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Toward a combined system of forward osmosis and reverse osmosis for seawater desalination

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Abstract

Forward osmosis (FO) is an osmotic process that uses a semi-permeable membrane to effect separation of water from dissolved solutes by an osmotic pressure gradient. Unlike reverse osmosis (RO), FO does not require high pressure for separation, allowing low energy consumption to produce water. However, the internal concentration polarization in FO is an important factor affecting the performance of FO processes.

This paper was intended to investigate the characteristics of FO and RO processes. A simple film theory model was applied to consider concentration polarization in FO and RO processes. This model allows the estimation of internal and external concentration polarization effects in FO process. A laboratory-scale FO device was used to find the model parameters for further calculations. The calculated flux was compared with experimental flux under a variety of operating conditions. It was found that the combination of FO and RO may result in a higher flux than FO-only process under some operating conditions. Further research will be required to investigate the effect of membrane materials on energy efficiency of FO and RO hybrid system.

Keywords: Desalination; Forward osmosis; Reverse osmosis; Concentration polarization; Combined system

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1. Introduction

Most membrane processes, such as reverse osmosis (RO), are pressure-driven systems where permeate water flux and recovery are controlled by the hydraulic pressure applied to the feed water. Unlike these pressure-driven systems, forward osmosis (FO) processes operate on the principle of osmotic transport of water across a semi-permeable membrane from a dilute feed solution into a concentrated draw solution [1,2]. Since FO does not require high pressure for separation, it has potential to allow lower energy consumption to produce water than RO systems. Therefore, FO has recently drawn attention as a novel method for wastewater treatment, food processing, and sea water and brackish water desalination [3,4].

However, a major limiting factor of FO system performance is a permeate flux decline due to concentration polarization [5]. Two types of concentration polarization in FO on both sides of the membrane play a prominent role in reducing the effective transmembrane osmotic pressure across asymmetric membranes: (1) The external concentration polarization occurs on the side of active layer and (2) the internal concentration polarization occurs on the side of porous support layer. The external concentration polarization may be reduced if turbulence is induced near the membrane surface, facilitating the diffusion of the concentrated solute back into the bulk solution. However, the internal concentration polarization cannot be mitigated by increased shear stress or turbulence because of the stagnant environment inside the porous support layer [6].

The internal concentration polarization is especially dominant in typical thin film composite membranes. These membranes comprise a polymer porous support layer cast upon a thick fabric backing layer, which provides mechanical strength. Recent development of new FO membrane allows reducing the internal concentration polarization by making the support layer thinner with embedded mesh structures [1,7]. The reduced internal concentration polarization in the new FO membrane results in a greater utilization of the osmotic driving force and a higher water flux. Unfortunately, this type of FO membrane is not common and expensive compared to typical RO membranes.

In this study, we focused on the combined use of FO and RO processes in seawater or brackish water desalination. A simple film theory model was applied to consider the effect of internal and external concentration polarizations on FO and RO processes. Preliminary experiments were carried out using asymmetric RO membrane in FO system. The final goal of this research is to develop an optimum hybrid system of FO and RO for Seawater Desalination.

2. Theoretical analysis

We have applied the solution-diffusion model modified with the film theory model to analyze the performance of FO and RO systems. For an RO system, in the absence of salt passage, the generalized flux equation is:

$$J_w = L_v\left(\Delta P - \pi_{F,b}\exp\left(\frac{J_w}{k_F}\right)\right) \quad (1)$$

where J_w is the permeate flux, L_v is the water transport parameter, ΔP is the transmembrane pressure, $\pi_{F,b}$ is the osmotic pressure on the feed side, and k_F is the mass transfer coefficient for external concentration polarization. The standard flux Equation for FO is given as [8]:

$$J_w = L_v\left(\pi_{D,b}\exp\left(-\frac{J_w}{k_D}\right) - \pi_{F,b}\exp\left(\frac{J_w}{k_F}\right)\right) \quad (2)$$