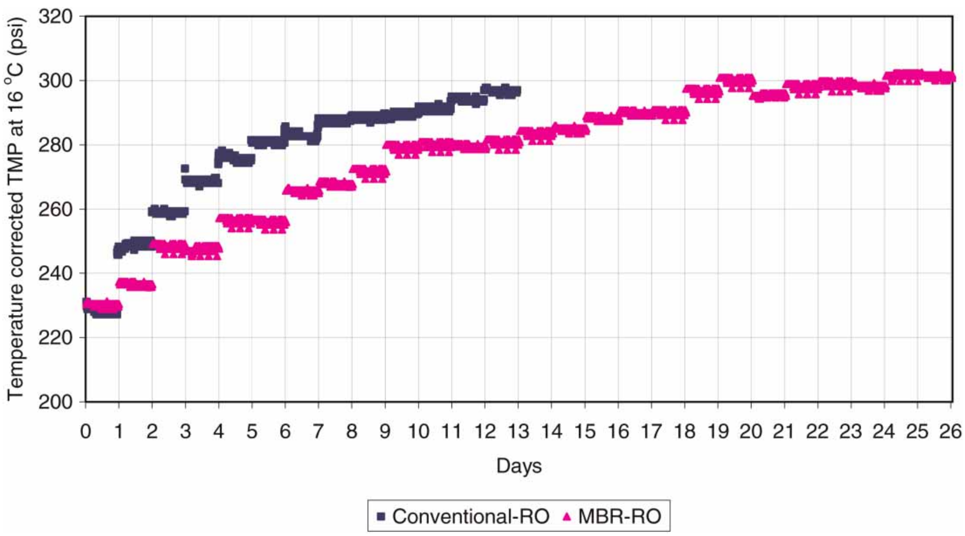

Figure 3 | Run 1 fouling rate of RO systems.

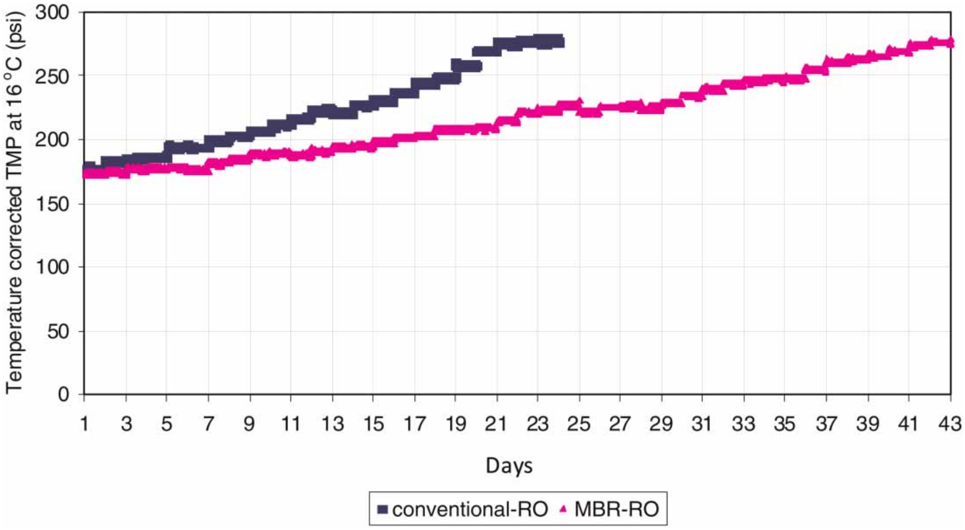

Figure 4 | Run 2 fouling rate of RO systems.

likely lead to higher particulate fouling compared with the MBR system which had an average turbidity of 0.11 NTU. The MBR membrane prevented more particles from entering the downstream RO modules. This is an important result suggesting the benefits of membrane processes over media filtration for polishing of secondary effluent prior to RO treatment.

Scaling potential

An analysis of the scaling potential of the system is given in Table 4. It indicates that $Ca_3(PO_4)_2$ and $Mg_3(PO_4)_2$ were both beyond their limits of solubility and likely caused some scaling on the membranes in both RO systems. However, the MBR effluent contained higher concentrations of

Table 4 | Analysis of scaling potential for both RO processes

Precipitate	Ion concentration (mg/L)		Ion concentration (moles/L)	Q	K_{sp}
Effluent from MBR pretreatment					
$CaSO_4$	Ca^{2+}	222.7	0.00557	1.39×10^{-5}	4.93×10^{-5}
	SO_4^{2-}	239.7	0.0025		
$Ca_3(PO_4)_2$	Ca^{2+}	222.7	0.00557	$\mathbf{4.56 \times 10^{-17}}$	2.07×10^{-33}
	PO_4^{3-}	1.56	1.65×10^{-5}		
$Mg_3(PO_4)_2$	Mg^{2+}	65.4	0.00273	$\mathbf{5.5 \times 10^{-18}}$	1.04×10^{-24}
	PO_4^{3-}	1.56	1.65×10^{-5}		
Effluent from conventional pretreatment					
$CaSO_4$	Ca^{2+}	189.3	0.00473	1.217×10^{-5}	4.93×10^{-5}
	SO_4^{2-}	237.6	0.00248		
$Ca_3(PO_4)_2$	Ca^{2+}	189.3	0.00473	1.54×10^{-19}	2.07×10^{-33}
	PO_4^{3-}	0.12	1.21×10^{-6}		
$Mg_3(PO_4)_2$	Mg^{2+}	54.9	0.00229	1.76×10^{-20}	1.04×10^{-24}
	PO_4^{3-}	0.12	1.21×10^{-6}		

Q – solubility product of the ions in the potential precipitate.
K_{sp} – solubility product constant of the precipitate.

scale-forming ions and likely led to a higher degree of scale formation. In Table 4 the solute calculated values for $Ca_3(PO_4)_2$ and $Mg_3(PO_4)_2$ were both more than two orders of magnitude higher for the RO with MBR pretreatment (shown in bold). It is interesting that despite the higher potential for scaling within the MBR-RO, the Conventional-RO consistently showed a higher fouling rate. These data suggest that the particulate fouling caused by higher turbidity in the Conventional-RO had more of an influence in the overall fouling rate. It is important to note that the scaling potential of $CaCO_3$ through a calculation of the Langelier Saturation Index (LSI) was not included in this study since the alkalinity was not measured. Given that the pH values of the two system effluents were not significantly different, the calcium concentrations were higher in the MBR effluent and the coagulation process within the conventional system would be expected to consume alkalinity, it is assumed that the LSI of the MBR effluent is not lower than the conventional effluent and thus the potential for $CaCO_3$ scaling in the MBR-RO is the same or more likely.

Organic fouling

Organics fouling is another important fouling mechanism that has been the focus of some recent research (Ang & Elimelech 2007; Li *et al.* 2007; Mo *et al.* 2008). The most important water quality parameter that gives an indication of the potential for organic fouling of the parameters measured in this study is TOC; however, the TOC values for the two different pretreatment processes were not significantly different as shown in Table 3. Therefore, it is not likely that differences in organic fouling contributed to the large differences found in RO fouling rate between these two processes. It is important to note that previous research on organic fouling of RO membranes has looked more closely at the specific organic compounds that make up the TOC and may lead to organic fouling of RO membranes. Specifically, proteins and polysaccharides have been identified as key fouling contributors. In this study the quantity of these specific compounds was not measured and only the TOC can be considered when evaluating potential differences in organic fouling. Although TOC concentrations in the feeds were not significantly different, it is possible that the MBR effluent or conventional effluent contained significantly different concentrations of TOC constituents that are known foulants. For example, previous work has shown that MBR processes have a tendency to retain proteins and polysaccharides while allowing humic substances to pass more readily (Masse *et al.* 2006; Liang *et al.* 2007; Dong & Jiang 2009). A higher make up of humic substances could lead to an effluent with the same TOC but with lower fouling propensity. Future work in this area should include quantification of these specific organic compounds.

Biofouling

The fouling contribution resulting from biofilm development on the RO surfaces is also a concern (Wintgens *et al.* 2005; Herzberg *et al.* 2010) and has been studied extensively by a number of researchers (Ridgway *et al.* 1984; Ivnitsky *et al.* 2005; Pang & Liu 2007; Herzberg & Elimelech 2008). In this study, as shown in Table 3, the total coliform levels of both effluents were relatively high at 267 ± 202 cfu/100 ml for the conventional effluent and 509 ± 243 cfu/100 ml for the MBR effluent. In addition, fecal coliforms were detected in both pretreatment effluents with 99 ± 63 cfu/100 ml in the conventional effluent and 84 ± 57 cfu/100 ml in the MBR effluent. These data suggest there was a potential for biofilm growth in both RO systems. What is particularly interesting is presence of relatively high levels of bacteria in conventional effluent despite the chlorine residual of 0.45 mg/L. Although it is likely that bio-growth occurred in both systems, there is no evidence suggesting that it would have caused significantly more fouling in either of these RO systems. If biofouling was the governing fouling mechanism, it likely would have been observed in the fouling trends by an accelerated fouling trend (i.e. fouling rate increases over time). Some researchers have found that in the early stages of biofilm development, the impact on permeability is small and becomes larger over time (Kent & Farahbakhsh 2011). This type of trend was not generally observed in the fouling data sets.

Overall, the data suggest that the observed differences in fouling rate were governed by particulate fouling for the following reasons:

1. There was a significant difference in the turbidity values between the MBR and conventional effluent streams. The system with higher turbidity (conventional pretreatment) had a higher fouling rate.
2. The system with higher scaling potential (MBR-RO) actually had lower fouling, suggesting that this mechanism did not govern the differences in fouling between the two systems.
3. There was not a significant difference in the TOC levels of the two systems.
4. The nature of the fouling trends was somewhat linear and did not increase dramatically as a function of time. If there was significant biological fouling, the fouling rate would be expected to increase with biofilm maturation. Also, the MBR effluent had a higher mean total coliform count which could suggest a higher biofouling potential.

RO removal efficiencies

Another important aspect of this research was to compare the MBR-RO and the Conventional-RO systems in terms of the removal of constituents. This is important for considering the reuse potential of the RO effluent. Table 5 shows the average effluent water quality for both processes as well as the percentage removals.

For all of the water quality analyses shown in Table 5, the Conventional-RO effluent had equal or lower values than the MBR-RO effluent. The coagulation process within

Table 5 | RO effluent water quality and RO removals

Parameters	Items	Conventional-RO Mean	Standard deviation	MBR-RO Mean	Standard deviation
Conductivity (μs/cm)	Effluent	9.4	4.1	13.0	2.5
	Removal (%)	99.6	0.20	99.5	0.11
TOC (mg/L)	Effluent	0.1	0.04	0.6	0.4
	Removal (%)	98.5	0.51	91.1	4.98
Ammonium (mg/L)	Effluent	0.005	0.003	0.002	0.003
	Removal (%)	94.3	3.38	94.0	6.3
Nitrite (mg/L)	Effluent	0.001	0.0005	0.002	0.001
	Removal (%)	98.1	1.30	97.3	1.99
Nitrate (mg/L)	Effluent	0.06	0.04	0.08	0.05
	Removal (%)	99.2	0.42	98.8	0.56
Sulphate (mg/L)	Effluent	0.07	0.05	0.13	0.13
	Removal (%)	99.94	0.056	99.92	0.072
Total phosphate (mg/L)	Effluent	0.003	0.003	0.003	0.003
	Removal (%)	93.8	6.50	99.7	0.31
Calcium (mg/L)	Effluent	0.05	0.04	0.16	0.099
	Removal (%)	99.9	0.03	99.9	0.08
Magnesium (mg/L)	Effluent	0.003	0.003	0.01	0.01
	Removal (%)	99.99	0.01	99.97	0.03
Sodium (mg/L)	Effluent	1.4	0.6	1.9	0.6
	Removal (%)	99.6	0.18	99.5	0.16
Chloride (mg/L)	Effluent	1.2	0.4	2.1	0.6
	Removal (%)	99.8	0.08	99.7	0.08
COD (mg/L)	Effluent	<DT	3.6	<DT	4.2
	Removal (%)	90.4	10.7	88.6	13.7
Total coliforms (CFU/100 ml)	Effluent	<1	<1	9	14
	Removal (%)	100	0.00	96.7	6.21
Fecal coliforms (CFU/100 ml)	Effluent	<1	<1	0.4	1.1
	Removal (%)	100	0.00	99.6	1.14

DT – detection threshold.

the conventional pretreatment resulted in slightly lower values of certain dissolved constituents. This may have caused the lower RO effluent values for conductivity and chloride. In general, the removal of all constituents of interest by both RO systems was very high and the effluent quality was similar from the perspective of water reuse applications. One interesting result is that the TOC of the Conventional-RO effluent was lower than that of the MBR-RO effluent, despite the fact that the RO feed values were not significantly different. Although both RO effluent TOC values are quite low, this is contradictory to results found by Tao *et al*. (2005) who compared treatment using a conventional activated sludge process with tertiary membrane polishing and an MBR. They found that the MBR effluent contained less TOC and for the same system Qin *et al*. (2006) reported that the RO effluent with MBR pretreatment had a lower TOC value compared with the conventional system with tertiary membrane polishing. The average value of TOC in MBR permeate for the present study (0.6 mg/L) is slightly higher than those reported in the study by Qin *et al*. (2006) (0.25–0.45 mg/L). It was also unexpected that total and fecal coliforms were detected in the MBR-RO effluent (they were not detected in the Conventional-RO effluent). RO filters do not allow coliforms to pass and this is possibly a result of re-growth of microorganisms on the permeate side of the membrane. This may have contributed to the unexpected TOC values that were observed.

CONCLUSIONS

An MBR system was operated in parallel with a conventional activated sludge system with tertiary RBCs and media filtration to examine their relative ability to provide pretreatment for two identical RO pilots. The RO fouling rate for the system with MBR pretreatment was found to be approximately half of the value found for the conventional plant. Water quality analyses indicated that the turbidity of the conventional plant effluent was significantly higher and it was concluded that this difference likely led to the observed fouling rate differences. Removal efficiencies of both RO systems for most constituents of interest were very high, generally above 99% although total and fecal coliforms were detected along with an unexpectedly high average TOC value in the MBR-RO effluent. The results suggest that membrane barriers to particulate matter play an important role in mitigation of RO fouling within water reclamation.

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