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Desalination 173 (2005) 269–286

DESALINATION

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Modeling of a spiral-wound module and estimation of model parameters using numerical techniques

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Received 28 May 2004; accepted 30 August 2004

Abstract

A model for a spiral-wound reverse osmosis system using the three-parameter membrane transport model by Spiegler–Kedem is presented. The pressure drops in the permeate channel, feed channel and also the variation of the mass transfer coefficient along the feed channel were taken into account. An analytical solution was not possible due to the large number of nonlinear model equations; therefore, a computer solution utilizing finite differences was employed. The data generated by the simulation of the proposed model clearly indicate that neglecting the variation in the mass transfer coefficient and pressure drop along the flow channels can lead to errors in permeate concentration, though the effect on permeate flow rate may not be significant. The significance of the reflection coefficient in the membrane transport model was also investigated. A method for estimation of the model parameters is also presented; previously reported experimental data were analyzed. Using this parameter-estimation program, a correlation for the mass transfer coefficient in the feed channel is proposed and compared with the correlation available in the literature.

Keywords: Reverse osmosis; Spiral-wound module; CFSK model; Parameter estimation

1. Introduction

Reverse osmosis (RO) is a pressure-driven process used to separate solute and solvent of the same order of molecular size. High pressure is applied on the feed side of the membrane to overcome the osmotic pressure and cause transport of the solvent from feed to permeate side.

The major advantage of RO is that it can be performed at ambient temperature, which allows separation of heat-sensitive material. But feed concentration and particle size are important because high concentration leads to high osmotic pressure, and large particles have a tendency to block the fine pores of the membrane and foul it. The typical sizes of particles involved are on the order of ionic sizes. The most common application of RO is the separation of salt from water

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0011-9164/05/$– See front matter
doi:10.1016/j.desal.2004.08.034

to obtain potable water. Other uses include wastewater treatment, production of industrial-grade water and de-watering of foodstuffs.

Four types of membrane modules are available in the marketplace: plate and frame, tubular, spiral-wound and hollow-fiber. The spiral-wound module occupies the largest market share because of its relative ease of cleaning, fabrication technology and very large surface area per unit volume. When compared with the hollow-fiber module in terms of the method of fabrication and cost, the spiral wound is the best. The flow of feed and permeate in a spiral-wound module is shown in Fig. 1. A typical spiral-wound module may have a packing density of 250 m^2/m^3. The flow channel size is on the order of 0.05 cm. The continuous change of flow in the spiral-wound module allows good mixing of the feed solution.

The emergence of membranes as an important method of separation and concentration process in the chemical industry makes it necessary to predict membrane performance accurately. Sirkar et al. [6] derived the two-parameter analytical design equation for spiral-wound modules without including pressure drop in the feed and permeate channel. He assumes linear approximation for the concentration polarization term, i.e., exp (J_v/k). However, the model is valid only for $(J_v/k) \ll 1$. Gupta [7] developed an analytical design equation for tubular, spiral-wound and plate-and-frame modules assuming constant pressure along the feed and permeate channel and by using the two-parameter solution diffusion model for describing membrane transport. This model is valid for all values of (J_v/k).

Evangelista [1] came up with explicit design equations for a two-parameter model assuming a constant mass transfer coefficient, constant concentration polarization and a negligible pressure drop in both the feed and permeate channel. Taniguchi [2] collected substantial experimental data and compared the performance characteristics of various spiral-wound modules. His model disregards the two-dimensional nature of fluid flow and concentration distribution. Avlonitis et al. [3–5] developed the model to determine the brine and permeate friction parameter and the hydraulic permeability from pure water permeability data for both Roga and Film Tech modules. For a water-solute system the solution diffusion model was combined with the concentration polarization model given by the film theory to explain solute transport through the membrane and liquid film layer surrounded by the membrane, respectively. The correlation for the hydraulic permeability as a function of feed pressure and feed temperature

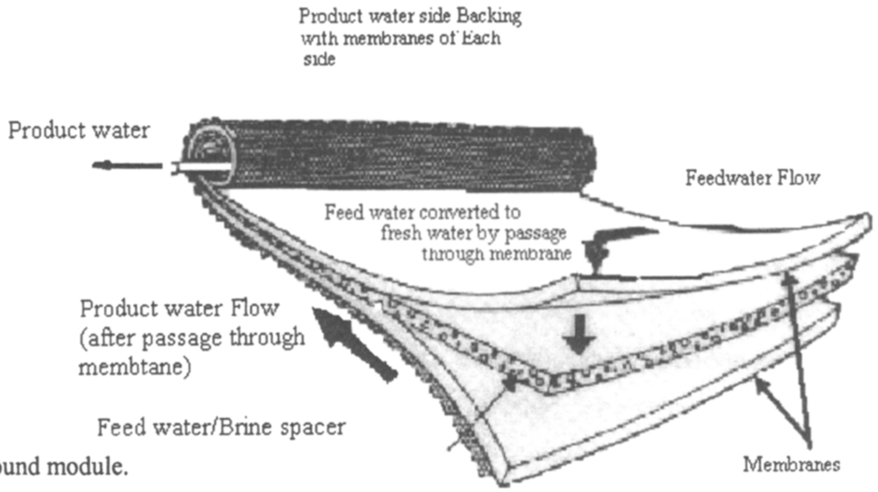

Fig. 1. Spiral-wound module.