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Application of ceramic membrane for seawater desalination pretreatment

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ABSTRACT

In this study, a ceramic microfiltration membrane was examined as a pretreatment of reverse osmosis (RO) process for seawater desalination. The performance of ceramic membrane with and without coagulant were compared in terms of permeate qualities and trans-membrane pressure (TMP). Various parameters were analyzed, such as turbidity, dissolved organic carbon (DOC), UV_{254}, SDI_{15} (silt density index), and TMP. When ceramic membrane system was operated without coagulation at flux 2 m^3/m^2 d, SDI_{15} value and turbidity of permeate water was less than 3 and 0.1 NTU, respectively. However, SDI_{15} and turbidity were reduced to 0.9 and 0.076 NTU, respectively, when coagulant of 6 mg/L was applied. The comparison of TMP on different membrane flux was controlled flux 2 and 5, 10 m^3/m^2 d with and without coagulation. The increase of TMP was significantly mitigated from 90 to 13.8 kPa at flux 5 m^3/m^2 d, from 87.4 to 21.5 kPa at flux 10 m^3/m^2 d, respectively, by coagulation followed by filtration. Ceramic MF system with coagulation showed more stable TMP behaviour than ceramic membrane without coagulation. The experimental results described that the membrane fouling was mainly caused by particulate matters which were flocculated and removed by coagulation, resulted in less formation of the cake layer. In terms of SDI_{15}, the value decreased significantly to 0.9 when the membrane system was operated with coagulation although the value of SDI_{15} showed 2.7 when operated without coagulation. Also, DOC and UV_{254} of ceramic MF with coagulation were reduced to 2.5 and 0.01 from 3.0 and 0.24 for filtration only. This study confirmed the effect of coagulation of ceramic MF for seawater desalination pretreatment. Ceramic membrane can be a competitive pretreatment process for desalination using RO in terms of its higher flux and more stable operation characteristics than common organic membrane systems.

Keywords: Ceramic membrane; Desalination; Coagulation; Pretreatment; Membrane process

1. Introduction

In recent studies, membrane desalination processes have been main stream for producing fresh water from seawater with wide use of reverse osmosis (RO) membrane, instead of the traditional distillation processes. And also the importance of pretreatment process for reducing fouling of the RO membrane is getting further emphasized from the economic view of point. Traditionally, foulants in seawater are removed by a series of source water conditioning processes

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(coagulation, flocculation, and pH adjustment) followed by conventional filtration. Over the past 10 years, advances in microfiltration (MF) and ultrafiltration (UF) membrane technologies, and their successful application for water and wastewater treatment are created an impetus for using membrane pretreatment in seawater desalination plants [1]. MF/UF have gained acceptance as a pretreatment method for various desalination processes as MF/UF can produce a desired quality of feed water to RO. It is because most of the particulate pollutants such as turbidity and bacterial contents will be reduced significantly after raw seawater passes through the membrane filtration [2]. Organic membranes made of polyvinylidene fluoride (PVDF), polyether sulfone (PES), and other polymers are used in typical MF/UF pretreatment to RO desalination. But raw seawater is characterized by high salt content, the presence of organic foulants and biological activity, which result in the rapid fouling of polymeric membranes. Ceramic membranes made of such as alumina and silica have shown superior mechanical strength, chemical resistance, long service time and thermal stability over polymeric membranes [3,4]. Their ability to provide consistent and high-quality feed to RO membranes at high flux and low fouling potential is still largely unexplored in the area of seawater desalination.

The objective of this study is to characterize the ceramic membrane for RO pretreatment applied in the desalination process to verify optimal conditions through the water as a pretreatment condition. The performance of ceramic membrane filtration was evaluated in terms of treated water quality and transmembrane pressure (TMP) behavior with various operating conditions such as flux changes and coagulant dosage.

2. Material and methods

2.1. Composition of artificial seawater

Artificial seawater was made with the procedure described in Standard Method 21st Edition [5]. The composition of the artificial seawater and the sequence of salt addition is presented in Table 1. Dissolution of each salt should be carefully monitored prior to the addition of the next salt. TDS concentration was set to 35,000 mg/L ± 10%. Kaolin (Showa, Japan) and Humic Acid (Fluka) were added to adjust the feed water for turbid (25 NTU) and organic matter (3 mg/L).

2.2. Preparation of humic acid stock solution

The humic acid stock solution was made by dissolving humic acid in deionized water dissolved by heating at 80˚C for 30 min to easily dissolution of HA. Then, the solution was filtered in polyphenyl sulfone magnetic filter funnel (Pall) using a microfiber filter (Whatman) with a mean pore size of 0.45 μm. The dissolved organic carbon (DOC) of the stock solution was analyzed by TOC Analyzer (Shimadzu TOC-V). It was reported that the alkaline degradation of HA occurs when the pH is greater than 8 [6], thus pH of the stock solution should be checked regularly [7].

2.3. Experimental set-up

Jar testing was performed to determine optimum ferric chloride ($FeCl_3$) dosing. For coagulation, experimental conditions include rapid mixing (120 rpm, 15 s), slow mixing (20 rpm, 20 min). A monolith ceramic MF membrane with a mean pore size of 0.1 μm was used in the study and the characteristics of ceramic membrane is shown in Table 2. Filtration period was based on trans-membrane pressure (TMP) and membrane filtration test using laboratory-scale experiment equipment. The filtration mode was dead-end filtration. Using artificial seawater, experiments were performed at different coagulant dose to determine the effects of coagulation on the membranes fouling. Effect of varying flux (2, 5, 10 m^3/m^2 d) to the filtration performance was performed on the system with and without coagulation. The Ceramic MF system used in the batch experiment is illustrated in Fig. 1.

2.4. Analytical methods

Various parameters, such as turbidity, SDI_{15}, UV_{254}, total dissolved solids (TDS), DOC, and TMP, were measured feed and permeate water. Turbidity was measured by HACH 2100N turbidimeter and TDS was measured by Thermo Orion potable, SDI_{15} was analyzed by GE Osmonics auto SDI tester. Silt density index (SDI) is one of the most commonly adopted measurements to determine potential fouling for RO membranes [8]. Shimadzu UV spectrophotometer UV-1800 and TOC-V were used to measure UV_{254} and DOC concentration, respectively. After completion of the test, calculates the SDI_{15} by using the equation below and the foulant removal efficiency (R) are defined [9,10]:

$$\mathrm{SDI} = \frac{100 \times (1 - T_{\mathrm{i}}/T_{\mathrm{f}})}{T_t} \tag{1}$$

where SDI is the silt density index, T_t is the total elapsed test time (either 5, 10 or 15 min), T_{i} is the initial time in seconds required to collect the 500 ml

Table 1
Composition of reconstituted seawater

Compound in order of addition	Final concentration (mg/L)
NaF	3
$SrCl_2 \cdot 6H_2O$	20
H_3BO_3	30
KBr	100
KCl	700
$CaCl_2 \cdot 2H_2O$	1,470
Na_2SO_4	4,000
$MgCl_2 \cdot 6H_2O$	10,780
NaCl	23,500
$Na_2SiO_3 \cdot 9H_2O$	20
Na_4EDTA	10
$NaHCO_3$	200

sample, T_f is the time in seconds required to collect the second 500 ml sample after test time T_t, (normally after 15 min).

$$R\ (\%) = \left(1 - \frac{C_p}{C_0}\right) \times 100 \quad (2)$$

where R (%) is the removal efficiency, C_p is the concentrate of permeate, and C_0 is the concentrate of feed.

3. Results and discussion

3.1. Effect of coagulant dose on the performance of water treatment in ceramic MF system

One of the parameters used to predict the extent of fouling developed on the membrane surface is to execute an SDI_{15} analysis. It was reported that the membrane filtration units were able to consistently achieve SDI_{15} values less than 3, while SDI_{15} values were over 4 and none were less than 3 over 60% of the conventional pretreatment unit [11]. Typically, spiral wound RO systems will need an SDI less than 5, and hollow fiber RO systems will need an SDI less than 3 [9] as feed water quality. Figs. 2 and 3 shown the results in permeate water quality of the ceramic membrane at different coagulant dose when filtration was operated at flux 2 m^3/m^2 d. For the permeate, the SDI_{15} value was maintained less than 3 and turbidity was 0.1 NTU at the filtration without coagulation condition. On the other hands, SDI_{15} and turbidity recorded 0.9 and 0.076 NTU, respectively, when filtration with coagulation at coagulant dose of 6 mg/L.

Fig. 4 shows the variation of DOC and UV_{254} retention rate with different coagulation dose. According to Fig. 4, very limited removal rate of around 5% for DOC and UV_{254} was observed at the condition of filtration with no coagulant. On the other hand, the removal performance was enhanced as the coagulant dose increased. The removal rate increased from about 10 to 30% for DOC and from 91 to 95% for UV_{254} when the coagulant dose increased from 2 to 10 mg/L.

3.2. The effect of filtration flux and coagulation on the evolution of TMP

The evolution of TMP at different condition of flux and coagulant dose was compared and described in Figs. 5 and 6. Each set of filtration experiment was carried out for 2 h. The TMP was measured at flux

Table 2
Characteristics of ceramic membrane

Ceramic membrane type	Contents	Membrane module
Material	Ceramic (Al_2O_3)	
Type	Inner-pressured type monolith	
Nominal pore size	0.1 μm	
Dimension	(Φ) 30 mm × 100 mm (L)	
Size of channel	*f* 2.0 mm	
Number of channel	55	
Membrane surface area	0.035 m^2	
pH range	1–14	
Max. operating pressure	20 kg f/cm^2	
Filtration type	Dead-end	
Manufactory	Metawater	

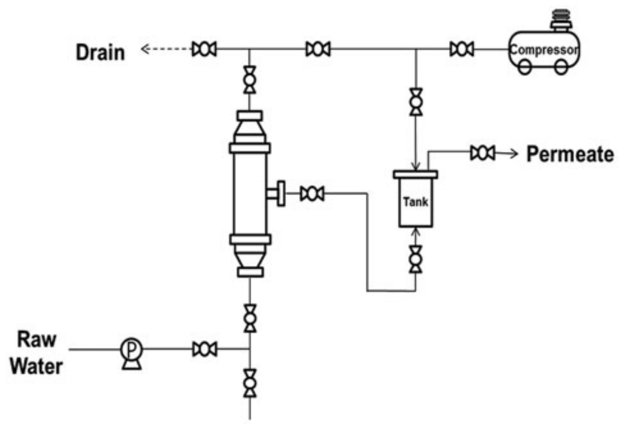

Fig. 1. Schematic diagram of the lab-scale ceramic MF system.

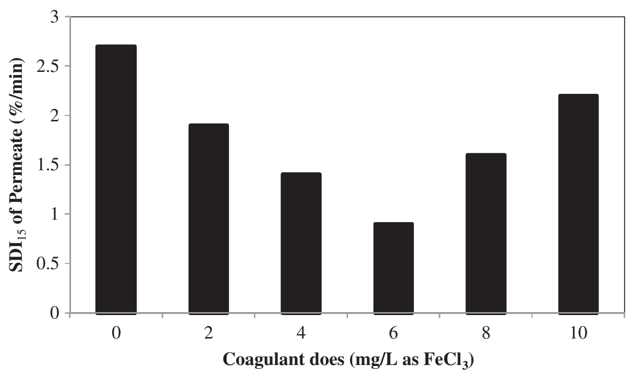

Fig. 2. Comparison of SDI_{15} at different coagulation dose in ceramic MF system.

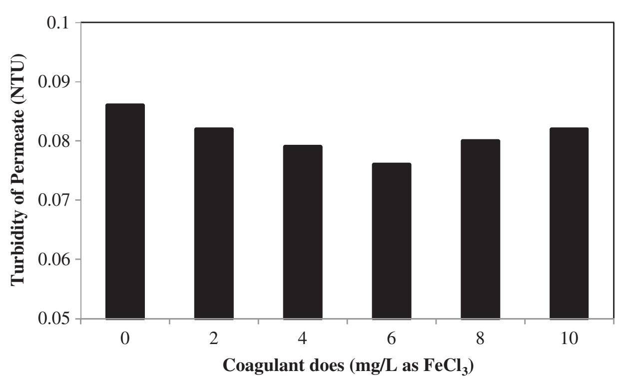

Fig. 3. Permeate concentration of turbidity.

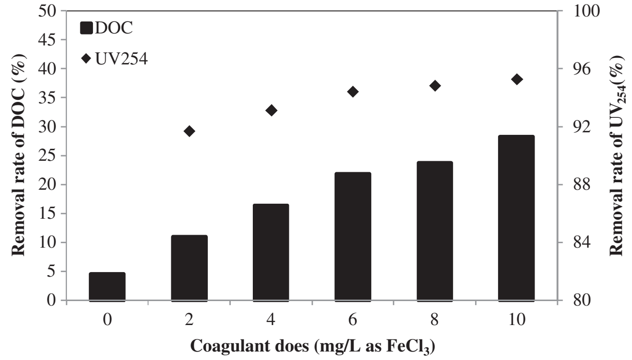

Fig. 4. Removal rate of DOC and UV_{254}.

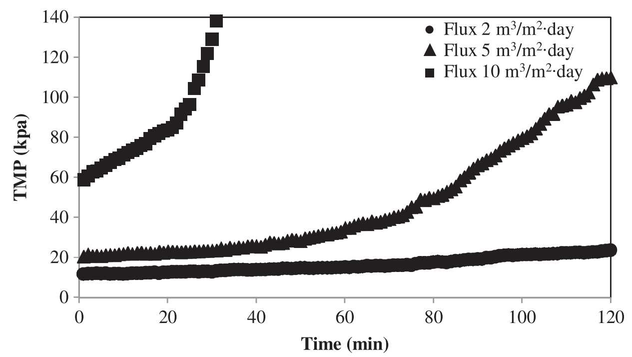

Fig. 5. TMP evolution at various membrane flux without coagulation.

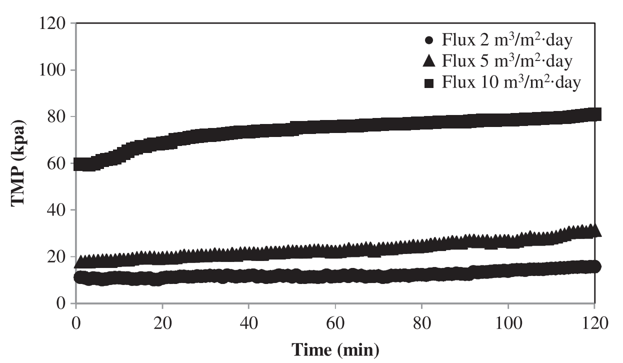

Fig. 6. TMP evolution at various membrane flux with coagulation ($FeCl_3$ 6 mg/L).

condition of 2 and 5, 10 m^3/m^2 d with and without coagulation. As shown in Fig. 5, rapid increase in TMP was observed during the filtration when coagulation was not served. The TMP increased from 11.7 to 23.6 kPa at flux 2 condition and from 20.5 to 110 kPa at flux 5 for 2 h of operation time. At the filtration condition of flux 10, TMP increased abruptly from 58.9 to 146.3 kPa within 30 min. On the other hand, the TMP increased from 10.9 to 15.6 kPa at flux 2,

Table 3
Treatment efficiency at different membrane flux and coagulation conditions

		W/O coagulant			W/ coagulant		
	m^3/m^2 d	Flux 2	Flux 5	Flux 10	Flux 2	Flux 5	Flux 10
Turbidity	NTU	0.06	0.07	0.08	0.05	0.05	0.07
	R (%)	99.81	99.77	99.74	99.84	99.83	99.78
DOC	mg/L	2.92	2.96	2.97	2.40	2.46	2.51
	R (%)	6.35	5.00	4.87	22.95	21.28	19.68
UV_{254}	cm^{-1}	0.23	0.23	0.24	0.01	0.01	0.01
	R (%)	8.92	8.74	8.02	97.86	97.81	97.73
SDI_{15} value		2.60	2.58	2.76	0.78	0.86	0.92

from 17.7 to 31.5 kPa at flux 5 and from 59.4 to 80.9 kPa at flux 10, respectively, at the condition of filtration with coagulant dose of 6 mg/L. The amount of increase in TMP during the filtration was significantly reduced from 89.5 to 13.8 kPa at flux 5 and from 11.9 to 4.7 kPa at flux 2, respectively, by coagulation followed by filtration. Furthermore, the evolution of TMP was so slow even at flux 10 that only 21.5 kPa of TMP increased during filtration time of 2 h. This result implied that filtration flux can be applied as high as 10 m^3/m^2 d which is too high for common MF or UF membranes made of polymers. Ceramic MF combined with coagulation showed much stable evolution of TMP than membrane filtration only. From the experimental results, the role of coagulation can be thought to mitigate the formation of the cake layer made of particulate matter that was regarded as main cause of the membrane fouling [12]. In previous studies, the effect of pre-coagulation on MF/UF as a pretreatment for RO in seawater desalination was discussed on the effect of coagulant dose in the coagulation–membrane filtration system [13]. It was obvious that the combination of membrane filtration with precoagulation was more effective than membrane filtration alone [14].

3.3. *Analysis of water quality and treatment efficiency*

Water quality of feed and permeate water from the ceramic MF process were measured during the operation of the test. Table 3 shows the treatment efficiency at different membrane flux and coagulation conditions. For the permeate, turbidity was rejected by more than 99% and SDI_{15} value recorded from 2.6 to 2.8 in the tested flux range. The permeate quality showed no big differences in spite of changes in membrane flux for any kinds of water quality items. The same tendency was found in the permeate quality at the condition of filtration with coagulation. The permeate water quality was enhanced by coagulation followed by filtration, drastically on UV_{254} and SDI_{15}. SDI_{15} decreased to less than 1.0 from 2.7 obtained in MF system without coagulation. Values of DOC and UV_{254} were also reduced to 2.5 and 0.01 from 3.0 and 0.24, respectively, by coagulation prior to filtration.

4. Conclusions

This study evaluated the performance of ceramic membrane filtration at various operating conditions for the application of seawater desalination pretreatment. The treated water quality and TMP evolution were observed and compared at the flux of 2, 5, and 10 m^3/m^2 d, and coagulant dose of 0 and 6 mg/L. The conclusive remarks are as follows:

(1) The permeate water quality was greatly enhanced by coagulation in combination with ceramic MF, resulted in less fouling potential and longer service life to RO systems.
(2) Filtration flux as high as 10 m^3/m^2 d can be applied with relatively small evolution of TMP during filtration service time, which means that the capacity of pretreatment process can be reduced comparing to MF/UF membranes that are made of organic material and usually operated at the flux ranging from 1 to 2 m^3/m^2 d.
(3) Based on the results, it is clear that ceramic MF systems can provide more flexible design and operating conditions and would be a promising alternative of pretreatment process for desalination processes using RO.

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