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Effect on backwash cleaning efficiency with TDS concentrations of circulated water and backwashing water in SWRO membrane

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ABSTRACT

The osmotic backwash in the seawater reverse osmosis (SWRO) membrane induced by the osmotic pressure of a salt feed solution was investigated. The system was shifted immediately to a backwash process by reducing the operation pressure to zero to allow a net backwash driving force. The backwash process has two distinct stages: first stage—the backwash flux drops sharply at the initial, second stage—the backwash flux reaches equilibrium with time. A backwash cleaning efficiency is affected by some factors such as circulated water concentration, operation pressure, and cross-flow velocity in the SWRO membrane system combined with osmotic backwash. The feed water (or circulated water) concentration is the most influential and the pressure and cross-flow velocity are relatively less significant. In this study, the influence of backwashing water concentration on backwash cleaning efficiency was investigated under various circulated water concentrations. When the circulated water concentration was higher, the backwashing flux became greater and required less time to reach equilibrium; however, the internal concentration polarization occurred in the permeate side more rapidly and the backwash accumulated volume curve could be reversed with time. These results support the necessity of the optimization of the SWRO filtration/osmotic backwash mode between the concentrations of the feed water, the permeated and circulated water, and the time between the filtration and the backwash.

Keywords: Reverse osmosis; Osmotic backwash; Cleaning; Fouling; Concentration polarization

1. Introduction

It is well known that, as with other membrane separation processes, membrane fouling in the seawater reverse osmosis (SWRO) desalination technique is the most serious problem affecting reverse osmosis (RO) system performance. To resume the original product permeation rate, cleaning-in-place (CIP) with chemicals is most widely used to remove foulants and maintain the membrane performance [1–5].

Chemical cleaning removes foulants by using chemicals which can weaken the adhesion between the membrane and the foulants. The typical chemical

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cleaning frequency is one or two times annually, yet, it can be increased according to operation circumstances. However, CIP needs a down time of frequent RO operation stoppage, resulting in low effectiveness of production. Also, CIPs shorten the membrane lifetime and create environmental issues related to waste chemical disposal.

On the other hand, physical cleaning does not have the side effects as mentioned above and periodic physical cleaning delays fouling by disturbing crystallization of silica scale or settlement of calcium. Recently, the forward osmotic or osmotic backwash cleaning technique of RO has become increasingly attractive as it is an efficient and environmentally friendly technique [6–14]. An osmotic backwash cleaning method is an appropriate cleaning method for dissolving the concentration polarization (CP) layer of brine solutions.

Backwashing efficiency is affected by various factors such as circulated water concentration (or feed water concentration), driving pressure, and cross-flow velocity. The circulated water concentration is the most influential, and the pressure and cross-flow velocity are relatively less important.

Sagiv et al. [14–16] changed the operation condition of the feed concentration and operating pressure and optimized the backwashing condition by predicting the volume of the CP layer and dilution time. In the initial stage, the accumulated volume was amplified because of the higher difference between the feed water concentration and the permeate water concentration; however, in the process of time, the accumulated volume could be reversed because of CP layer dilution. When the feed water concentration is high, the CP layer is rapidly diluted and the driving force becomes weaker. As the CP layer is diluted, the C_w value is decreased and $C_w = C_F$ and the greater backwash makes $C_w < C_F$ (C_w = the concentration of membrane wall, C_F = the concentration of filtrate).

Avraham et al. [12] evaluated the backwash efficiency with NaCl concentration. The system was operated with different concentrations until the system was stabilized and then the operation pressure was removed and backwash was performed. Up to the specific concentration of NaCl, the accumulated volume increased, yet over the specific concentration, the volume decreased due to the internal CP on the permeate side.

Qin et al. [17] demonstrated that the internal CP can be neglected when feed water concentration is low; however, in the case of the higher feed water concentration, the CP layer significantly affects the accumulated volume.

Traditionally, in the SWRO system combined with backwashing process, the feed water or concentration water as circulated water was used and permeate water as the backwashing water was used. However, in this study, the influence of backwashing water concentration on backwash cleaning efficiency was investigated in various circulated water concentrations using artificial backwashing water and circulated water as some facilities such as backwashing tank and backwashing pump were added to control the concentration of the circulated water in backwashing process.

2. Materials and methods

2.1. Materials

This study adopted the SW3OHRLE400 SWRO membrane manufactured by Dow Filmtech. To apply the membrane to continuous lab-scale RO equipment, a common 8 inch spiral module of the membrane was cut out to a plate shape and the properties of the membrane are shown in Table 1. This membrane material is polyamide, which has the weaknesses of chemical resistance of Cl^- and propagation of microorganisms. While the membrane was stored, a conservative solution was used with a mixture of 20% of propylene glycol and 1% of sodium bisulfate. The lab-scale equipment of RO was the SEPA cell of General Electric and was linked with a high pressure pump, impeller, temperature controller, digital press meter, and flow meter (Fig. 1). The equipment comprised an all-in-one system and could operate automatically and continuously. Also, the high pressure pump material is SUS-316 which is not decayed by seawater. Fig. 1 shows that the feed water flows into the SEPA unit by the high pressure pump, and the permeate water is filtered by the RO membrane in the SEPA unit and brought into the balance to measure the flux. After stopping the RO process, the backwashing process is progressed, while the permeate water above the balance is used as backwashing water and the water in the backwashing tank is circulated water.

The three types of circulated water were: low NaCl concentration of 20,000 mg/L and normal NaCl concentration of 35,000 mg/L based on standard seawater, and high NaCl concentration of 50,000 mg/L to evaluate the osmotic backwash efficiency depending on the circulated water concentration.

2.2. Operating conditions and methods

To evaluate the effects on the efficiency of osmotic backwash from concentrations of permeate water and circulated water, the operating pressure is set to 50 bar and the circulated flow is fixed to 1 L/min. The

Table 1
Characteristics of SWRO membrane

Model	Material (surface charge)	Permeate flow rate	Stabilized salt rejection	Max. operating pressure
SW30HRLE400	PA (negative)	28 m^3/day	99.80%	83 bar

Note: 32,000 ppm NaCl, 800 psi (55 bar), 25 °C, pH 8, 8% recovery.

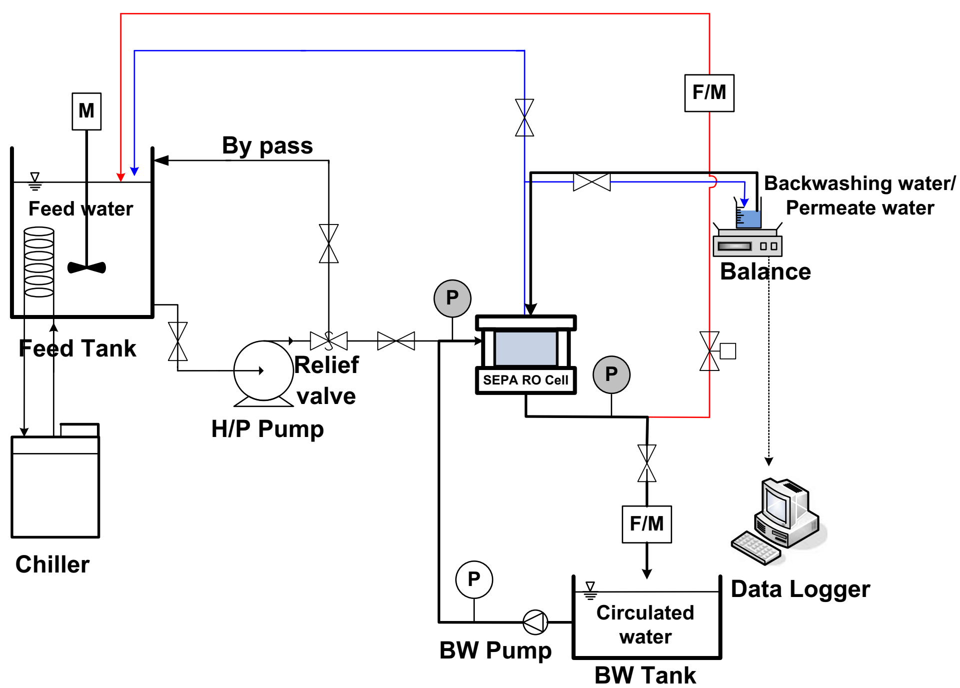

Fig. 1. Schematic description of the cross-flow RO membrane test unit.

physical backwash with osmosis can be classified into two methods: (1) decreasing operating pressure to 0 or less than osmotic pressure and (2) injecting high concentration of salt while maintaining the operating pressure. In this study, the first method of osmotic backwash was used. Since the circulated water flow is maintained, the backwash continues when the permeate is sufficient. By this method, backwash efficiency with time could be tested with circulation during the backwash process. To minimize the influences when a process changes filtration to backwash, the operating pressure was sharply decreased to 0. The feed water total dissolved solids (TDS) concentration was changed to 20,000, 35,000 and 50,000 mg/L, and filtration was performed for 5 min at 50 bar. When backwashing was enacted, the backwashing water was replaced with deionized (DI) water, TDS 1,000 and 2,000 mg/L with NaCl and DI water instead of produced water. While changing filtration into backwash, the prepared backwashing water was spilled onto the surface of the RO membrane to diminish the effects of permeate water. Also, backwashing with permeate water was tested and compared with previous conditions. Instantaneous flux and accumulated water volume were measured during the backwashing test to analyze the physical cleaning efficiency.

3. Results and discussion

3.1. Backwash efficiency in backwashing water concentration

First, the circulated water concentration was fixed at 20,000, 35,000, and 50,000 mg/L and the backwashing water of the arbitrary TDS concentration was prepared instead of permeate water. Then, the backwashing flux was analyzed with backwashing time. As shown in Fig. 2, the flux showed the highest part at initial time, irrespective of the circulated water concentration, and the flux suddenly decreased and reached a stable condition. However, when the circulated water concentration increased, the flux had a

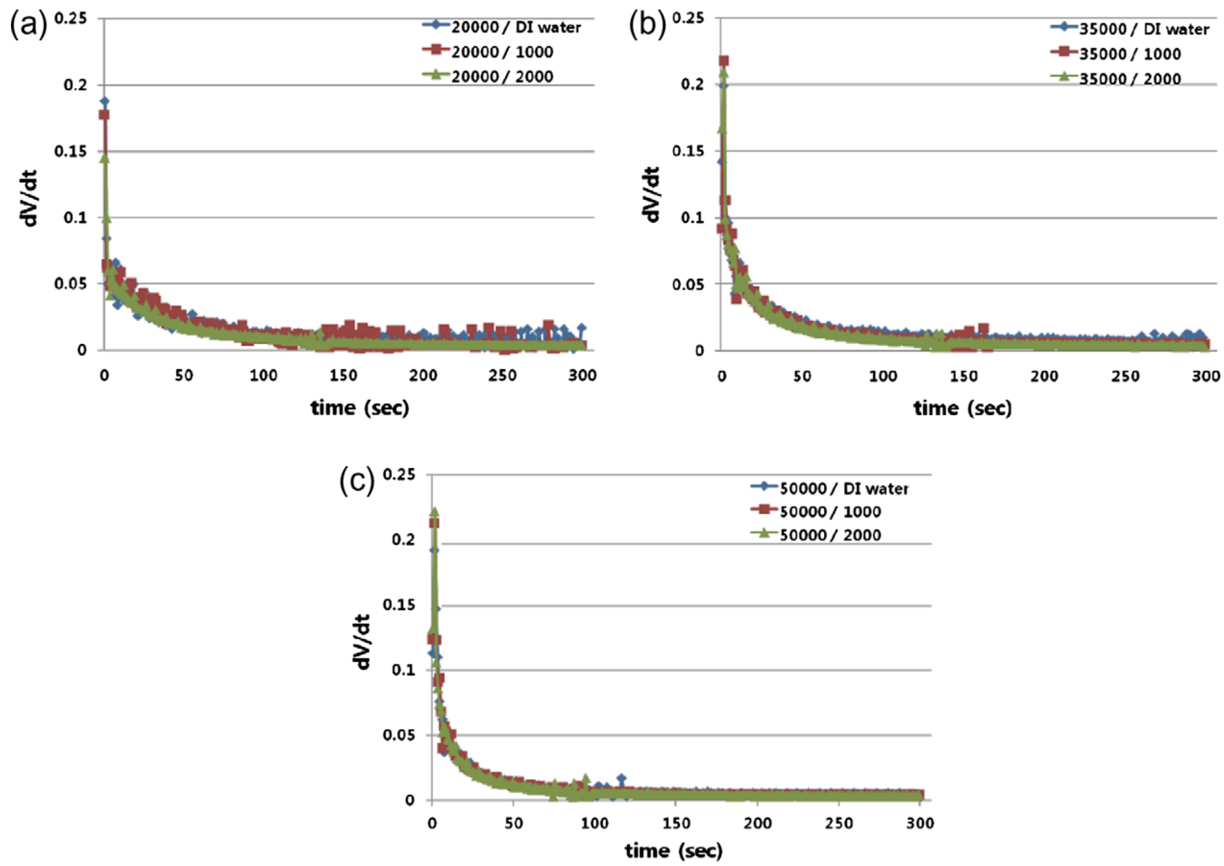

Fig. 2. Backwashing flux with backwashing water concentration (TDS of circulated water is (a) 20,000 mg/L, (b) 35,000 mg/L, and (c) 50,000 mg/L, respectively).

high value and required a shorter time to reach a stable condition, followed by a precipitous decrease. It was thought that the osmotic pressure, which is the driving force of the osmotic backwash, increased while the circulated water concentration was high.

Fig. 3 illustrates the accumulated water volume of the backwash with time. Likewise, from the result of Fig. 2, the accumulated volume declined increasingly more in the period of initial backwash and reached a constant quantity. Also, at the same concentration of circulated water, the accumulated water had a larger volume as the TDS concentration of backwash water decreased. Comparing the results of the DI water in Fig. 3(a)–(c), the backwash of (c) had the lowest accumulated volume. It was considered that the permeate water concentration impacted on the membrane surface during backwash and the accumulated volume was obtained less than the predicted quantity.

3.2. Backwash efficiency in circulated water concentration

From the accumulated volume results, the slopes required to reach equilibrium differed with circulated water concentrations. At a backwash water concentration of 1,000 mg/L as shown in Fig. 4(a), the denser circulated water had greater driving pressure and the initial accumulated volume was exceptional; however, the accumulated water volume results were reversed as time elapsed. Sagiv et al. [16] concluded that the backwash accumulated volume could be reversed with time due to the CP. The high concentration of feed water produced denser permeate and this intensified the CP and decreased the backwash driving force, which is generated by the difference of concentrations between feed and permeate water.

Fig. 4(b) shows the result of backwashing with 2,000 mg/L concentration of backwash water. At the initial point, the accumulated water volume on 50,000 mg/L of circulating water was dominant and reversed from the lower concentrations. However, 20,000 and 35,000 mg/L concentration results were not reversed. This explains the case of 50,000 mg/L, in which backwash caused the significant CP by large driving force, but 20,000 and 35,000 mg/L had a relatively similar level of CP.

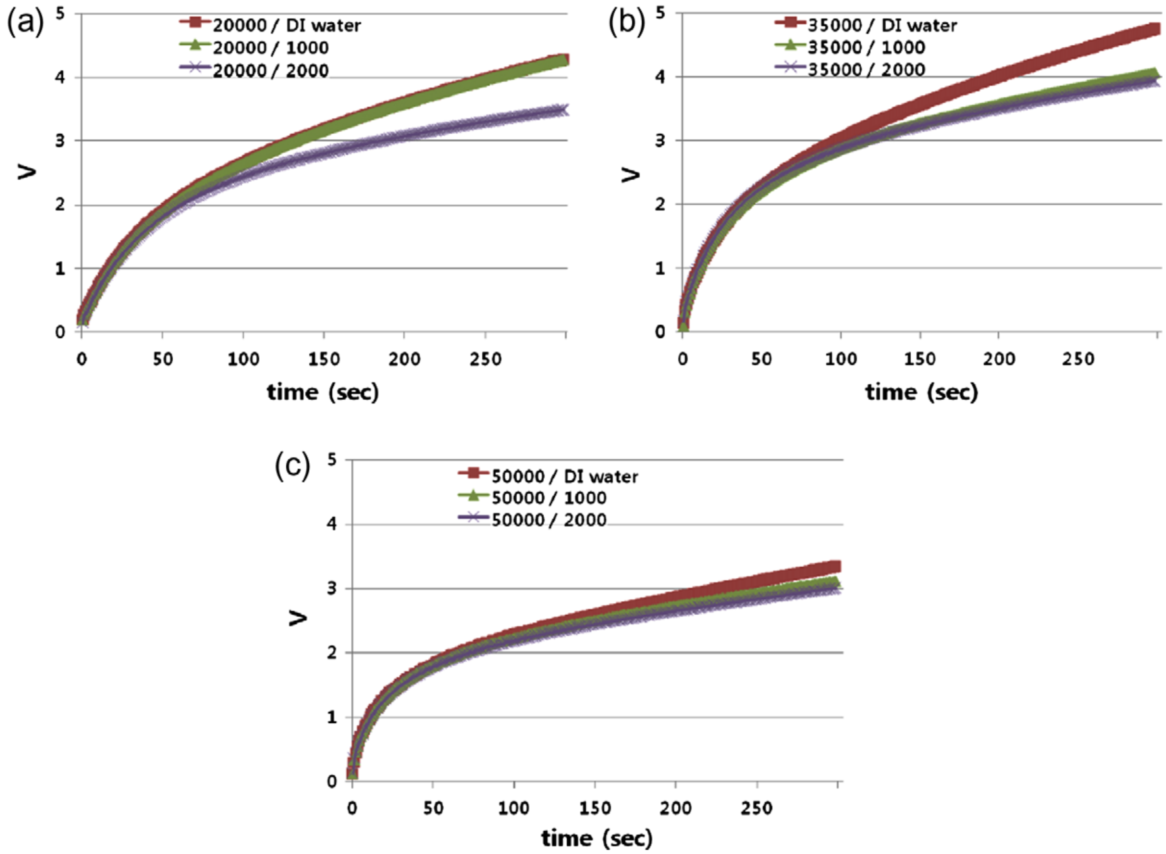

Fig. 3. Accumulated water volume with backwashing water concentration (TDS of circulated water is (a) 20,000 mg/L, (b) 35,000 mg/L, and (c) 50,000 mg/L, respectively).

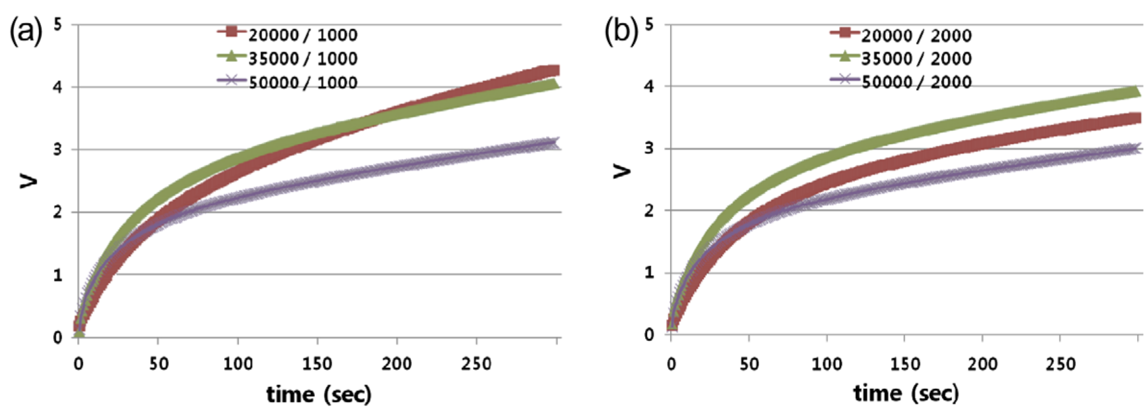

Fig. 4. Accumulated water volume with circulated water concentration (TDS of backwashing water is (a) 1,000 mg/L and (b) 2,000 mg/L, respectively).

3.3. Comparison of backwash efficiency with permeate water

In comparison with the backwash of the prepared backwash water, the backwash with permeate water was tested. When the feed water TDS concentrations were 20,000, 35,000, and 50,000 mg/L, the TDS concentrations of the permeate water were 337, 600, and 1,202 mg/L, respectively. The initial driving pressure was the highest at the feed water of 50,000 mg/L of TDS concentration; however, the accumulated volume curve had reversed with time

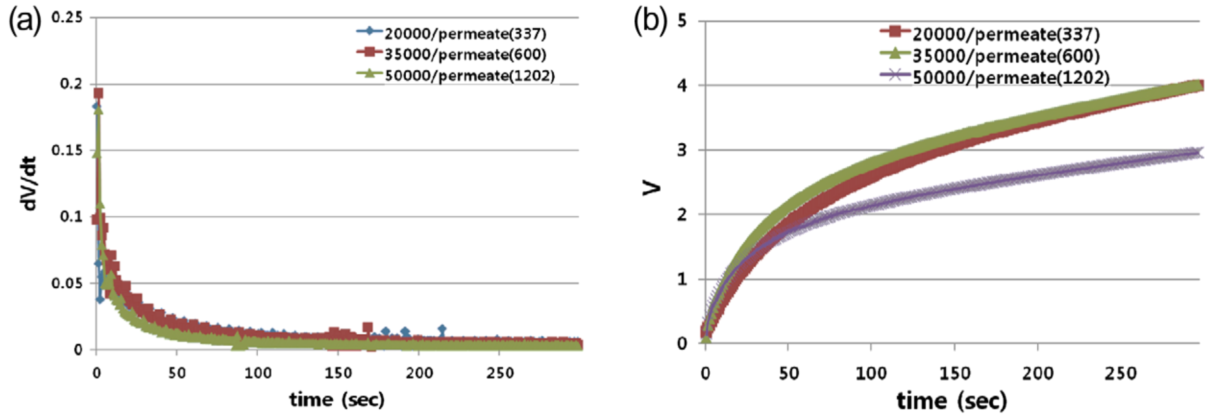

Fig. 5. Backwashing flux and accumulated water volume during backwashing by permeate water ((a) Backwashing flux and (b) Accumulated water volume).

due to the internal CP in the permeate side (Fig. 5). Moreover, after 5 min of backwash, the TDS concentration 20,000 mg/L of feed water showed the largest accumulated volume. It was assumed that the lower concentration delayed the decrease of driving force since it corresponded to the result of the CP and backwash by Sagiv et al. [16].

4. Conclusion

This study evaluates the effects of the concentrations of circulated water and permeate water in the SWRO membrane system combined with the backwash process. In every case of backwash, the flux showed a peak at initial backwash and suddenly declined to equilibrium. Also, as the circulated water concentration was higher, the flux became greater and required less time to reach equilibrium since it had a rapid decreased slope. When the circulated water concentration was steady, the accumulated volume of backwash depended on the backwash water concentration due to the decrease of driving force.

It was thought that the osmotic pressure, which is the driving force of the osmotic backwash, increased as the circulated water concentration was higher, however, decreased with time due to the internal CP [16]. In the practical SWRO membrane process, higher feed water concentrations produced permeated water of higher concentrations. Also, the concentrated water may be used as the circulated water considering cost efficiency. Therefore, in the case of using concentrated water as circulated water, the initial flux increased because the circulated water concentration was denser. However, the permeate water had higher concentrations, and the internal CP occurred more rapidly.

In the plotted result of the accumulated volume, the curves were subsequently reversed with time [16]. As the operation pressure increases or the filtration time increases, the permeate water concentration decreased [13,16]. These results support the necessity of the optimization of the SWRO filtration/osmotic backwash mode between the concentrations of the feed water, the permeate water, and the circulated water, and the time between the filtration and the backwash.

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