

Reverse Osmosis Membranes for Wastewater Reclamation
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Abstract

Wastewater reclamation has become a viable alternative to supplement water supplies in water-short areas. In particular, membrane treatment has played an important role in purifying the water cost-effectively. Reverse osmosis membranes have been shown to significantly reduce total dissolved solids, heavy metals, organic pollutants, viruses, bacteria, and other dissolved contaminants. Experience from commercial membrane wastewater treatment plants has demonstrated that there are key design parameters which must be followed to prevent rapid membrane fouling, and thus reduce high system maintenance costs and significant downtime. In particular, current best practices include the use of ultrafiltration or microfiltration membranes to remove colloidal debris, maintain a chloramine residual to prevent biogrowth, select proper antiscalant chemicals limit RO recovery rates to prevent membrane scaling, and utilize membranes which minimize organic fouling. Select conventional polyamide and low fouling membranes have been used successfully at plants such as the West Basin Wastewater treatment plant in California or the Bedok and Kranji plants in Singapore. These large-scale plants provide the basis for even larger plants, and greater contribution to the water supply in needy regions.

Introduction

Membrane technology is playing an increasingly important role in the reclamation of municipal wastewater. Due to the growing demand for high quality water in urban areas, purification of wastewater is become one of the preferred means of augmenting the water resources.(1) In particular, high quality reclaimed wastewater can be used for industrial customers. For example, it is being used for making boiler feedwater and semiconductor process water. Reverse osmosis (RO) membranes have been proven to successfully treat such water and provide water which exceeds reuse quality requirements. Numerous large-scale commercial membrane plants are now being used to reclaim municipal wastewater. These plants include the 50,000 m³/day West Basin, CA, Kranji 40,000 m³/d in Singapore, and the 32,000 m³/d Bedok plant in Singapore. (2) Additionally, even larger plants are planned such as the 270,000 m³/d plant in Orange County, California and the 380,000 m³/d plant for Sulayabia, Kuwait. The magnitude of these RO-based reclamation plants demonstrates the acceptance that this technology has gained recently.

Background

A typical process for municipal wastewater consists of primary, secondary and tertiary treatments. The resulting effluent is low in turbidity and can be disinfected for discharge. However, the level of dissolved solids is not reduced by this process and the water is not generally suitable for reuse. When tertiary effluent from a conventional treatment process is supplied to a RO system, it is common to have all forms of fouling - colloidal, biological, scaling and organic fouling. Examples of magnified membrane surfaces which have been fouled in these ways are shown in Figures 1 and 2. The coatings of foulant will impede water transport through the membranes. Early attempts to treat this water with RO membranes resulted in rapid fouling and required membrane cleaning as

frequent as twice per week. This shortened membrane life and greatly increased operating cost.

In the past 5-10 years significant research has demonstrated that RO membranes can run at very stable rates when operated at optimum conditions. This work was largely the result of studies (3) at the Water Factory 21 in Orange County, California, and the large-scale demonstration for the past 3 years at the 10,000 m³/d plant in Bedok Singapore.

Improved Treatment Process

Through careful research, the various modes of RO fouling have been addressed. (4) Figure 3 shows the key features of an optimized RO membrane-based wastewater treatment process. Colloidal material is effectively controlled by the use of ultrafiltration (UF) or microfiltration (MF) membrane pretreatment.

Chlorine can be added prior to the membrane pretreatment to control biofouling in this step and again added after the membrane pretreatment to minimize biogrowth. RO membranes have little tolerance of free chlorine, but high levels of tolerance to chloramines. Chloramine concentrations of 1-2 ppm should be maintained in wastewater to prevent biogrowth in the RO membranes.

Figure 1a Top surface of clean, unfouled Polyamide membrane

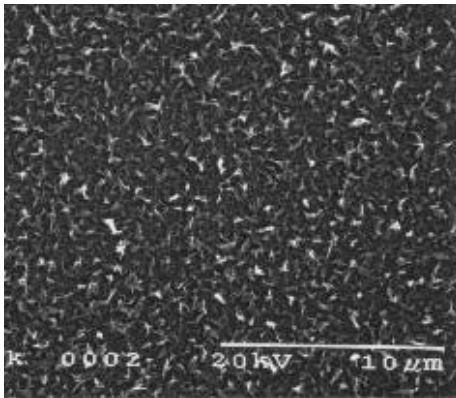


Figure 1b Cross-section view of membrane with colloidal solids coating the top surface

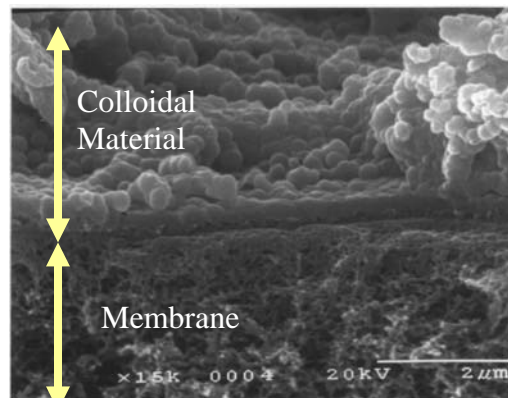


Figure 2a Top surface of polyamide Membrane covered with bacteria and extra cellular polymeric substance.

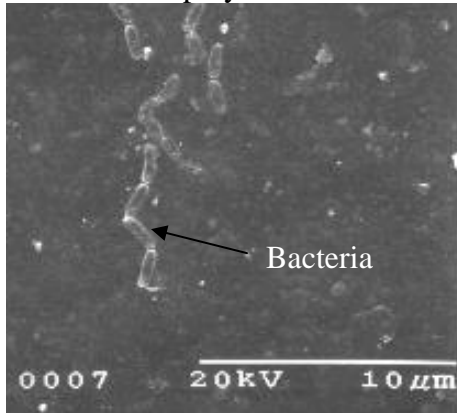
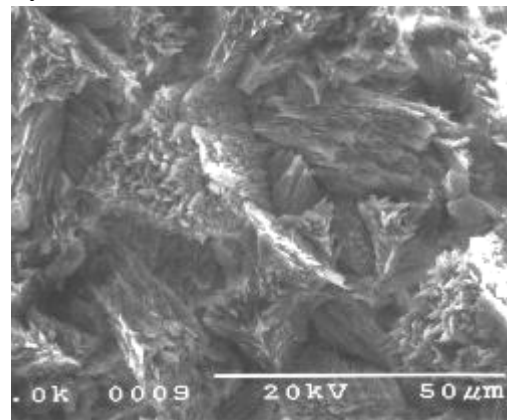


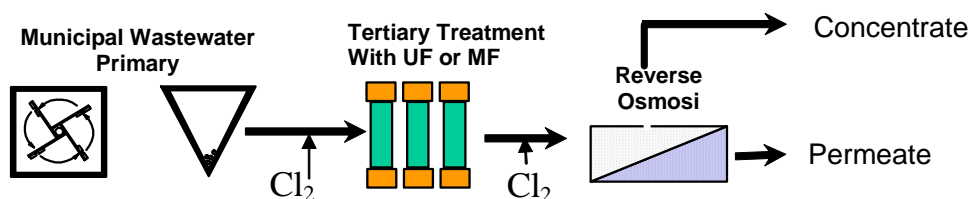
Figure 2b Top surface of polyamide membrane coated with mineral scale crystals



Scaling is controlled by a combination of suitable antiscalant chemicals, lower recovery and lower pH. It is not uncommon to have high levels of calcium, silica, phosphate, carbonate, and other ions which can form scale. One of the more problematic scalants is calcium phosphate. The mineral has very low solubility and phosphate concentrations can vary widely in municipal wastewater. Some scalants can be easily removed with cleaning, while others like silica are very difficult to remove.

Finally, organic fouling can cause flux loss problems for RO membranes. Surface waters may contain only 2-5 ppm of dissolved organics, while wastewater may have 10 to 20 ppm of organics. These materials can adsorb on the membrane, causing flux decline. (5) They can also react with antiscalant chemicals to form precipitate on the membrane. A recent report by Alexander et al. (6) shows that various membranes tested on wastewater have very different performance. In particular they found that conventional polyamide membranes like Hydranautics' energy-savings ESPA2 can effectively treat wastewater with very stable flux and rejection. Low fouling membranes such as the low fouling LFC1 used at Bedok have also shown very successful performance on wastewater. (4)

Figure 3 Membrane Based Wastewater Reclamation Process

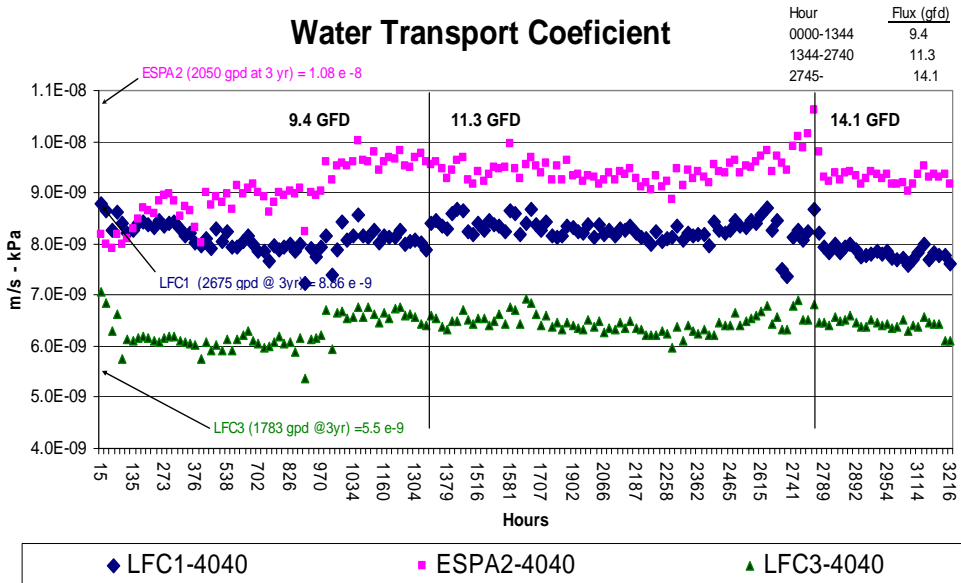


We have recent pilot tests made in Oceanside, California and have further demonstrated the excellent performance of this design scheme when treating wastewater. At this site secondary municipal wastewater effluent is treated by Hydranautics' HYDRAcap UF hollow fiber membranes to produce RO feed water with a turbidity of 0.03 NTU. Both conventional low pressure polyamide membrane (ESPA2) and low fouling (LFC1 and

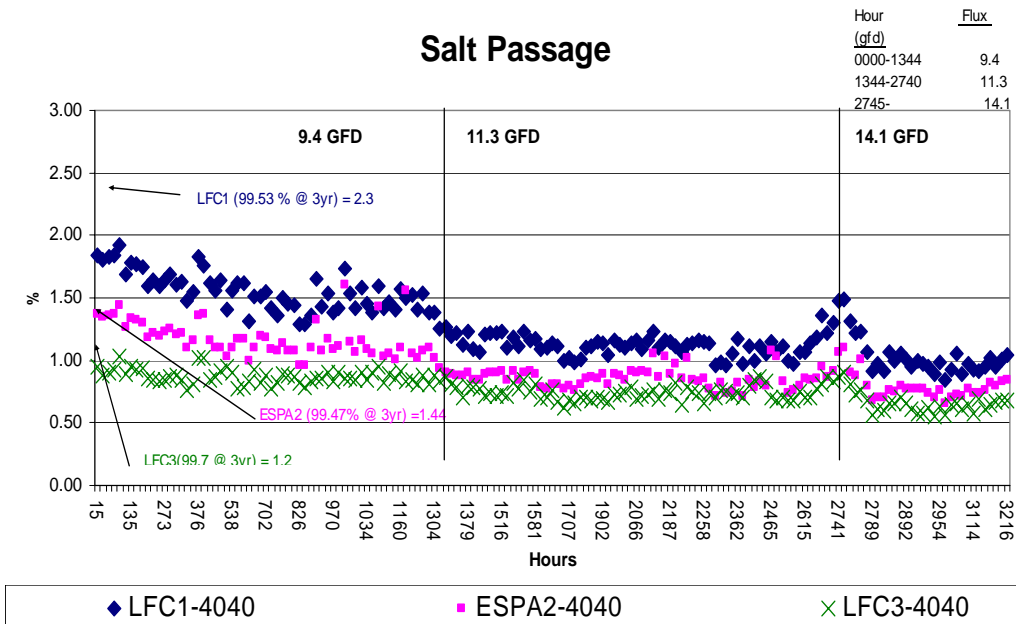
LFC3) membranes have operated without flux loss and have maintained stable salt rejection for an extended operation. (Figure 4).

Figure 4 Performance of Polyamide Membrane on UF Pretreated Wastewater, (a) Normalized Water Transport Coefficient and (b) Normalized Salt Passage Factor

(a)



(b)



The Bedok Demonstration plant is one commercial plant that has successfully utilized membrane-based reclamation. This plant has operated for nearly 3 years and typically

produces 10,000 m³/d of high quality treated wastewater. The low fouling LFC1 RO membranes purify wastewater pretreated by MF membranes. The design flux was 19 l/mh with a recovery of 85%. After some fine tuning, the plant operated with very consistent performance, such that chemical cleaning of the first stage is done once every 130 days, while cleaning of the second and third stage is done once every 74 days on average.

Based on this excellent experience of the demonstration plant, the Public Utilities Board (PUB) in Singapore has installed two additional plants, the 8.5 MGD (32,000 m³/d) Bedok and the 10.5 MGD (32,000 m³/d) Kranji wastewater treatment plants, both using Hydranautics' low fouling RO membranes. The process design for these two plants is given in Table 1. The RO train at Kranji is shown in Figure 5.

Both plants have met water production and quality goals and have been operating over one year. The main difficulty encountered in the operation of the two plants was at the Bedok plant. This plant treated more difficult, high salinity water. During the initial operation of this plant, there was a rapid increase in the feed pressure during the first month of operation. Analysis of the flux values indicated that the problem was isolated to the second stage. The flux in this stage dropped from 13.6 to 6.1 l/mh, while the flux in stage 1 was increased to compensate for the lower flow in stage 2. This clearly indicated that there was significant fouling of the elements in stage 2. Analysis of elements removed from the second stage indicated a combination of organic fouling and calcium phosphate scaling. Changes to the antiscalant have minimized this flux decline problem.

Table 1 RO Plant Design for Bedok and Kranji Wastewater Treatment Plants

Parameter	Bedok Design	Kranji Design	Units
Total Trains	4	4	
Element Array	50x23	49x24	1st x 2nd Stage
Element Area	37.2	37.2	sq m per element
System Recovery	75	75	%
Temperature	30	30	degrees C
Feed Pressure	8.2	7.5	Bar
Total Permeate Flow	32000	40000	m ³ /day
System Flux	17.6	21.9	Lmh
1st Stage Flux	18.9	23.1	Lmh
2nd Stage Flux	14.8	19.6	Lmh
Feed TDS	987	633	mg/L
Permeate TDS	46.6	46.6	mg/L
Rejection	98.1	97.1	%
Total Chlorine	1.8	1.8	mg/L

Figure 5 RO Train at Kranji Wastewater Treatment Plant



Conclusion

Membrane technology is being used for the large-scale reclamation of wastewater. Success of this new technology depends on proper pretreatment, chemical control and RO membranes that are resistant to fouling. With proper design parameters, certain conventional polyamide membranes and low fouling composite membranes have been shown to have stable flux and rejection over long operational periods, with time between membrane cleanings in excess of 6 months in many cases. This technology will be very important for communities who need to extend their water supply and for industries that require ultra-high quality water for their operation.

VI Acknowledgements

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References

- 1 Crook, J., R. Hultquist R., Sakaji, R., Wehner, M., Evolution and status of California's proposed criteria for groundwater recharge with reclaimed water. Proc. 2002 AWWA Annual Conf., San Antonio Texas.
- 2 Chilekar, S., Production of High Purity Water for Semi-conductor Industry using City Sewage by Public Utility Board of Singapore: A Case Study.
- 3 Leslie, G.L. et al., Microporous membrane pretreatment options for reverse osmosis in municipal wastewater, Orange County Water District, private communication.
- 4 Bartels, C, Wilf, M., Andes, K., and Iong, J., 2003 IDA World Congress on Desalination and Water Reuse, Bahamas.
- 5 Wilf M., and Alt S., Application of low fouling RO membrane elements for reclamation of municipal wastewater, Desalination 132 (2000) 11-19.

- 6 Alexander, K., Alt, S., Owens, E., Patel, M., McGovern, L., Low fouling reverse osmosis membranes evidence to the contrary on microfiltered secondary effluent. Proc. 2003 AWWA Memb. Technology Conf., Atlanta, GA.