

A simplified simulation model of RO systems for seawater desalination

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Received 15 November 2007; Accepted 31 January 2008

Abstract

Desalination of seawater has been considered as one of the most promising techniques for supplying fresh water in the regions suffering water scarcity. Reverse osmosis (RO) is one of the major technologies for mid- and large-size desalination plants because it offers a means of producing high quality of water from seawater with lower energy consumption than other processes such as evaporation processes. In this study, RO systems for seawater desalination were theoretically investigated to provide insight into the optimum process design. A simple model based on the solution–diffusion theory and multiple fouling mechanisms was developed and used to analyze the performance of RO systems. The effect of recovery ratio and permeate flux on the efficiency of the whole RO system was investigated for a wide range of operating conditions. The model was also applied to optimize the design of RO process for low energy requirement and high boron removal.

Keywords: Desalination; Seawater desalination; Reverse osmosis; Fouling mechanism; Process simulation; Optimization

1. Introduction

Seawater desalination has been gaining popularity as a feasible option for potable water production, as available water sources are gradually depleting due to water scarcity as well

as quality deterioration [1,2]. High pressure reverse osmosis (RO) processes have been the technology of choice for seawater desalination in the US and many other countries in the world [3,4]. The market share of RO desalination was 43% in 2004 and is forecasted to increase up to 61% in 2015 [5]. This is because RO has many

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Presented at the First International Workshop between the Center for the Seawater Desalination Plant and the European Desalination Society, November 15–16, 2007, GIST, Gwangju, Korea.

advantages including low energy requirements, low operating temperature, small footprint, modular design, and low water production costs.

However, the performance of RO plants is quite sensitive to the quality of the feed water and plant operating conditions. This means that the availability of reliable RO models is of great importance for process design and operation [6, 7]. Unfortunately, it is difficult to obtain a rigorous mechanistic model of RO process, which accounts for several important operating factors such as permeate recovery, flux, feed temperature, concentration polarization, and fouling [8]. Although the membrane makers have developed several softwares to help possible customers to design an RO plant, they mainly focus on the performance analysis of some RO modules rather than the optimization of RO process in terms of energy consumption and product water quality. Recently, a few works have focused on the development of new RO models for the optimization of membrane modules and desalination plants [8–11]. Nevertheless, these models are still limited to consider the long-term performance of RO systems because the impact of membrane fouling and compaction on RO performance are often ignored.

The main objective of this paper is to develop a computer model for simulating and optimizing the RO process for seawater desalination. The model can make predictions of any operating and performance parameter of the RO plant regardless of the type of membranes used. Using the model, the effects of various factors including recovery ratio, permeate flux, temperature, and fouling mechanism were examined on the RO plant performance. Moreover, the optimum operating conditions were explored to minimize energy consumption and maximize boron rejection.

2. Model development

We have applied the solution–diffusion model modified with the concentration polarization

theory to predict RO performance and optimize energy requirement as well as permeate quality.

The following assumptions were used for the model derivation:

- The solution–diffusion model is valid for the transport of water and solute through the membrane [Eqs. (1) and (2)].
- An RO membrane module is made up of flat channels with spacers.
- Diffusion coefficient is independent of solute concentration.
- The brine concentration varies linearly along an RO element [Eq. (9)].
- The thin film theory is applicable for calculating concentration polarization effect [Eq. (8)].
- Pressure drop in permeate side is neglected [Eq. (3)].
- Osmotic pressure is proportional to the salt concentration [Eq. (4)].
- Mass transfer coefficient is constant for a given fluid condition [Eq. (10)].
- The transport constants for solutes except for boron are same as that for NaCl. In other words, binary solute system (salt and boron) is assumed for simplification.
- The permeate flow rate is constant while feed flow rate changes depending on the recovery.
- Energy consumption by the high-pressure feed pump accounts for most energy use of RO process.

Fig. 1 shows the flow in a RO membrane system for seawater desalination. The main components of RO system are a pump unit, energy recovery device (ERD), and RO unit. A pump unit supplies high feed pressure (P_f) and flow rate (Q_f) to RO unit. An energy recovery device transfers the energy from the concentrate stream directly to feed flow to RO unit. An RO unit is a physically packed group of RO vessels arranged in rows and an RO vessel comprises of 6–8 membrane modules. Since there is a pressure drop (P_d) along a vessel, the concentrate pressure (P_r)

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