ELSEVIER

Desalination 174 (2005) 145–159

DESALINATION

www.elsevier.com/locate/desal

Incorporation of osmotic pressure in an integrated incremental model for predicting RO or NF permeate concentration

Yu Zhao, James S. Taylor*

Department of Civil and Environmental Engineering, University of Central Florida, PO Box 162450, Orlando, FL 32816-2450, USA
Tel. +1 (407) 823-2785; Fax +1 (407) 823-3315; email: taylor@mail.ucf.edu

Received 24 March 2004; accepted 8 September 2004

Abstract

Consideration of concentration, recovery and osmotic pressure has been incorporated in a fully integrated diffusion based mass transfer model identified as integrated osmotic pressure model (IOPM). Osmotic pressure was incorporated into the model using correction coefficients that were calculated from boundary conditions, which were determined from the feed and concentrate streams osmotic pressures. Predicted permeate stream water quality using IOPM and the homogenous solution diffusion model (HSDM) were compared with and without consideration of osmotic pressure. IOPM was verified using independently developed data from full and pilot scale plants. The numerical simulation and statistical assessment show that osmotic pressure corrected models are superior to non-osmotic pressure corrected models, and that IOPM improved predictability of permeate stream water quality.

Keywords: Osmotic pressure; Reverse osmosis; Nanofiltration; Solution diffusion; Mass transfer

1. Introduction

Reverse osmosis (RO), low-pressure reverse osmosis (LPRO) and nanofiltration (NF) are diffusion controlled, pressure-driven membrane processes. Non-linear modifications of pressure and concentration differentials across and through the membrane as well as integration of recovery and film theory have been incorporated into membrane mass transfer models that predict permeate concentration [1–4]. Typically, the linear or log mean of pressure and osmotic pressure in the feed and permeate streams have been used for development of these models. Membrane bulk osmotic pressure was described in the initial homogenous diffusion models using a TDS-osmotic pressure analogue that correlated TDS to osmotic pressure [6]. Linear approximation of a non-linear concentration profile of the membrane feed stream incorporates a known error that can

*Corresponding author.

doi:10.1016/j.desal.2004.09.008

bias model predictions in current diffusion models. While the linear model is still useful, there is no doubt that describing actual mass transfer conditions as accurately as possible will improve model application. Obstacles to incorporating osmotic pressure into membrane mass transfer models are: (a) to accurately describe the solute concentration profile and (b) to solve the resulting differential equation that incorporates non-linear variations of osmotic pressure along the membrane feed stream channel. The development of a fully integration model that incorporates increments of osmotic pressure is presented in this work. This model is an integrated osmotic pressure model (IOPM) consisting of a simple equation that utilizes coefficients for correction of osmotic pressure, which are determined from the feed and concentrate stream TDS.

Development and verification of the model was done using data from two full scale plants as documented in the USEPA Information Collection Rule database [7] and a 0.2 MGD membrane pilot study. Verification was done using independently derived data that was not used for model development.

2. Model development

The homogeneous solution diffusion model (HSDM) is developed from the five basic equations shown in Eqs. (1)–(5). The HSDM equation is shown in Eq. (6) and was the first model developed for a high recovery system [8]. The HSDM has been developed by mathematically relating the average feed stream concentration to system recovery in a mass balance approach [2]. HSDM can be utilized to predict permeate concentrations for any RO or NF membrane application given the feed stream concentration, flux, recovery and solvent and solute mass transfer coefficients (MTCs, K_w and K_s),

A single element flow diagram showing input and output stream flow, concentration and pressure of the feed, permeate and concentrate streams is shown in Fig. 1.

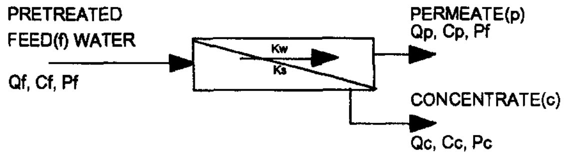

Fig. 1. Basic diagram of mass transport in a membrane.

$$F_w = K_W\left(\Delta P - \Delta\Pi\right) = \frac{Q_p}{A} \quad (1)$$

$$J_i = K_s \Delta C = \frac{Q_p C_p}{A} \quad (2)$$

$$R = \frac{Q_p}{Q_f} \quad (3)$$

$$Q_f = Q_c + Q_p \quad (4)$$

$$Q_f C_f = Q_c C_c + Q_p C_p \quad (5)$$

Membrane solvent mass transfer is pressure driven and is opposed by osmotic pressure, Π, which can be related to solute concentration by the Van't Holf equation, however in practice Π is related to solute total dissolved solid TDS as shown in Eqs. (6), (7). ΔC is defined as the difference of the average feed and concentrate stream concentration and the permeate stream concentration.

$$C_p = \frac{K_s C_f}{k_w\left(\Delta P - \Delta\Pi\right)\left(\frac{2-2R}{2-R}\right) + K_s} \quad (6)$$

$$\Delta\Pi = k_{\mathrm{TDS}} \times \Delta C_{\mathrm{TDS}} \quad (7)$$

An integrated solution diffusion model has been developed based on the diffusion model. The concentration increment along the membrane channel is illustrated by finite units with respect to R (recovery) as shown in Eq. (8). Schematic representation of the model geometry is shown in Fig. 2.