

# Characteristics of RO foulants in a brackish water desalination plant

Hui Ling Yang, Chihpin Huang\*, Jill R. Pan

*Institute of Environmental Engineering, National Chiao Tung University,  
75 Po-Ai Street, Hsinchu, Taiwan 300  
Tel. +886 3 5726463; Fax +886 3 5725958; email: [cphuang@mail.nctu.edu.tw](mailto:cphuang@mail.nctu.edu.tw)*

Received 21 December 2006; accepted 7 January 2007

## Abstract

This study identified the membrane fouling of a two-stage RO process of the Bai-sha brackish water desalination plant facing serious fouling problems. Two membrane modules, one from each stage, were autopsied and diagnosed for the cause for the failure of the RO system. Different morphologies were exhibited on the fouled membrane. Results suggested that the fouling on the first-stage membrane tended to be organic and biological, while that on the second-stage membrane appeared to be scaling. Higher than 85% of the foulants on the first stage membrane were organic substances in opposed to the 5 to 8% of those on the second stage membrane. However, the total organic matter on the second stage membrane was more than that on the first stage one. The thick layer of scalants on the surface of the second-stage membrane was identified to be calcium carbonate of which the crystal was clearly seen in the SEM images. The scaling was thickest at the outlet of the membrane. Huge amount of microbes were found on both membranes. The FTIR results also suggested the existence of extracellular polymeric substance (EPS) on the first stage membrane. This study recommended that the recovery rate, pH and the potential for bio-fouling should be defined at the real operation.

**Keywords:** Brackish water; Scaling; Fouling; Membrane autopsy; Foulants identification

## 1. Introduction

Penghu archipelago located in the Taiwan Strait, southwest of the Taiwan Island, is an arid area. The water sources for the water supply include groundwater and seawater. Bai-sha desalination plant is a brackish water desalination plant

which produces 1200 cubic meters per day (CMD) of water for potable use. The raw water is taken from the Chih-Kan Ground Reservoir, a subsurface reservoir, collecting water from an unconfined aquifer which is contaminated by seawater. The plant is facing serious problem of membrane fouling.

The characteristics of the foulants are closely related to the raw water quality. It has been found

\*Corresponding author.

*Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece, April 22–25, 2007.*



that two neighboring aquifers have produced water with different qualities [1]<sup>1</sup>. Therefore, each plant must identify the fouling character before its initiation. Effective control of fouling requires a thorough diagnosis of the foulants [2] because each foulant requires different means of removal. For instance, the carbonate-based scales can be controlled by maintaining the feed pH in the range of 4–6 with H<sub>2</sub>SO<sub>4</sub>, whereas the sulfate-based scales can be prevented by using inorganic phosphate, usually sodium hexa-meta-phosphate (SHMP) [3]. For fouling diagnosis, membrane autopsy plays an important role. Many researches have performed membrane autopsies to identify the species of foulants and the mechanism of fouling [3–8].

The objective of this work was to identify the composition of the foulants on the membrane of a two-stage RO system in the Bai-sha brackish water desalination plant. Two membrane modules, one from each stage, were autopsied and analyzed to diagnose the cause for the failure of the RO system. Foulants were extracted and characterized by element analysis, dry weight identification, microbiological quantification, SEM-EDX and FTIR.

## 2. Materials and methods

### 2.1. Bai-sha desalination plant

Bai-sha desalination plant was constructed in year 2003 to supply the potable water for the Bai-sha village at a capacity of 1200 CMD. Because of the high TDS content, around 1700 mg/L, the brackish raw water from the Chih-Kan Ground Reservoir has been pretreated including media filtration and cartridge filtration prior to the RO

system. The pH of feed into the RO system has been kept at 5.8 to prevent the occurrence of scaling. The two-stage RO system contains five pressure vessels in a 3:2 array. Each pressure vessel contains six elements.

### 2.2. Membrane autopsy and foulants identification

Two elements were removed from the first and the second stage individually for autopsy and analysis. Small pieces (1.7 × 1.7 cm<sup>2</sup>) were cut from different locations of the membrane followed by the sequential extraction with DI water, sulfuric acid and sodium hydroxide solution in ultrasonic bath. The extract was analyzed with ICP to identify the elements content. Microbe quantification was performed by DAPI (4'-6-diamidino-2-phenylindole) stain. Organic content was estimated by the mass difference before and after the 550°C incineration. The foulants on the membrane were also characterized by SEM-EDX, and FTIR.

## 3. Result and discussion

### 3.1. Visual observation

The second-stage membrane was much heavier than the first-stage membrane. The surface of the first-stage membrane revealed a shade of brown and a touch of slippery, Fig. 1 (a). The brown color was stronger at the inlet end of the membrane suggesting the settling of contaminant from the raw water. The second stage membrane had a rough yellow surface, Fig. 1(b). The yellow scaling was thicker at the outlet end indicating scaling from the concentration of the brine water.

The SEM photographs of the two membranes were shown in Fig. 2. The surface of the first-stage membrane was amorphous, and several rod shape microbes with a length of 1 to 2 μm were detected. On the second stage membrane, a crystal morphology was observed. The composition was confirmed later.

<sup>1</sup>Hadi (2002) had performed analysis of 41 wells to determine the properties of groundwater for two neighboring aquifer, Dammam limestone aquifer and the clastic Kuwait Group aquifer, and found that the Kuwait Group aquifer water is Cl–Mg and Cl–Ca genetic water types, and the Dammam limestone aquifer water is Na–SO<sub>4</sub> and Cl–Mg genetic type.



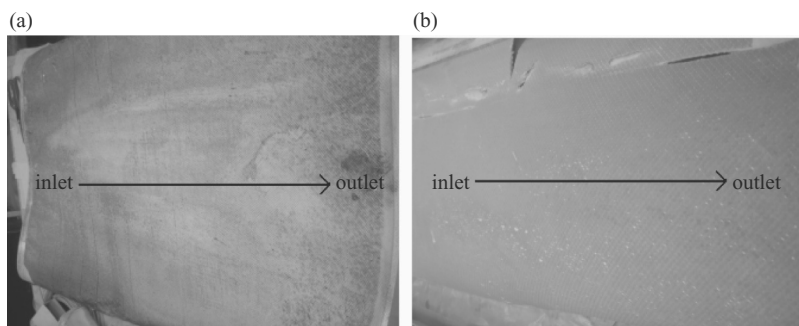


Fig. 1. Photos of spread RO membranes (a) first stage (b) second stage.

### 3.2. Identification of organic foulants

Several small pieces of membranes were incinerated at 550°C, and the mass loss was taken as the amount of organic contamination on the membrane. Fig. 3 shows the mass distribution of

the organic contaminants on the different sites of the first and second-stage membranes. The organic contaminants were collected on the second-stage membrane, especially at the outlet end of the second-stage membrane probably due to the co-precipitation with the scalants.

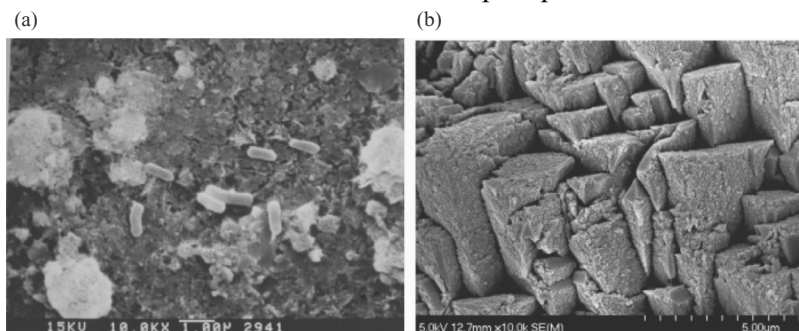


Fig. 2. SEM photographs of RO membranes (10,000×) (a) first stage (b) second stage.

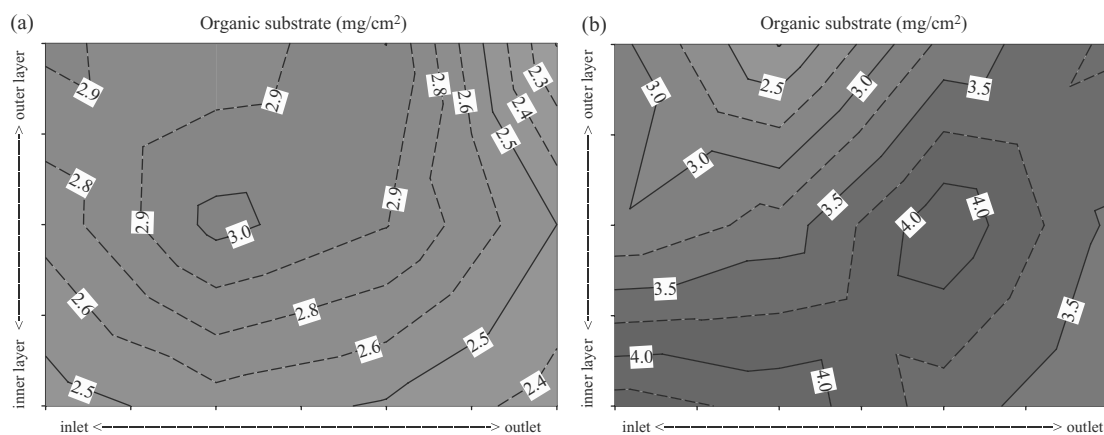


Fig. 3. The distribution of organic foulants on membranes (a) first stage (b) second stage.



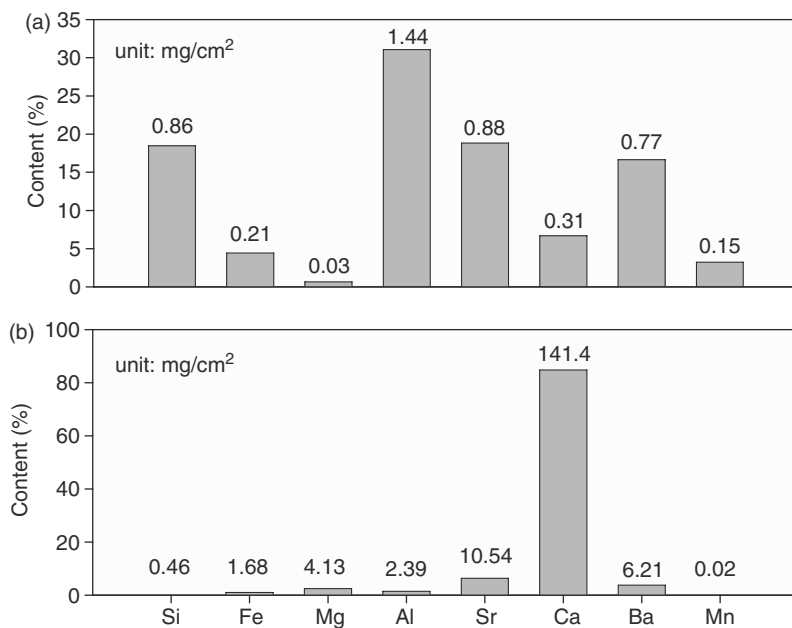


Fig. 4. The percentage content of elements on membranes (a) first stage (b) second stage.

The degree of organic fouling was determined by its weight percentage in total foulants. There were 85–93% organic fouling on the first-stage membrane, while 5–8% on the second-stage membrane. Therefore, the first-stage membrane could be considered organic fouling.

### 3.3. Identification of scalants

To estimate the amount of scalants, ICP and AA were applied for element analysis. The percentage of element content was given in Figs. 4 and 5. The first-stage membrane contained less scalants and the major components of the scalants are

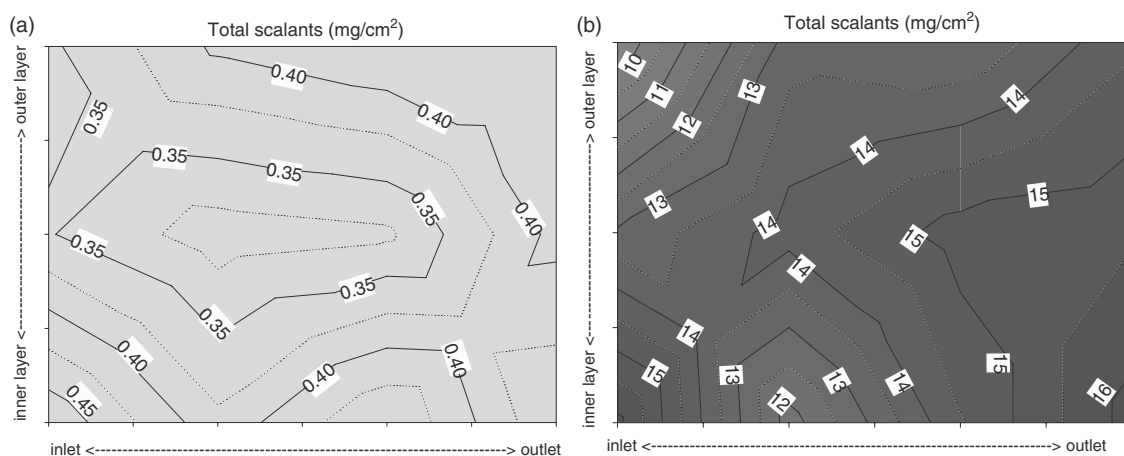


Fig. 5. The distribution of scalants on membranes (a) first stage (b) second stage.



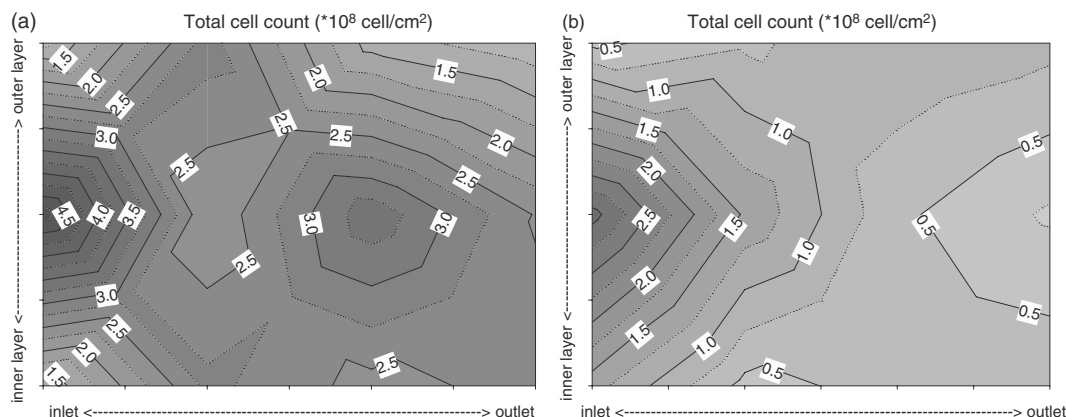


Fig. 6. Distribution of microbes on membranes (a) first-stage (b) second-stage.

Si, Al, Sr and Ba. On the contrary, calcium dominated the second-stage membrane foulants. Similar results were found from the EDS analysis. It was concluded that the second stage membrane was calcium salt scaling, and the first one was not.

In summary, the highest accumulation of scalants on the first-stage membrane was 0.5 mg/cm<sup>2</sup>, however, the accumulation on the second stage one was higher than 10 mg/cm<sup>2</sup>. It was clear that scalants accumulated at the outlet end of the second stage membrane. It was similar to the

results of the organic foulants analysis which demonstrated the co-precipitation of organic foulants and calcium salt.

### 3.4. Estimate of bio-fouling

For investigation of the bio-fouling, DAPI stain was applied to quantify the bacteria. Fig. 6 is the distribution topography of bacteria on the two membranes. It showed that the membranes had as many as 10<sup>7</sup> to 10<sup>8</sup> cells per square centimeter on them indicating serious bio-fouling.

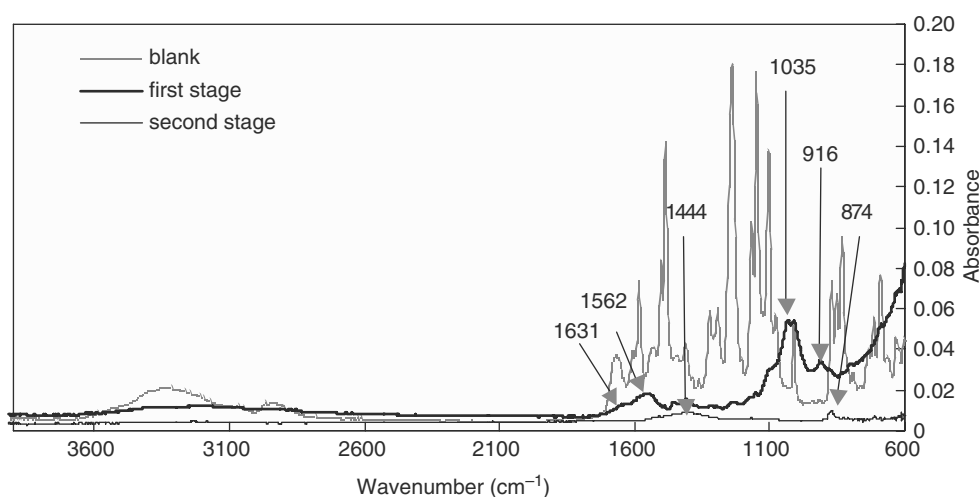


Fig. 7. FTIR spectrum from blank and fouled membranes.



### 3.5. FTIR analysis

The FTIR analysis was performed to qualitatively assess the types of the organic foulants deposited on the membrane surface. The results of the control and the fouled membrane were shown in Fig. 7. The control was taken from the clean polyamide membrane. Both results of the first and second-stage membranes revealed much fewer peaks than the blank due to the covering with foulants and scalants. The peaks located at 1035 and 916  $\text{cm}^{-1}$  were characteristics of polysaccharides, while the peaks located at 1562 and 1631  $\text{cm}^{-1}$  were characteristics of peptide of protein. Both are clearly shown in the first-stage membrane indicating the presence of EPS. On the other hand, the peaks at 1444 and 874  $\text{cm}^{-1}$  were observed in the second-stage membrane, indicating the presence of inorganic carbonate,  $\text{CO}_3^{2-}$  [9]. Therefore, it is concluded that the calcium salt on the second-stage membrane was calcium carbonate.

### 4. Conclusion

The foulings in the upstream and downstream of the RO train can be represented by the membrane analysis of the first and second-stage membrane. It is concluded that organic and bio-fouling occurred at the inlet end of the membrane in the RO system. And both of these two foulings were more serious in the beginning of the system, which might be due to the sedimentation of insoluble organic matter and microbes. The survived microorganisms then released EPS on the membrane. The brine water was concentrated down the stream, which lead to the precipitation of calcium carbonate. The population of the microbe was reduced by approximately an order although still very significant. Contrary to bio-fouling, the organic fouling was serious at the outlet end similar to the trend of scaling. This phenomenon suggested the co-precipitation of

calcium salt and soluble organic substrates. In summary, the RO system has faced complex problem of organic fouling, bio-fouling and scaling. Consequently the recovery rate, pH and the bio-fouling potential should be well defined at the real time operation.

### Acknowledgement

Thanks are due to the Taiwan Water Corporation for the help of providing the RO membrane for the research, and Sinotech Engineering Consultants, Inc. for partially funding in this study.

### References

- [1] K.M.B. Hadi, Evaluation of the suitability of groundwater quality for reverse osmosis desalination, *Desalination*, 142 (2002) 209–219.
- [2] J.S. Vrouwenvelder, J.W.N.M. Kappelhof, S.G.J. Heijman, J.C. Schippers and D. van der Kooij, Tools for fouling diagnosis of NF and RO membranes and assessment of the fouling potential of feed water, *Desalination*, 157 (2003) 361–365.
- [3] F.H. Butt, F. Rahman and U. Baduruthamal, Identification of scale deposits through membrane autopsy, *Desalination*, 101 (1995) 219–230.
- [4] F.H. Butt, F. Rahman and U. Baduruthamal, Characterization of foulants by autopsy of RO desalination membranes, *Desalination*, 114 (1997) 51–64.
- [5] L.Y. Dudley and E.G. Darton, Membrane autopsy — a case study, *Desalination*, 105 (1996) 135–141.
- [6] M. Luo and Z. Wang, Complex fouling and cleaning-in-place of a reverse osmosis desalination system, *Desalination*, 141 (2001) 15–22.
- [7] E.M. Gwon, M.J. Yu, H.K. Oh and Y.H. Ylee, Fouling characteristics of NF and RO operated for removal of dissolved matter from groundwater, *Water Res.*, 37 (2003) 2989–2997.
- [8] R.P. Schneider, L.M. Ferreira, P. Binder and J.R. Ramos, Analysis of foulant layer in all elements of an RO train, *J. Membr. Sci.*, 261 (2005) 152–162.
- [9] B.C. Smith, *Infrared spectral interpretation—a systematic approach*, CRC Press, Florida, U.S.A., 1998.