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Determination of a constant membrane structure parameter in forward osmosis processes

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ABSTRACT

The membrane structure parameter (S) is an intrinsic membrane parameter used to determine the degree of internal concentration polarization (ICP) in the porous support structure of forward osmosis (FO) membranes, and is crucial in evaluations of FO membrane performance. Although S values only depend on membrane properties, and should be close to a constant value, experiments to determine the S values produce various values, which vary with respect to the concentrations of the feed and draw solutions. In this study, we develop a numerical model based on the finite element method (FEM) to determine a constant membrane structure parameter. In contrast to other FO models, the developed model successfully simulates the performance of FO processes, and maintains a consistent S value. Here, the most influential factor causing inconsistent S values is found to be the assumption that the ratio of concentrations is approximately identical to the ratio of osmotic pressures, as is frequently used in FO modeling due to lack of availability of concentration profiles at the active layer–support layer interface. However, use of a constant diffusion coefficient had little influence on either the simulation result or the S value consistency.

1. Introduction

Reverse osmosis (RO) processes have increasingly gained popularity in seawater desalination due to their relatively low energy consumption compared to thermally driven membrane processes such as multi-stage flash distillation (MSF) and multiple-effect distillation (MED) [1,2]. Although RO technology is becoming dominant in the seawater desalination market, challenges remain if additional reductions in operating costs and energy consumption are to be achieved, since RO requires not only a high operating pressure, but also a large amount of concentrated brine that needs to be post-treated due to its low recovery rate [3,4].

In order to overcome the drawbacks of RO processes, forward osmosis (FO) has been spotlighted as an alternative process since appropriate membranes for osmotically driven processes have been developed and the discovery of ammonia–carbon dioxide as a draw solution was made [5,6]. These accomplishments have contributed to the amount of FO-based research being conducted, and the tremendous progress in FO technology being made.

In line with the advances in FO technology, a number of predictive models have also been developed in attempts to predict the performance of FO processes. In FO modeling, one of the most intractable problems is to calculate the internal concentration polarization (ICP), since it cannot be measured directly. In addition, mass transfer in the support layer cannot be directly enhanced by the cross-flow, and as such it has been posited that ICP significantly influences FO performance and plays a decisive role in FO separation [7–10]. In order to examine the degree ICP affects the flux of FO processes, a membrane structure parameter (denoted as S) is frequently employed during modeling procedures. Theoretically and physically, since S only consists of intrinsic membrane parameters such as support layer thickness, tortuosity, and porosity, it should be consistent regardless of operating conditions – including feed and draw solution concentrations – in which the same membrane is used [8]. The significance of S value consistency is that it is a key parameter such as water and solute permeability for evaluating the performance of FO membranes. However, previous research results have shown variant S values with respect to operating conditions [9–13]. To assess FO membrane performance, however, although existing FO models can be used to successfully predict the performance of FO processes, it is crucial to develop a model that not only simulates FO with a constant S value, but is also capable of obtaining an S value from experiments. For this reason, we need to review the development history of previous

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