



Seasonal fouling on seawater desalination RO membrane[☆]

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ABSTRACT

A pilot study has been performed to investigate the seasonal characteristic of seawater reverse osmosis (RO) membrane fouling. Two batches of experiment during summer and winter were both performed 18 days to provide a clear picture on microbial population variability. The feed water of the pilot from seawater desalination plant has significant difference in temperature and silica content between the two seasons.

In our experiments, scaling and biofouling are more serious in summer. And the permeate flux decline is closely related to the rise in microbial population, and it was dominated by cell multiplication rather than adhesion. In addition, the summer cell multiplication is much more abundant. Moreover, the extracellular polymeric substance (EPS) feature intensity detected by Fourier-transform infrared spectroscopy was also stronger in summer. The abundant EPS was one of the major reasons to cause the inorganic matter adsorption. Si, Al, Fe, Ca and Mg were found as the major inorganic foulants deposited on the RO membranes. Silica and calcium in summer appeared obvious higher amounts than that in winter, which indicated that they should be affected by microbial action directly or indirectly more than other elements.

In summary, there exists a seasonal effect on membrane scaling and fouling, and scaling is associated with biofouling in some degree. Further researches could be focus on actual association between microbial action and inorganic fouling.

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1. Introduction

Taiwan is an island country surrounded with the Pacific Ocean and Taiwan strait. Similar to other island countries, Taiwan has rich marine resources. However, with the increased water demand from the population and economic growth, fresh water shortages are increasing seriously; in particular in off-shore islands of Taiwan [1]. The scarcity of conventional fresh water supplies has been a serious threat and a major challenge to sustainable growth and development in the region. Consequently, how to develop marine resources effectively, especially transform seawater into portable water, has been the most urgent issue at present.

Construction of seawater desalination plants seems to become the major solution for fresh water shortage in recent years [2]. However no matter at the design or operation period, the water product efficiency and fouling problems are most concerned. They both depend on the feed water condition and operation situations [2]. Among these effects, the parameters of feed water, such as water quality and microorganism content, has always varied with seasons. It is well known that biofouling must be more serious in hot season; however, scaling is always affected by biofouling. Microbial actions, such as extracellular polymeric substance (EPS) release and bio-

accumulation, could enhance inorganic ions to stay on the membrane [3]. Besides some particular species of microorganism could have particular effects, such iron bacteria [4,5]. Therefore, a pilot was set in Wuken desalination plant, the oldest and largest seawater RO plant in Penghu, Taiwan, to explore the seasonal fouling characteristic of RO membrane. The experiments were designed to conduct in summer and winter, respectively. And major attentions were focused on inorganic fouling and biofouling on the RO membrane. Fluorescent labeling was applied to identify the multiplication and adherence of the microbe. Characteristics of foulant and scalant were identified with Inductively coupled plasma (ICP) and Fourier-transform infrared (FTIR) spectroscopy.

2. Experimental

2.1. Flat-sheet RO desalination module and experimental process

The pilot with two cartridge filters (both pore size are 5 μm) and one flat-sheet RO module was fed with the media filter effluent of the practical plant. After 5 μm cartridge filter, the pretreated water was led into the flat RO module at the flowrate of 2 L/min. The flat RO membranes were cut from a spiral wound RO membrane, Filmtec SW30-2514, to fit the GE Osmonics crossflow membrane filtration unit. The permeate flux of this membrane is recommended to run at 1 m³/m²-day at 25 °C. Parameters, such as flow rate, input and output pressure, and product of permeate were continuously recorded.

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Table 1
RO feed water quality of the pilot identified during 2007.

Parameters	Unit	Winter (18 Feb)	Summer (31 Aug)
pH	--	8.2	8.2
Temp.	°C	23.7	31.3
TDS	ppm	39261	38618
Alkalinity (HCO ₃ ⁻)	ppm as CaCO ₃	142.5	140
Anions			
SO ₄ ²⁻	ppm	3113	1028
PO ₄ ⁻	ppm	ND	1.23
Cl ⁻	ppm	19104	18964
Br ⁻	ppm	40	40
I ⁻	ppm	0.062	0.060
Cations			
Na ⁺	ppm	10593	10690
K ⁺	ppm	340	350
Ca ²⁺	ppm	160	160
Mg ²⁺	ppm	1000	1000
Si ²⁺	ppm	8.6	8.6
Ba ²⁺	ppm	0.012	0.014
Fe ²⁺	ppm	1.3	1.4
Al ³⁺	ppm	0.059	ND
NH ₄ ⁺	ppm	ND	186
SiO ₂	ppm	0.321	2.781
Microorganism			
TDC	10 ⁶ cells/ml	1.25	1.68

During the test process, the microbial count with fluorescent labeling was performed every three or four days. Foulants and scalants analysis of the membrane were carried out at the end of the test. The inorganic foulants were extracted from the membrane by deionized water with ultrasonic bath, and then identified with ICP, and FTIR was also used to obtain the foulant information from the membranes.

2.2. Fluorescent labeling

A persistent labeling dye, PKH-26, was applied. It could provide to study the behavior, growth and differentiation of individual cell, and to label a population of cells without affecting their morphology or function. Each quantity procedure included microscopy observations before and after PKH-26 stain, which helped identify the microbes multiplying on or adhering onto the surface of RO membrane. The difference in the amount of cells between the last stain and the present time before stain represents the net multiplication amount including the original cells' proliferation, death and dis-adhere. However, the difference of cell amount between before and after stain at present expresses the new adhered cells from the bulk solution also including their proliferation, death and dis-adhere. Protocol of staining process and counting parameters are detailed elsewhere [6].

3. Results and discussions

The experiments were performed in winter and summer between January to February and June to July, respectively. Each test was maintained 18 days to obtain a clear morphology of microbial population variation.

During the experimental periods, the feed water quality identified in February and August in 2007, were shown in Table 1 and which could represent the raw water characteristic in winter and summer respectively. The water quality were similar in these two seasons except water temperature and silica content. Water temperature of RO feed in summer is around 29–32 °C, and 20–25 °C in winter. Concentration of silica in summer was about 8 fold than that in winter; however, both of them are much lower than the silica scaling threshold.

3.1. Water production and desalt efficiency

The performances of the flat-sheet RO module in winter and summer were shown in Fig. 1. The permeate flux during winter was apparently lower than that during summer. In addition, due to the frequent change of temperature in winter, the permeate flux was unstable during the experimental period. However, there was no significant permeate decline in winter. Different from the winter result, the performance of summer test could be divided into three phases. In the beginning, around two days, the permeate kept on the level of theoretical permeate flux, 1.15 m³/m²-day, recommended at 31 °C (the average temperature during test period). Then the permeate flux decreased quickly in the second phases (about 3–7 day), and then the decline mitigated in the third phases. Similar to the results of permeate flux, total dissolved solid (TDS) rejection rate in winter was maintained upon 95%, and in summer the results could also be divided into three phases which were matched to the water production trend. In the first phase, the rejection rate was maintained upon 95%, and then it declined quickly during the second phase, and maintained at about 60% in the third phase. These results should associated with microbial growth on the RO membranes, and this issue will be discussed further in a later section.

3.2. Growth and adherence of microbes

The growth curves of microbes on the membrane were shown in Fig. 2(a). It is clear that the population growth of microbes in summer was faster and more abundant than that in winter. In addition, after about 10 days' experiment, the microbial growth curve reached plateau phase and present stable [7], and the cell order is about

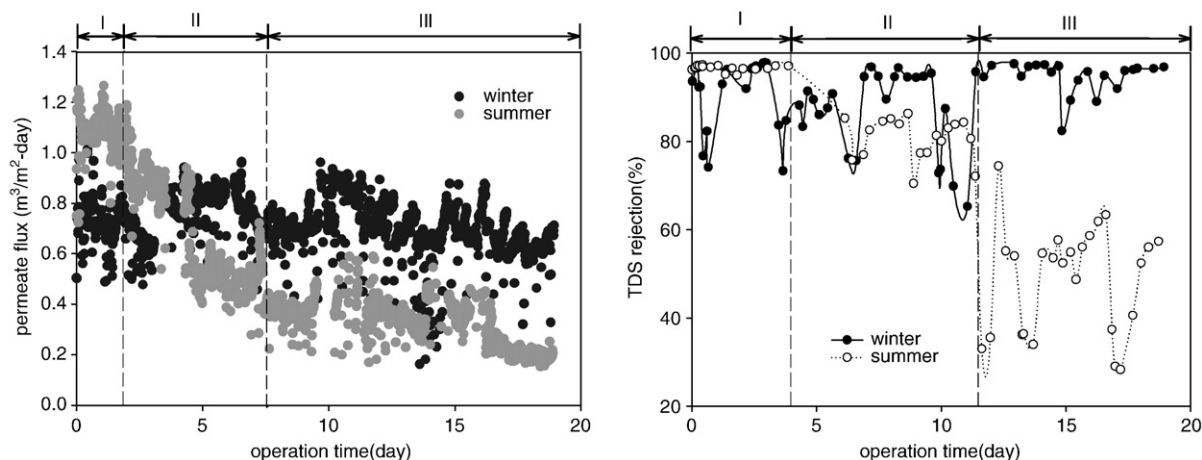


Fig. 1. The variation of flux and TDS rejection of permeate in winter and summer.

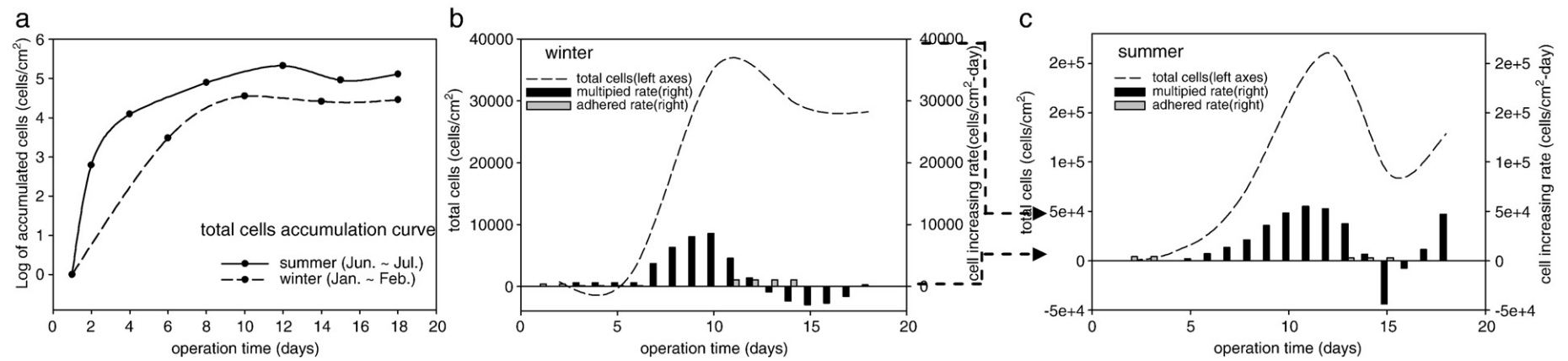


Fig. 2. The seasonal growth of microbe on the RO membranes (a) the Log growth curve (b) the variation of total, multiplied and adhered cells in winter; (c) the variation of total, multiplied and adhered cells in summer.

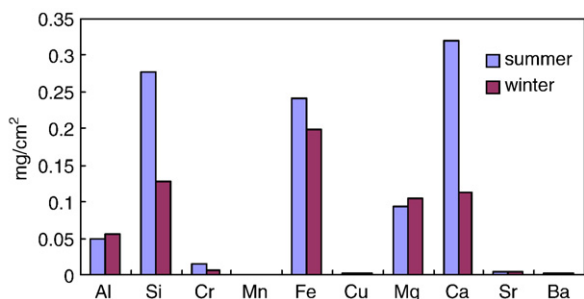


Fig. 3. The inorganic scalants on the RO membranes in winter and in summer.

10^5 degree cells/cm² in summer and $10^{4.5}$ cells/cm² in winter, respectively.

Total, multiplied and adhered cells variation were shown in Fig. 2 (b) and (c). The microbial amount declined immediately after massive multiplication, and then the curve present gentle fluctuation on the plateau phase. As regards the factors that affect the microbial population, the multiplication was the predominance. Adhesion of microbes merely at the level of 3000–6000 cells/cm²-day in summer and below 1000 cells/cm²-day in winter. Additionally, the microbial population growth curve could be rationally illustrated the trend of permeate flux and TDS rejection. In summer, during the first 5–10 day, the population grew and the permeate flux and TDS rejection decline. After 10 days operation, the growth curve maintained stable and the permeate flux and TDS rejection also had a similar trend. In winter, the multiplication was much slighter than that in summer, therefore the RO efficiency decay was also slighter. The phenomenon indicated that the efficiency decay of RO system was significantly associated with biofouling.

3.3. Inorganic foulant

The inorganic foulant was extracted from RO membranes with ultrasonic bath and then analyzed by ICP. From Fig. 3, it reveals that Si, Al, Fe, Ca and Mg are the major composed elements in inorganic foulants in both two experiment seasons. Based on the solubility concept, some researches [8,9] have derived scaling indices to evaluate the inorganic scaling. With applying these indices, our system suggested that the precipitation of Si and Ca would not occur; however, we still found a lot of these two elements scaling on the membranes. Actually, the mineral ions precipitated on the membrane was not induced by the condensed effect of RO, especially in our small scale pilot. In addition, it deserves to be mentioned that the silica and calcium content appeared an obvious

difference between summer and winter, i.e., these two elements present to be much more abundant in summer. Although the silica concentration was about 8 fold higher in summer, the higher water temperature would result in higher solubility and have lower silica scaling potential. Several studies [10–12] have reported that the SiO₂ scale occurred even when it is way below its saturation level and the precipitation of silica could be enhanced by cations, such as Al, Fe and Ca, due to the formation of sparingly soluble mixed silicates. In our study, the existing of calcium seems to have a strong relationship with the formation of silica and was influenced with seasons. The FTIR spectrum in Fig. 4 could help for further discussion. Feature peaks of protein (1656–1530 cm⁻¹) and polysaccharide (1106–970 cm⁻¹) represented the existence of EPS [13,14] that were significant in summer. Which might be the reason to cause the calcium and silica present on the membrane more abundantly in summer. The EPS surround or released from microbes contains large quantity of negatively charged functional groups and has strong capabilities to adsorb heavy metals [15,16]. Besides, silica relative peaks at 802 cm⁻¹ represented Si–O–Si and 760–670 cm⁻¹ represented Si–CH₂ were detected in both seasons and stronger in summer. Which has indicated the existence of organic and inorganic silica content compounds at the same time [14] and provide evidence of silica precipitated with organic matter including EPS. Therefore it could be concluded that precipitation of silica and calcium was affected more seriously by seasons than other elements in our study, and which might be due to the microbial action directly or indirectly. Further researches could focus on the microscopic association between the microbial action and inorganic fouling in the desalination system.

4. Conclusion

Not only biofouling but also scaling was associated with seasonal variation. The variation of microbial population is varied predominantly by cell multiplication, instead of adherence. Multiplication of cells and EPS feature on the membrane are much more significant in summer. Precipitation of silica and calcium is affected with seasons more seriously than other elements. It should associate with EPS adsorption. Further researches could focus on microscopic association between the microbial action and inorganic fouling.

Acknowledgements

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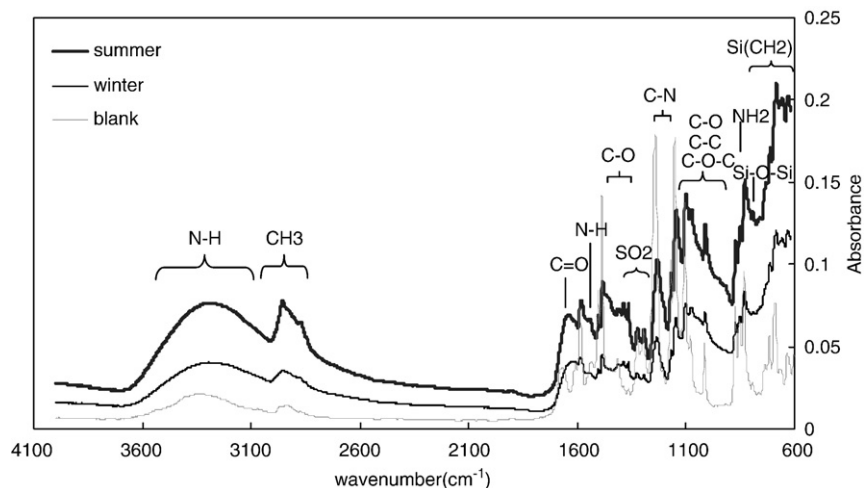


Fig. 4. The FTIR spectrum of contaminated RO membranes in winter and in summer.

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