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Simulation of forward osmosis membrane process: Effect of membrane orientation and flow direction of feed and draw solutions

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ABSTRACT

Performance of forward osmosis (FO) process is significantly affected by factors such as membrane properties, concentration polarization (CP), and fouling. In this study, FO performance of a plate and frame type membrane is investigated via a numerical simulation based on mass conservation theorem. To evaluate the FO membrane performance, permeate flux and recovery rate are simulated according to membrane orientation, flow direction of feed and draw solutions, flow rate, and solute resistivity (K). In the case of membrane orientation, all-inside case, in which the draw solution faces the active layer, displays a relatively higher performance than all-outside and all-up cases. Notably, the membrane performance is highly affected by K indicating the extent of the internal CP. During the simulation approach, the spatial variation of the concentration profile was observed on a 2-dimensional membrane area; it was expected to cause a high diffusion load on a particular area of membrane, due to the relatively higher flux at that location. Moreover, it can result in unexpected fouling in a specific area on a membrane. Accordingly, the findings in this study suggest that the numerical simulation can be applied to optimize both physical properties and operation conditions, thereby ensuring cost-effective operation of FO processes.

1. Introduction

Desalination processes, used to produce fresh water from seawater, have been increasingly applied to resolve the projected worldwide water shortage problem. In particular, the seawater reverse osmosis (SWRO) desalination process is preferred to thermal processes due to its relatively lower cost and the recent development in processing water, membrane materials, and equipment [1,2]. However, the high energy consumed during SWRO desalination plant operation is still considered a limitation inhibiting the more widespread deployment of reverse osmosis (RO) technology in desalination [3–10].

Recently, the forward osmosis (FO) process has gained attention as an alternative desalination process, based on its relatively lower energy consumption. The driving force of the FO process is that osmotic pressure allows water to flow from the low concentration of the feed solution side to the high concentration of the draw solution side. The FO process has already been used in fields such as the treatment of landfill leachates, industrial wastewater, and liquid foods since the concept of FO process was suggested in the 1970s [11–13]. In comparison to SWRO, the FO process has advantages such as a low requirement of hydraulic pressure and low membrane fouling.

A number of studies pertaining to factors affecting the performance of FO processes have been carried out, including: FO membrane material, draw solution, and concentration polarization (CP) [11]. Since the driving force of the FO process is osmotic pressure, to ensure practical and effective use, the draw solution is required to be highly soluble, highly recoverable, non-toxic, nonreactive with membranes, easily separable from water, and economically feasible. Previously, ammonium bicarbonate (NH_4HCO_3) solution was suggested as a novel draw solution [14]; in this study, ammonium bicarbonate is applied as the draw solution. This solution can be decomposed into two gases (i.e., ammonia and carbon dioxide) at a relatively low temperature (about 60 °C). Therefore, product water passing through the FO membrane can be separated from the diluted draw solution by distillation methods via a distillation column or membrane distillation [11,15]. The separated gases can then be recycled to use as a draw solution again.

Concentration polarization (CP) is considered as a critical drawback for lowering the permeate flux during FO membrane processes,

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