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Application of immersed MF (IMF) followed by reverse osmosis (RO) membrane for wastewater reclamation: A case study in Malaysia

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Abstract A pilot scale membrane plant was constructed and monitored in Shah Alam, Malaysia for municipal wastewater reclamation for industrial application purposes. The aim of this study was to verify its suitability under the local conditions and environmental constraints for secondary wastewater reclamation. Immersed-type crossflow microfiltration (IMF) was selected as the pretreatment step before reverse osmosis filtration. Secondary wastewater after chlorine contact tank was selected as feed water. The results indicated that the membrane system is capable of producing a filtrate meeting the requirements of both WHO drinking water standards and Malaysian Effluent Standard A. With the application of an automatic backwash process, IMF performed well in hydraulic performance with low fouling rate being achieved. The investigations showed also that chemical cleaning is still needed because of some irreversible fouling by microorganisms always remains. RO treatment with IMF pretreatment process was significantly applicable for wastewater reuse purposes and promised good hydraulic performance.

Keywords Immersed microfiltration; industrial applications; reverse osmosis; secondary wastewater

Introduction

Wastewater initially is legally required to be treated before it can be discharged to the environment for natural hydraulic circulation. Recently, the increasing need for improved water intake quality for potable supplies for human and industrial purposes has resulted in the emergence of new water re-use technologies. The main challenges of water reuse projects are to ensure that the water produced can be effectively distributed and safely used (Lawrence *et al.*, 2002). RO membrane filtration has been widely adopted in treated water reclamation process. Gagliardo *et al.* (1998) concluded that RO membrane shows significant contaminant rejection to meet and exceed drinking water standards.

Microfiltration (MF) significantly removes particulate contaminants (clay, algae, bacteria and microorganisms) with minimal energy consumption among the membrane family (Ujang *et al.*, 2002; Meier-Haack *et al.*, 2003). A module-less MF membrane was developed as an alternative for conventional module MF. This type of MF promises better fouling control and can hybrid with other treatment processes. MF processes are the best choice for RO systems because of the (a) consistency of treated water quality with variable feed water quality; (b) non-sensitivity on chemical reactions and

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adjustments to achieved good results; (c) stable membrane operations; (d) higher fluxes as compared to conventional pretreatments; (e) RO chemical cleaning intervals was extended subsequently extending membrane lifespan; (f) less land area needed for the plant; (g) lower energy consumption; and (h) lower operating and maintenance costs (Chakravorty and Layson, 1997; Suda *et al.*, 1998).

The RO membrane was firstly applied in the seawater desalination process for potable water production, especially in the USA and Middle East countries. Recently, RO membranes have been wholly involved in wastewater reuse processes as a new alternative water source to tackle water shortage problem especially in arid areas. The increasing application of RO membranes recently has observed in fact better water quality among all the alternatives recently. The success of the RO membrane was also boosted by economically and reliable performance factors (Jacangelo *et al.*, 1997; Lawrence *et al.*, 2002).

Fouling problems are a major difficulty in membrane technology. Sheikholeslami (1999) mentioned fouling mitigation techniques can be classified into three categories, which were fouling control, pretreatment technologies, and anti-fouling membranes and modules. The fouling mechanism was significantly affected by operating parameters and the feed solution conditions. Methods such as critical flux and critical conversion or the application of antiscalants/antifoulant agents was recommended. Pretreatment by integrating a larger pore membrane (MF/UF) into the systems resulted in longer membrane lifespan. Modification in membrane properties, modules and also feed water physical properties are intended to reduce fouling problems. Future development in membrane technologies should include more environmental friendliness and cost effectiveness.

The objective of the testing study described was to investigate the performance of a membrane system treating domestic secondary effluent. The effluent water quality was compared with WHO drinking water standards and Malaysia Effluent Standard A. The hydraulic performances of the CMF-s and RO units were also prominent in this study.

Method and materials

Hollow fiber polypropylene membrane (Memcor® 1S10x CMF-s Pilot Unit) with nominal pore size of 0.2 μm was used as IMF for RO pretreatment. During filtration, feed water was drawn through the fiber walls (outside to inside) under suction pressure. A timer initiates regular backwash after 18 minutes filtration by using filtrate water and aeration was conducted to create shear forces on the membrane surface to reduce concentration polarization problems. A high-pressure packaged skid mounted polyamide RO membrane was utilized (supplied by US Filter) into a 1-1 array system for further treatment.

Figure 1 illustrates the system layout. A secondary municipal wastewater effluent after chlorine contact tank was selected as feed water. Feed water was pumped into the feed tank. NaOCl (Accot Tech.) with 0.5–1.0 ppm was dosed into the feed stream to prevent further bacteria growing at the further process stream. Feed water was directed into the CMF-s tank. CMF-s filtrate was sucked out to the filtrate tank by applying a negative pressure suction pump. The rejected water was drained out from the IMF tank after the backwash process. Filtrate was fed into the RO system under high pressure. Antiscalant was added to the feed stream. The RO permeate from both RO membranes was collected in the final processes. 75% of RO rejected water was recycled into the RO feed stream and the remainder was drained. Table 1 shows the operating conditions of both IMF and RO membrane systems. For complete operating procedures and manuals for both IMF and RO membranes refer to Veolia Water System (Malaysia) Sdn. Bhd.

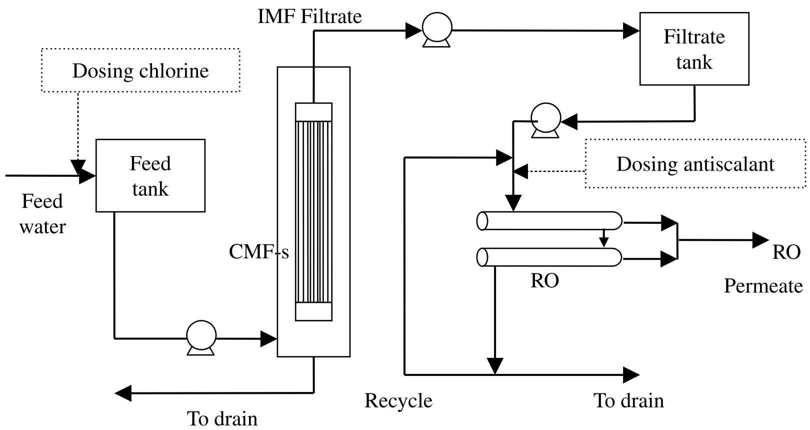

Figure 1 Secondary municipal wastewater reclamation CMF-s/RO system layout

Results and discussion

Removal analysis

Table 2 illustrates the average removal performances of the IMF-RO membrane system on secondary effluent treatment. Weekly composite sampling was carried out to analyze feed and treated water quality. Generally, high removal efficiency was achieved, only the bacterial total plate count was unsatisfied. This may be due to the growth of bacteria within the permeate streams piping during non-operation mode (night time). Bacterial problem count has not been solved during the current operating mode (which was 8 hours per day). Continuous operation mode and sequencing of chemical pipe cleaning were suggested to overcome this problem.

Based on the recommendations for raw water intake of the WHO drinking water guidelines, monthly sampling was conducted every first Friday of the month. This study shows that RO permeate met the requirements of raw water intake for WHO drinking water guidelines. However, ammonia concentration showed slightly higher at 2.29–3.12 mg/L compared to the guidelines (1.5 mg/L). Although high ammonia level was found in RO permeate, the MF–RO membrane systems showed on average 91.18% ammoniacal nitrogen removal.

Table 1 Operating conditions of the pilot plants

Operating parameter	Conditions
CMF-s unit	
Filtrate flow rate (m^3/hr),	0.80
Backwash interval setting (min),	18 minutes/2 minutes
Filtrate temperature (°C),	30–35 °C
Backwash aeration flow,	9
Backwash liquid flow (m^3/hr),	2.20–2.25
Feed chlorine lever (ppm),	0.5–1.0
RO unit	
Feed flowrate	28 L/min
Permeate flowrate	4.5 L/min
Rejection flowrate	5 L/min
Recycle flowrate	15.5 L/min
Feed pressure	8–9 bar
Permeate pressure	1 bar
Rejection pressure	1 bar
Salt density index (SDI)	3.7–5.5

Table 2 Average removal performances of membrane system on secondary effluent treatment (July–Nov 2003)

Parameters	Feed, mg/L	Effluent, mg/L	Rejection, %
BOD	25.13	1.31	94.78
COD	69.31	14.00	79.80
SS	19.50	1.06	94.55
Hardness	97.46	12.08	87.61
TOC	19.57	1.14	94.18
Ammoniacal nitrogen	33.40	2.79	91.64
Nitrate	0.30	0.13	56.41
Total phosphorus	5.18	0.46	91.20
Iron	0.47	0.03	92.65
Manganese	0.08	0.02	74.77
Silica	8.29	0.54	93.52
Total plate count	775×10^3 cfu/100 mL	291×10^3 cfu/100 mL	62.44

In addition, the feed and treated water were compared to Standard A (Malaysia's Environmental Quality for Sewage and Industrial Effluent, 1979). Treated water accomplished the standard consistently. BOD, COD and manganese concentration for feed stream were out of range. As a conclusion, the RO permeate is safely recommended as an alternative for potable or industrial water application.

Hydraulic performances

Hydraulic performance of the IMF unit was carried out by measuring the changing of TMP with time interval. Figure 2 illustrates the TMP distribution of the IMF unit for 500 operating hours. The IMF unit showed insignificant TMP rises for three months operation. Consistent TMP value was observed during 500 operation hours. Figure 3 shows effective TMP after 18 minutes operation was adequately recovered by conducting the backwash process. The backwash process sufficiently removed the entire fouled components deposited on the membrane surface. It was concluded that only reversible fouling occurred during the 18 minutes operating time. However, TMP was slightly increased after long time periods of operation as a sign of biological irreversible fouling occurring. Chemical cleaning was recommended after 200 operating hours to prevent the eternal fouling problem. By the application of appropriate backwash process, membrane fouling could be minimized to the lowest level. The effect of different backwash operating modes on the fouling mechanisms should be used to optimize the output volume.

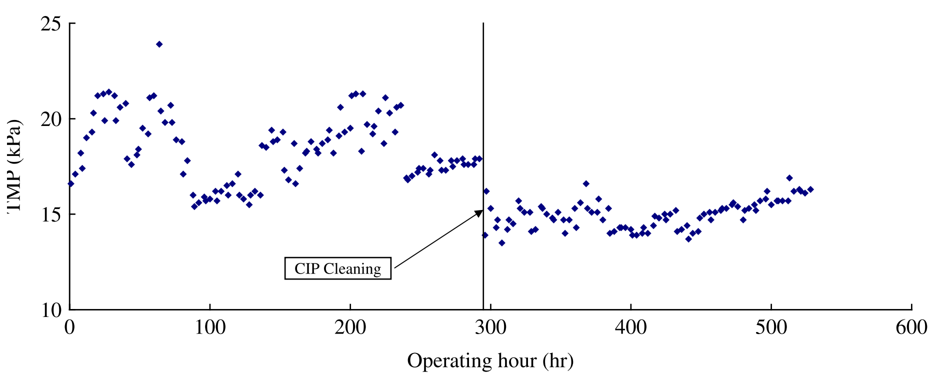

Figure 2 CMF-s operating TMP vs operating hour

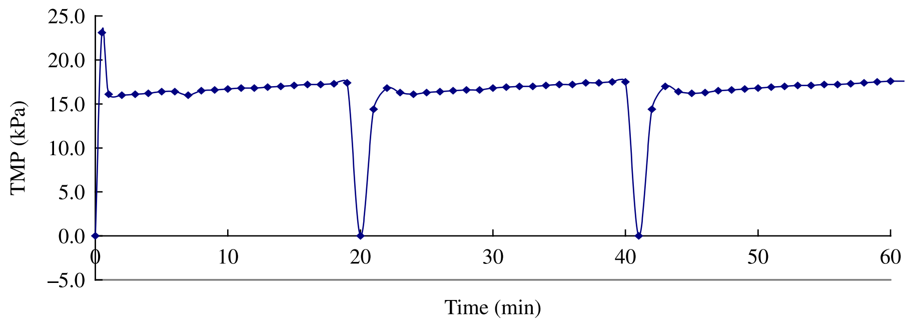

Figure 3 TMP with short experiment period

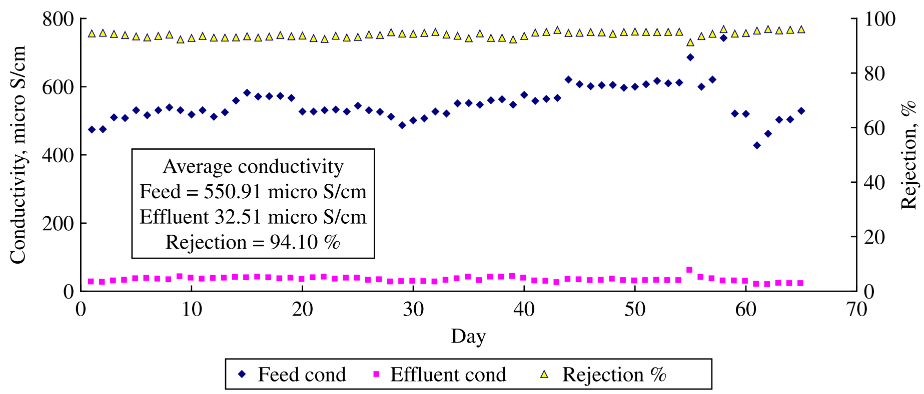

Figure 4 RO membrane conductivity

Electrical conductivity is related with the concentration of dissolved salts; this parameter was selected to analyze RO membrane performance (Bodalo-Santoyo *et al.*, 2003). Conductivity was measured in the RO feed and effluent streams during operation. Percentage rejection was calculated as $\{R = (1 - (\Omega_p/\Omega_f)) \times 100\%\}$. Figure 4 illustrates the feed and effluent conductivity distribution and the rejection percentages for 67 days of operation. Feed conductivity was in the range of 428–680 micro S/cm with 550.91 micro S/cm average, but in the, range of 18–42 micro S/cm and 32.52 micro S/cm average for effluent. Average percentage conductivity rejection was 94.10% on top of 92% minimum rejection. The permeate water conductivity was consistent although, there was significant variation of the feed water quality.

Conclusion

The following can be concluded from the results of this study.

1. An IMF/RO membrane system has been effective to treat secondary effluent for a water reclamation scheme. The permeate water quality was satisfied both raw water intake for producing water based on the WHO Drinking Water Standard and the Malaysian Effluent Standard A.
2. Appropriate backwash process was sufficient to overcome fouling problem of the IMF unit. Irreversible fouling did not occurr for 18 minutes of operation.
3. The RO membrane showed average 94% conductivity rejection. Consistent and stable operation could be achieved even with variable feed water quality.

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