

Sodium Dodecyl Sulfate Surfactant on High Flux Osmotic Membrane: Behavior in Flux Decline

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Abstract Surfactants, often used in cleaning agents, can cause pollution issues in the ecological system if released into the environment. The membrane process is one of the most widely applied technologies for removing pollutants in water or wastewater. Nowadays, forward osmosis (FO), which has gained increasing interest in membrane technology, has been used as an effective process to separate contaminants from domestic wastewater. There are many advantages of the osmotic process, such as its high performance of pollutant separation, lower energy compared with pressure-driven membranes, and its widespread use in clean water applications. However, the performance decline caused by surfactant molecules has been less investigated. In this study, we focused on the performance and behavior of water flux decline during the FO process under different operating flow conditions. Three operating conditions were applied for the FO experiment conducted in the presence of surfactants in the feed solution: the cross-flow velocity, pH of the feed solution, and the different sodium dodecyl sulfate (SDS) concentrations in the feed solutions. The results indicated that the diffusion of water molecules increased when higher cross-flow velocities and adjusted pH levels were used in the feed solutions. Moreover, the reduction in performance was not significant when the SDS concentration in the feed solution was increased. The results suggest that the increased hydrodynamics and elevated pH in the feed solution play a dominant role in the FO process.

Keywords Forward Osmosis, Anionic Surfactant, Surfactant Fouling

1. Introduction

Pollutants increasing as a result of industrial development have become a challenging issue for environmental problems, particularly due to the increase in wastewater discharges and the deterioration of water sources used for clean water production. The surfactants, one of the most commonly employed products in daily life, are widely used in the textile, food processing, pharmaceutical, metal processing, and paper industries [1], as well as in the production of many household cleaning agents [2]. After usage, the surfactant molecules become pollutants and are often released into the environment through the wastewater process, resulting in severe pollution issues. Several processes have been developed to remove or minimize surfactants in wastewater, including chemical precipitation, adsorption, and biological degradation. Nowadays, membrane technology is an alternative method widely adopted to effectively remove surfactants and support recovery processes. Despite membrane technology being reported to have high performance, many factors related to the membrane and properties of the surfactants can affect the overall

performance. Microfiltration (MF) and ultrafiltration (UF) are not suitable for removing surfactants from wastewater because surfactant monomers can pass through these membranes [3]. In contrast, nano-filtration (NF) can be effectively applied to remove surfactants at low concentrations in permeate [4]. In order to increase the separation of surfactant molecules, reverse osmosis (RO) is commonly employed due to its high rejection of salt molecules, low contaminants, and monovalent ions from wastewater [5]. However, there are several drawbacks in the RO process, including flux decline, adsorption of surfactant molecules on the surface of RO membrane, increased pressure-driven energy consumption, and membrane-surfactant interaction [6]. Although the RO process is an effective method for the separation of surfactant from wastewater, it often generates membrane fouling with lower performance efficiency [7, 8, 9]. Nevertheless, forward osmosis (FO) technology, as a physical separation process, can also be applied to separate solutes/particulates in water and wastewater [10, 11]. FO technology has been applied in processes such as water purification, wastewater reclamation, industrial wastewater treatment, desalination, food processing, and pharmaceuticals [12, 13]. Even though the FO process is effective for contaminants, some constraints can decrease the performance due to membrane fouling and the generation of scaling on the membrane surface [14, 15]. Such issues can reduce the reliability of using FO technology for surfactant removal. Therefore, we presently focus on the behavior of flux in the FO process under different conditions, including variations in cross-flow velocities of both sides, changes in pH levels in feed solution, and the various concentrations of sodium dodecyl sulfate (SDS).

2. Materials and Methods

2.1. Chemicals

In this study, we selected the surfactant as a representative environmental pollutant. The surfactants were selected to represent the generated agents and are commonly found in the effluent from wastewater. The characteristic of SDS was applied as an anionic surfactant (Ajax Finechem Pty Ltd.). The molecular weight of SDS is 288.0 g/mol, and its critical micelle concentration (CMC) is 8.2 mM at 25 °C [1]. In order to control the solution pH during the experiment, 0.02N NaOH and 0.02N HCl were applied for this study.

2.2. Osmotic Membrane

To set up the experiment, a high-water diffusion membrane was prepared (model FO-4040, Toray Advanced Materials Korea Inc., South Korea). Prior to the experimentation, the membrane sheet was continually

immersed in the de-ionized water for 24.0 hours at 4.0 °C. Surfactant fouling experiments were conducted using a model FO-4040 osmotic membrane, with the feed solution (surfactant solution) contacting the active layer of the osmotic membrane, and the draw solution exposed to the supporting layer (in all conditions). Diffusion and transportation of water molecules occurred in the effective area of the osmotic membrane (20.0 cm²). For membrane sample preparation, the membrane was carefully cut according to the membrane unit specification. A new membrane sample was prepared and applied for each surfactant fouling experiment.

2.3. FO Surfactant Fouling Operation

The parameters relevant to this research study are described in the data collection procedure and experimental conditions following the methodology described in our previous research [16]. In summary, the experimental process involves studying the FO process by selecting a thin membrane (osmotic membrane) capable of effectively separating small molecules and water. The diffusion and circulation of the solution between the feed and draw reservoirs are performed using peristaltic pumps (BT100M/YZ1515x), while changes in the solution are continuously recorded using a weighing balance (GF-4000, A&D Company, Japan) to collect weight data. This experiment used a solution volume of 2.0 liters and was conducted for 8.0 hours at a controlled temperature of 25.0±0.5 °C.

3. Results and Discussion

3.1. Flux Decline Behavior under Various Cross-Flow Velocities

In this topic, operational conditions were carefully set up to investigate the flux decline behavior of the SDS as feed solution using the FO process. The experiments were conducted under different cross-flow velocities to evaluate their effect on flux decline behavior. Firstly, SDS (anionic surfactant) was observed to induce flux decline due to a change in cross-flow velocity. The cross-flow velocity of both feed and draw solutions was modified (0.5, 0.9, 7.0, and 10.5 cm/s). The concentration of the draw solution was adjusted (10.0 mM NaCl) while the temperature was steadily controlled at 25.0 °C. The SDS concentration is prepared and set at 2.4 g/l across the entire experiment. The effect of various cross-flow velocities was investigated. The results showed that the performance and the average diffusion of water molecules increased at higher cross-flow velocities in the FO procedure (Table 1). Normalized flux (J/J_0) under the different cross-flow velocities in the FO process is illustrated in Figure 1. The normalized flux ratio (J/J_0) decreased less at higher cross-flow velocities. As a result, it is clearly seen that the impact of the membrane on

the J/J_0 ratio was reduced at higher cross-flow velocities, with the smallest effect observed at 10.5 cm/s, followed by 7.0, 0.9, and 0.5 cm/s, respectively. The performance of FO has improved when an elevated cross-flow rate was applied, which may be related to the reduced accumulation of surfactant molecules on the osmotic membrane surface. Surfactant molecules continually accumulated on the osmotic membrane during the FO operation, while the cross-flow velocity retarded the generation of membrane fouling. At a high cross-flow velocity, flow rate forces reduced the formation of surfactants on the osmotic membrane. As the cross-flow velocity increased from 0.5 to 10.7 cm/s, the permeate flux rate increased from 16.8 to 34.5 L/m²h. The experimental results and phenomena observed in this research are consistent with previous research [17], which found that the difference in osmotic pressure between solutions promotes the diffusion of water molecules. Furthermore, increased solution velocity has beneficial effects on water molecule diffusion, specifically by reducing the accumulation of salt molecules on the membrane surface, decreasing surface tension, and mitigating the effects of internal concentration polarization (ICP) [5, 18, 19]. Therefore, we can conclude the result that increased cross-flow velocities reduce the attachment of surfactant molecules on the FO, resulting in enhanced diffusion of water molecules through the membrane.

3.2. Flux Decline Behavior under Evaluated pH in Feed Solution

To evaluate the impact of various pH levels in feed solution, the FO experiment was set up at 4.0, 7.0, and 10.0. In this section, we investigated the impact of different feed solution pH on flux decline behavior during SDS-surfactant fouling experiments. To control the pH of the feed solution, two types of solutions were adjusted by applying 0.02N NaOH and 0.02N HCl while the pH in both the feed and draw solutions was modified at 4.0, 7.0, and 10.0, respectively. The temperature of each side was controlled at 25 °C, and the velocity of FO process was set at 7.0 cm/s during the entire experiment. The findings were shown in Table 2. As a result, a high diffusion of water molecules was observed when the pH of feed solution was set at 10.0, followed by 7.0 and 4.0. Accordingly, with increasing diffusion efficiency, the productivity of the FO process increased, reaching 36.7 (L/m²h) at pH 10.0, but decreased to 32.6 and 27.7 (L/m²h) at pH 7.0 and 4.0, respectively. As shown in Figure 2, the decline in normalized flux ratio (J/J_0) became less pronounced as the pH of the feed solution increased from 4.0 to 10.0. Therefore, higher pH values in the feed solution reduced the adsorption of surfactants on the membrane surface,

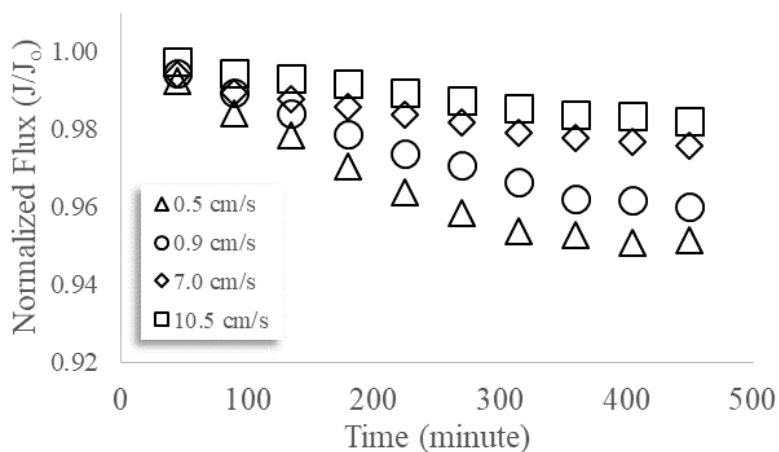
leading to lower mass-transfer resistance and a less pronounced decline in the normalized flux ratio (J/J_0). As a result, the permeate flux was higher in the experiment with elevated pH. Childress and Deshmukh [20] stated that when the pH of the solution is increased, it causes the osmotic membrane surface to become more negatively charged, promoting the diffusion of water molecules. Therefore, the increasing pH of the feed solution promoted the diffusion of water molecules and affected the properties of the membrane. As summarized above, it can be explained that the FO membrane surface became more hydrophilic due to the elevated pH in feed solution and the covered surfactant molecules, which enhance the diffusion of water molecules.

3.3. Flux Decline Behavior under Evaluated SDS Concentration in Feed Solution

In all experiments, the impact of SDS concentrations (1.20, 2.40, and 4.80 g/l) was also investigated using a temperature of 25 °C, a fixed cross-flow velocity of 7.0 cm/s, and a feed solution ionic strength of 10 mM NaCl. Table 3 shows the results of the experiment. Increasing the SDS concentration in the feed solution from 1.20 to 4.80 g/L resulted in a slight increase in water diffusion from the feed side to the draw side. Consequently, the permeate flux increased from 31.4 to 33.1 L/m²h. We also observed that the normalized flux (J/J_0) slightly decreased with increasing SDS concentration on the feed side, as shown in Figure 3. In addition, the FO performance reduction was minimal, and the trend of flux decline was not clearly observed. The findings can be explained by the interaction of SDS molecules and the resulting changes in the surface properties of the FO membrane. At the first interaction, the molecules of SDS readily adsorb onto the osmotic membrane, resulting in increasing its hydrophilicity and passing more water molecules from the feed side. On the other hand, the changes in the osmotic membrane were not significant when the SDS concentration was increased. The phenomenon observed in this experiment can be explained by the fact that the adsorption and accumulation of SDS at the membrane surface occur rapidly and promote the diffusion of water molecules in the initial stages of the experiment. As time passes, the adsorption effect decreases the diffusion of salt molecules, and increasing the concentration does not significantly affect the movement of water molecules [3, 4]. Therefore, it can be stated that the adsorption of SDS molecules alters the properties of the FO membrane, resulting in the rapid diffusion of water molecules. However, increasing the SDS concentration in feed solution did not display a significant impact on flux decline.

Table 1. Experimental conditions and results of the FO process under different cross-flow velocities

Velocity (cm/s)	Active Layer			Supporting Layer		Flux in 8.0 h (LHM, average)
	NaCl (M)	π (atm)	SDS (g/l)	NaCl (M)	π (atm)	
0.5	0.01	0.48	2.4	1.0	48.3	16.8
0.9	0.01	0.48	2.4	1.0	48.3	18.6
7.0	0.01	0.48	2.4	1.0	48.3	32.6
10.5	0.01	0.48	2.4	1.0	48.3	34.5

**Figure 1.** Normalized flux (J/J_0) on FO process under various velocities (cm/s). The temperature of the feed and draw solution was controlled at 25 °C, and the pH of the solution was set at 7.0**Table 2.** Experimental conditions and results of the FO process under different pH levels

pH feed solution	Active Layer			Supporting Layer		Flux in 8.0 h (LHM, average)
	NaCl (M)	π (atm)	SDS (g/l)	NaCl (M)	π (atm)	
4.0	0.01	0.48	2.4	1.0	48.3	27.7
7.0	0.01	0.48	2.4	1.0	48.3	32.6
10.0	0.01	0.48	2.4	1.0	48.3	36.7

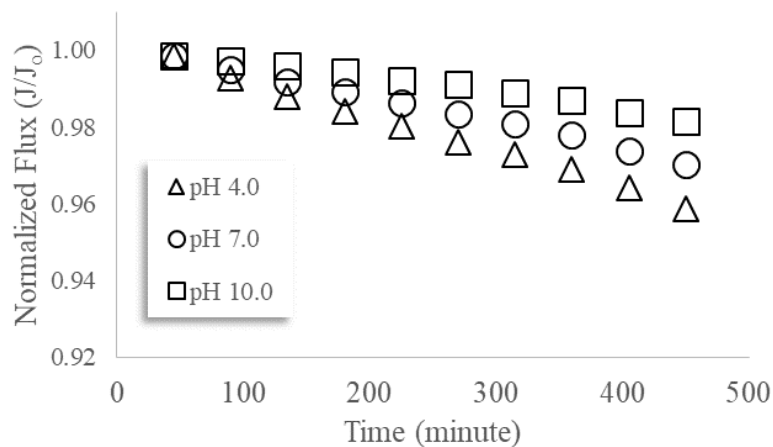
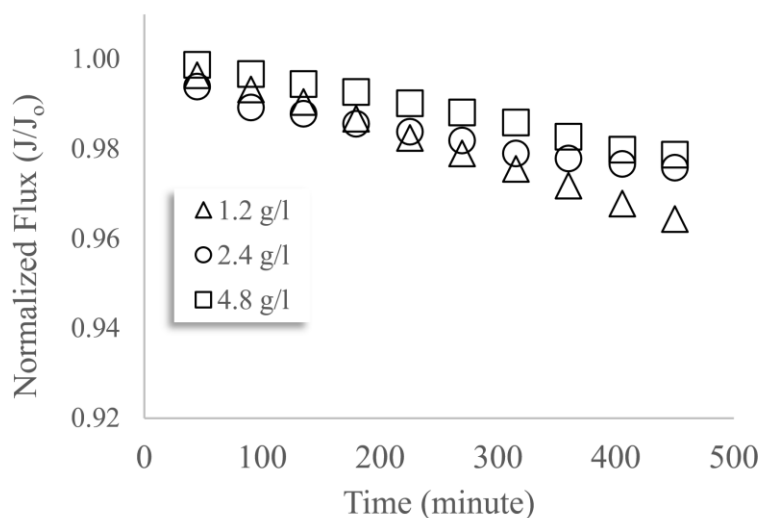
**Figure 2.** Normalized flux (J/J_0) on FO process under different pH levels of feed solution. The temperature was controlled at 25 °C. The velocity of both feed and draw solutions was set at 7.0 cm/s in all experiments

Table 3. Experimental conditions and results of the FO process under different SDS concentrations

SDS (g/l)	Active Layer			Supporting Layer		Flux in 8.0 h (LHM, average)
	NaCl (M)	π (atm)	Cross-flow (m/s)	NaCl (M)	π (atm)	
1.20	0.01	0.48	7.0	1.0	48.3	31.4
2.40	0.01	0.48	7.0	1.0	48.3	32.6
4.80	0.01	0.48	7.0	1.0	48.3	33.1

**Figure 3.** Normalized flux (J/J_0) on FO process under different SDS concentrations. The temperature was controlled at 25 °C, pH in feed solutions was adjusted and set at 7.0, and the velocity was controlled at 7.0 cm/s

4. Conclusions

This study investigated the performance and fouling behavior associated with flux decline using the FO process. The SDS was applied as a representative foulant commonly found in household wastewater effluent. We focused on the effect of cross-flow velocities of both feed and draw side, elevated pH levels, and SDS concentration in the feed solution on the diffusion of water molecules. The findings demonstrated that the water molecules diffused rapidly from the feed side to the draw side when the cross flow was adjusted from 0.5 to 10.5 cm/s. The higher hydrodynamic shear force effectively reduced the attachment of SDS molecules on the surface of FO membrane, resulting in an increase in the transportation of water molecules. In addition, the water molecules also passed through the osmotic membrane more quickly when the pH levels in feed solution were adjusted from 4.0 to 10.0. The interaction of SDS with the FO membrane altered its surface properties, increasing surface hydrophilicity and thereby enhancing water transport, while higher hydrodynamic shear forces minimized SDS adsorption.

Varying the SDS concentration from 1.20 to 4.80 g/L had no significant effect on the water flux, and the normalized flux (J/J_0) did not reveal a clear flux-decline trend.

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