SAEHAN INDUSTRIES INC.
Korea

A PILOT STUDY FOR EVALUATION OF SAEHAN FRM RO ELEMENTS AT BEDOK WATER RECLAMATION PLANT, SINGAPORE

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EXECUTIVE SUMMARY

This report summarizes the results of a pilot study for the evaluation of SAEHAN FRM RO elements at Bedok Water Reclamation Plant, Singapore using a MF/RO system with the capacity of 20 m^3/day. RE-4040-FL RO membranes from Saehan were tested with pre-treatment of 0.1 μm PVDF MF membranes. The pilot plant consists of 6 elements of RO membrane (7.9 m^2 each). The RO train was configured in single stage. The pilot plant was designed with automatic control system and it was operated continuously (24-hour) during the study. The objective of this study was to evaluate the RO membranes under different operating conditions.

Trial runs on various fluxes of the RO membranes were conducted from 12th May to 20th August. The RO membrane under test showed a low operating pressure of 52-62 psi at the flux rate of 10 GFD and at water recovery of 51%, indicating the membrane had a high flux. When the RO unit was operated at flux rate of 15 GFD and 10 GFD, the normalized flux declined by 18.3% over 3 weeks and by 20% over 5 weeks, respectively. The flux after CIP comparing to the initial flux could be recovered at 97%. It was found that rejections of the RO membrane in terms of conductivity at different fluxes were over 96% throughout the study. Also the results showed that TOC (on-line) of the RO permeate reached 36-66 ppb at operating pressure of 60 psi. RO permeate quality in terms of conductivity, turbidity, TOC, ammonium-N, nitrate, hardness (as CaCO3), total bacteria and total coliform were 37 μS/cm, 0.08 NTU, 0.20 mg/L, 0.46 mg/L, 4.8 mg/L, 0.22 mg/L, 67 counts/100mL and <1 count/100mL, respectively, which met the target quality as NEWater.

1. Introduction

Advanced membrane separation has become increasingly attractive as a promising technology for the reclamation of municipal wastewater [1-6] as it is highly efficient, easy and economical to operate. The reclamation of water from sewage effluent as a secondary source of water for non-domestic use is a national strategy of Singapore. A demonstration plant of a dual MF/RO membrane process with the capacity of 10 000 m^3/day for production of High Grade Water (so-called NEWater) from the secondary treated domestic sewage effluent has been successfully operated since May 2000 in Singapore [2]. Two factories at Bedok and Kanji with the capacity of 22 500 m^3/day have been commenced in January 2003 to supply NEWater to the wafer fab industry and indirect potable use. The Singapore government has planned to increase NEWater use up to 15% of total demand by 2008.

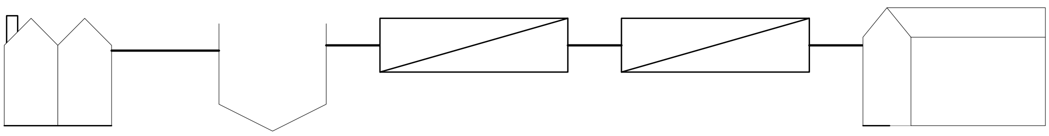

Fig. 1 A typical flow chart using MF (or UF)-RO process for reclamation of municipal wastewater

Fig. 1 shows a typical flow chart for the reclamation of municipal wastewater using a dual MF (or UF)-RO membrane process. In this process, MF or UF is used as a pretreatment step prior to RO to remove suspended solids and colloidal materials. RO membranes remove dissolved solids and organics. The effectiveness of RO depends on many factors including the type and surface charge characteristics of the RO membrane, feed concentration, operating pressure and percentage product recovery, etc. [7-8].

Fouling of RO membrane may be indicated by normalized flux decline with time. Control of fouling is an important issue in RO processes as fouled membranes need frequent cleaning, resulting in disruption of supply. Elimelech' group [9,10] investigated the colloidal fouling mechanism of RO and NF membranes and found that the membrane surface roughness influenced colloidal fouling remarkably. Hoek et al. [11] applied the antiscalant Flocon-100 in combination with acid dosage and successfully controlled the scaling caused by $BaSO_4$ and $CaSO_4$ in the treatment of river water using RO membranes. However, it was found that addition of Flocon-100 in the feed caused biofouling of RO plant. Bonne et al. [12] eliminated this biofouling by using an organophosphonate antiscalant PermaTreat 191,also scaling was well under controll at a recovery of 87%. Al-Rammah [13] conducted a pilot study on application of acid free antiscalant to mitigate scaling in RO membranes and optimized a non flammable phosphino-carboxylate based antiscalant with regard to the autopsy analysis. Recently, Pearce and Kumar [14] conducted the evaluation of new generation RO membranes (4040-BL) produced by SAEHAN Industries Inc (SAEHAN) to treat brackish groundwater in the National City, CA, USA. They demonstrated that the SAEHAN 4040-BL membrane could be operated at high fluxes (about 20 gfd) and high recoveries (85-90%) and decline of flux during 500 hours of testing was not observed.

The objective of the pilot study was to evaluate the 'Fouling Resistant Membrane' (FRM) RO elements newly developed by SAEHAN for the reclamation of the secondary treated sewage effluent at Bedok WRP. Moreover, it was a challenge for RO membranes to produce NEWater with low TOC concentration for use by the electronics industry. The performance of the RO membrane was studied under different operating conditions.

2. Materials and methods

2.1. Description of overall pilot plant process

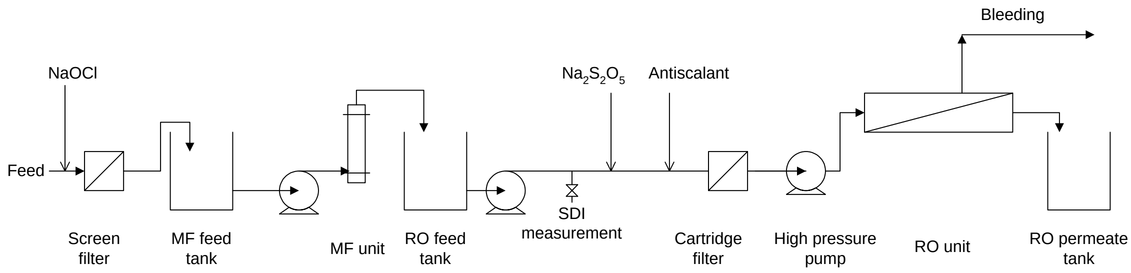

Fig. 2 Schematic diagram of the pilot plant process

The pilot plant was continuously operated during the study. The schematic diagram of the pilot process is shown in Fig. 2. The secondary treated effluent was transferred by a submersible pump from outfall sump through an automatic strainer (200 μm) to the MF feed tank. The large suspended solids in the raw feed water were removed by the strainer to prevent membrane fibers from being blocked or abraded. The filtrate water was then transferred to the MF unit by the MF feed pump. The MF unit further removed suspended solids and colloidal materials. NaOCl solution was dosed into MF feed to reduce biofouling. The MF permeate was collected in the backwash tank and then transferred to RO feed tank. RO feed was transferred by feed pump and high-pressure pump to RO unit. Sodium metabisulphite was dosed into RO feed to protect the RO membranes from the attack of free chlorine. An antiscalant PermaTreat 191 was also dosed into RO feed to minimize the fouling of RO membranes. Concentrate water was discharged to drain and permeate was stored in RO permeate tank.

There was also a CIP system attached with the RO unit. 2% citric acid was used for cleaning at pH 2.0 over 3 h. Then 1% EDTA was used at pH 12.0 over 1h operation followed by 16 h soaking and 0.5 h operation.

2.2. Hollow fiber MF membrane

The MF unit contains eight modules of 0.1 μm PVDF hollow fiber membranes with a pretreatment capacity of 2.4-4.0 m^3/hr. It is equipped with advanced PLC auto-control system. The programmes for filtration and backwash have been programmed.

2.3. Spiral-wound RO membrane

The RO unit contains 6 elements of membranes installed in two pressure vessels in series as single stage configuration. Pressure, flow, conductivity and temperature indicators were also installed. The specification of RO membrane unit is given in Table 1.

Table 1 Specification of RO membrane unit

Membrane type	CSM: RE4040-FL
Membrane maker	Saehan Industries Inc.
Membrane material	Polyamide
Membrane area	85 ft^2 per element
Number of element	6
Length of element	40 inch
Pressure vessel type	Standard 4-inch
Pressure vessel length	3 meter (2 Nos)
Capacity per element	2,600 GPD at 225 psi, 2000 ppm NaCl, 25 °C

2.4. Pilot trials

Table 2 Variable operating conditions of the RO membrane unit

Parameter	Test 1	Test 2	Test 3	Test 4
Flux (GFD)	26	20	15	10
Feed flow (m^3/h)	3.2	2.8	2.1	1.6
Recovery (%)	66	58	56	51
Operating pressure (psi)	136-141	117-136	75-83	52-62

Pilot trials on various membrane fluxes in a range of 10-26 GFD at operating pressure of 52-141 psi and product recovery of 51-66% for the RO unit were conducted from 12th May-20th August 2003. Variable operating conditions of the RO unit are shown in Table 2. The RO membrane unit was operated under the conditions of Test 4 showed in Table 4 during the last 5-week study.

Flux of RO membranes and operating pressure as a function of time were observed. Qualities of feed and permeate were determined.

2.5. Sample analysis

During the pilot study, samples were analyzed for pH, conductivity, turbidity, silt density index (SDI), total hardness, ammonium, nitrate, TOC, and total coliform. Representative samples of RO feed and permeate were collected weekly for analysis. pH and conductivity were measured by benchtop models Ecomet P25 and Ecomet C75, respectively. Turbidity was measured using HACH model-2100 N turbidity meter. SDI, as per ASTM D-4189-82 standard, was measured using a 0.45-μm membrane filter. Total hardness analysis was performed according to APHA 2340B standard using a Perkin Elmer model DB3000 Inductively Coupled Plasma Emission Spectrometer. Ammonium analysis was conducted as per APHA 4500N standard. Nitrate was analyzed using a Dionex DX-120 Ion Chromatograph following USEPA 300.0 standard. TOC measurements were done using Shimadzu TOC analyzer model 5000A as per USEPA 415.1 standard. APHA 9222B standard was followed for total coliform analysis. On-line TOC was monitored using Sievers portable TOC analyzer model 820.

Membrane performance refers to the normalized flux as defined in equation (1):

$$\text{Normalized flux} = Q / (A \times \Delta P) \quad (1)$$

where Q is volume flow rate of permeate (m^3/h), A is effective membrane area (m^2), ΔP is transmembrane pressure (MPa).

Membrane performance in terms of the percentage rejection of a particular component is defined as per equation (2):

$$\text{Rejection} = (1 - C_p / C_f) \times 100\% \quad (2)$$

where C_f and C_p are the component concentration in the feed and permeate, respectively.

3. Results and discussion

The raw feed water contained a wide range of suspended solids and colloidal substances. A micro-strainer was required to remove large suspended solids for protecting the MF membranes. The MF membranes further removed smaller suspended solids and colloidal substances. Throughout the study, RO feed SDI was in the range of 2.9-3.2. Table 3 shows typical characteristics of the feed to the RO unit.

Table 3 Typical characteristics of the RO feed

Parameters	Value
pH	6.9
Conductivity (μS/cm)	1010
Turbidity (NTU)	0.14
Ammonium-N (mg/L)	2.77
Nitrate (mg/L)	34.7
Hardness as CaCO3 (mg/L)	102
TOC (mg/L)	9.0
SDI	3.1

Free chlorine and total chlorine of MF feed after dosing NaOCl of 6 mg/L were found to be 0.31-0.40 mg/L and 0.80-0.83, respectively. The MF permeate in the RO feed tank contained free chlorine of 0.09-0.10 mg/L and total chlorine of 0.37-0.67 mg/L, respectively. Sodium metabisulphite of 2 mg/L was dosed into RO feed to protect RO membrane from the attack of free chlorine.

3.1. Permeate quality of RO membrane

Table 4 shows the permeate quality of RO membrane at different fluxes during the study and the target quality as NEWater [15]. It can be seen that quality of the RO permeate meets the target quality as NEWater in terms of the parameters measured except pH which could be easily raised by adding NaOH.

Table 4 Comparison of the RO permeate quality and the target quality

Parameter	20 GFD	15 GFD	10 GFD	Target quality
pH	6.0	5.8	5.8	7-8.5
Conductivity (µS/cm)	36	28	37	<200
Turbidity (NTU)	0.08	0.09	0.08	<5
Ammonium-N (mg/L)	0.37	0.10	0.46	<0.5
Nitrate (mg/L)	-	1.83	4.8	<15
Hardness as $CaCO_3$ (mg/L)	0.09	0.15	0.22	<20
TOC (mg/L)	0.10	0.32	0.20	<0.5
Total bacteria HPC (counts/100mL)	-	-	67	<30000
Total coliform (counts/100mL)	-	-	<1	<1

3.2. On-line monitoring of RO permeate TOC

Fig. 3 shows TOC (on-line) of the RO permeate as a function of time during the period of 6th-20th August 2003. It can be seen that the on-line TOC fluctuated regularly between 36.2 µg/L and 65.7 µg/L, which was much lower than that of off-line measurements as shown in Table 6. Fig.3 also illustrated that the maximum of TOC normally appeared during noon and the minimum showed during midnight. It might be due to high and low organic loading of influent to WRP, which subsequently produced the secondary treated effluent with high and low TOC during noon and midnight, respectively.

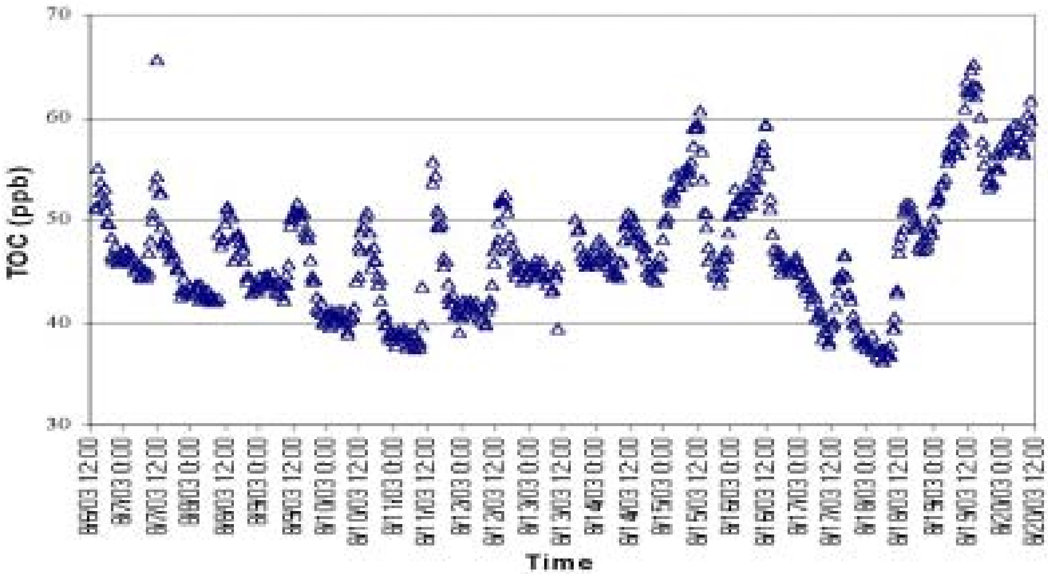

Fig. 3 TOC (on-line) of the RO permeate as a function of time

3.3. Normalized flux and rejection as a function of time

Normalized flux and rejection in terms of conductivity of the RO membranes under different flux rate as a function of time throughout the study are shown in Figs. 4 and 5. The results are summarized in Table 5.

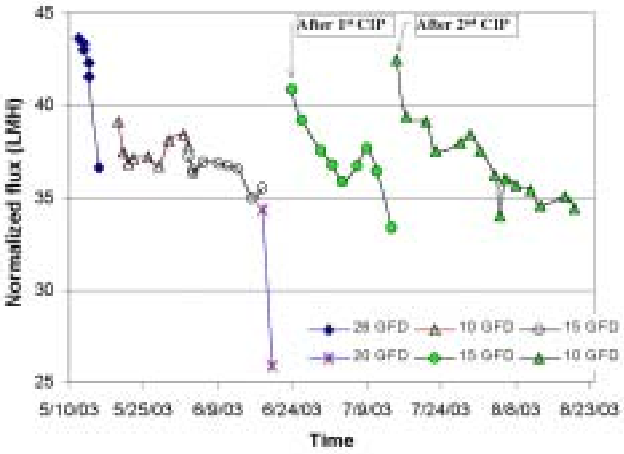

Fig. 4 Normalized flux at different flux rates as a function of time

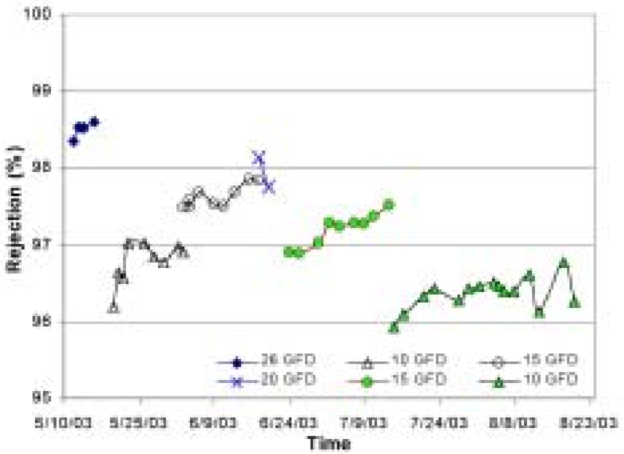

Fig. 5 Rejection in terms of conductivity at different flux rates as a function of time

Table 5 Normalized flux and rejection of the RO membrane

Parameter	Test 1	Test 2	Test 3	Test 4
Flux rate (GFD)	26	20	15	10
Operating pressure (psi)	136-141	117-136	75-83	52-62
Normalized flux ($L\ m^{-2}\ h^{-1}\ MPa^{-1}$ at 25°C)	43.6-36.6	34.3-25.9	40.9-33.4	42.4-34.0
Rejection (%) in terms of conductivity	98.4-98.6	98.1-97.8	96.9-97.5	96.1-96.5

It can be seen that the normalized flux dropped obviously from 43.6 to 36.6 $L\ m^{-2}\ h^{-1}\ MPa^{-1}$ (LMH) at 25°C when the RO unit was operated at the flux of 26 GFD from 12th - 16th May. When it was operated at 10 GFD for two weeks from 20th May-3rd June, the normalized flux dropped slightly from 39.1 to 37.7 LMH. When the flux was increased to 15 GFD, the normalized flux dropped slightly from 37.2 to 35.5 LMH during two weeks during 3rd-18th June. When the flux was further increased to 20 GFD, the normalized flux declined significantly from 34.3 to 25.9 LMH within 2 days, 18th-20th June. Then, the first CIP was conducted. When RO unit was operated again at 15 GFD, the normalized flux declined from 40.9 to 33.4 LMH for 18.3% over 3 weeks, 24th June-14th July. CIP was done for the second time. Finally, RO unit was operated at 10 GFD during 15th July-20th August and the normalized flux declined from 42.4 to 34.0 LMH for 20% over 5 weeks. Fig. 4 also showed that the flux recovery after the first CIP and second CIP comparing to the initial flux was 94% and 97%, respectively.

Fig.5 and Table 5 showed that rejections of the RO membranes were over 96% throughout the study. Higher flux rate was the RO membrane operated at, higher rejection was obtained. Higher rejection was mainly due to the operation of the RO membranes at higher pressure to obtain higher flux.

The analytical results shown in Appendix 2 also indicated that the average rejections of the RO membrane for TOC and nitrate were >97% and >85%, respectively.

4. Conclusions

The conclusions from the pilot study of Saehan RO membrane are summarized as follows:

1) RO permeate quality in terms of conductivity, turbidity, TOC, ammonium-N, nitrate, hardness, total bacteria and total coliform matched the quality of NEWater.
2) TOC (on-line) of the RO permeate were in the range of 36-66 ppb at operating pressure of 60 psi.
3) Rejections of the RO membrane in terms of conductivity, TOC and nitrate were higher than 96%, 97% and 85%, respectively.
4) When the RO unit was operated at flux rate of 15 GFD and 10 GFD, the normalized flux declined for 18.3% over 3 weeks and for 20% over 5 weeks, respectively. Flux after CIP was 97% of the initial flux.
5) The RO membrane under test showed a low operating pressure of 52-62 psi at the flux rate of 10 GFD and at water recovery of 51%, indicating the membrane had a high flux.

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