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Reuse of treated wastewater from steel industry by reverse osmosis membrane: flux decline study

Tea-Ouk Kwon[a], Jae-Wook Lee[b], Il-Shik Moon[a*]

[a]*Department of Chemical Engineering, Sunchon National University, Suncheon 540-742, Korea*
Tel. +82 (61) 750-3581; Fax +82 (61) 750-3580; email:reaction@sunchon.ac.kr
[b]*Department of Chemical Engineering, Seonam University, Namwon 590-170, Korea*

Introduction

Membrane technology is widely employed as a means of producing various qualities of water from surface water, well water, brackish water and seawater. This is also used in industrial wastewater treatment and its recycling process. A large volume of wastewater is generated by the steel industry. Presently, the treated wastewater from the steel industry cannot be recycled, because some of its components cause either direct or indirect problems. For instance, the high conductivity of some ions cause line corrosion and scaling during the recycling process. Therefore, better purification technologies are required if the treated wastewater is to be successfully recycled and the demand for industrial water significantly reduced. For this purpose, reverse osmosis membrane has been widely used for the removal of dissolved pollutants. However, flux decline resulted from concentration polarization and fouling is a main problem in reverse osmosis membrane where the estimation of mass transfer coefficient is very important for evaluation of flux decline. A number of studies on the estimation of mass transfer coefficient in reverse osmosis have addressed [1,2]. They can be divided into three main groups: (a) direct measurements, using optical or microelectrode measurements; (b) indirect measurements, in which the true rejection is calculated by extrapolation to infinite feed circulation; (c) indirect measurements, in which a concentration polarization model combined with a membrane transport model is used for the required calculation. The objective of the present work is to estimate membrane parameters and the mass transfer coefficient by indirect measurements using the combined film theory/solution-diffusion (CFSD) model and the combined film theory/Spiegler-Kedem (CFSK) model by a nonlinear parameter estimation.

Theory

Flux decline can be caused by several factors, such as concentration polarization, adsorption, gel layer formation and plugging of the pores [3]. The extent of these phenomena is strongly dependent on the types of membrane process and feed solution employed. Eq. (1) is the new working equation of the combined film theory and the solution-diffusion model.

$$R_0 /(1-R_0) = [J_V /(D_{AM} K / \delta)][\exp(-J_v / K)] \quad (1)$$

By supplying R_0 vs. J_V data, taken at different pressures but at a constant feed rate and constant feed concentration for each set, the parameter $(D_{AM} K / \delta)$ and the mass transfer coefficient, k, can be estimated numerically. On the other hand, the working equations of the nonlinear Spiegler-Kedem model is:

$$R_0 /(1-R_0) = a_1[1-\exp(-J_V a_2)][\exp(-J_V / k)] \quad (2)$$

where, $a_1 = \delta /(1-\delta)$ (3)

$$a_2 = (1-\delta) / P_M \quad (4)$$

$$R_0 \equiv (C_b - C_p) / C_b \quad (5)$$

Here, δ is the reflection coefficient which represents the rejection capability of a membrane, i.e., $\delta = 0$ means no rejection and $\delta = 1$ means 100% rejection, P_M is the overall permeability coefficient. By using a nonlinear parameter estimation method, we can estimate the membrane parameters o and P_M and the mass transfer coefficient, k, simultaneously, namely, by supplying the data of R_0 vs. J_V taken at different pressures but at constant feed rate and constant feed concentration for each set.

Experimental

In this study, treated wastewater from steel company was used. The treated wastewater was treated through a coagulation-precipitation, sand filtration, and activated carbon filtration process. Flat-sheet type NF (nanofiltration) membrane models HL and DK, and RO (Reverse osmosis) membrane model AG were used in the flat-sheet membrane experiment. Table 1 shows the specifications of the used membranes. All used membrane was cleaned with distilled water before the experiment. The pretreatment process was carried out by the BMF (Backwashable Micro Filtration) process before the flat-sheet experiments. The flat-sheet membrane cell was designed for a cross-flow filtration system and experiments were carried out at 5-30 kg_f/cm^2, and 25℃. The permeate flux and conductivity rejection rate were calculated over a range of operating pressures. Also, in the AG flat-sheet membrane experiment, fouling performance was observed through a long operating trial. The system operated in a full re-circulation mode (both permeate and concentrate were re-circulated to the feed tank) except during sampling. Feed and permeate water conductivity were measured using conductivity meter model 47C (Istek, Korea) and conductivity sensor model 3-2819 (SIGNET, U.S.A). Dissolved ions were analyzed using a Shimadzu CLASS VP Series Ion-Chromatography LC-10A system equipped with conductivity detector CDD 10A (Shimadzu, Japan), C3 cation, and A3 anion column (Shim-pack, Japan).

Table 1. Specifications of NF & RO membrane

	Model	Area, m^2	Typical operating Pressure, kg_f/cm^2	Material	Type
NF	HL	1.132×10^{-2}	5-21	Polyamide	Flat type
(Osmonics Co.)	DK	1.132×10^{-2}	5-28	Polyamide	Flat type
RO	AG	1.132×10^{-2}	14-40	Polyamide	Flat type
(Osmonics Co.)	AG 2540	2.5	14-40	Polyamide	Spiral wound

Results and Discussion

Fig. 1 shows the flux decline and rejection rate for different membranes. The Marquardt method [4], a nonlinear parameter estimation method was used to solve Eqs. (1) and (2). The experimental data supplied are R_0 vs. J_v taken at different operating pressures keeping feed rate and feed concentration constant for each set of data. The parameters determined are listed in Table 2.

Table 2. Parameters estimated for the combined film theory/solution-diffusion (CFSD) model and the combined film theory/Spiegler-Kedem (CFSK) model from a nonlinear parameter estimation.

Set	Parameters of CFSD model		Parameters of CFSK model		
no.	$(DAMK/\delta)\times10^7$, m/s	$K\times10^5$, m/s	$P_M\times10^7$, m/s	δ	$k\times10^5$ m/s
S1	3.026	2.160	3.168	1.0	2.386
S2	3.176	2.155	3.208	0.99	2.316
S3	3.081	2.171	3.199	0.98	2.157

S1: 1L/min, 3,000 mg/L, S2:1 L/min, 6,000 mg/L, S3:1L/min, 9,000 mg/L

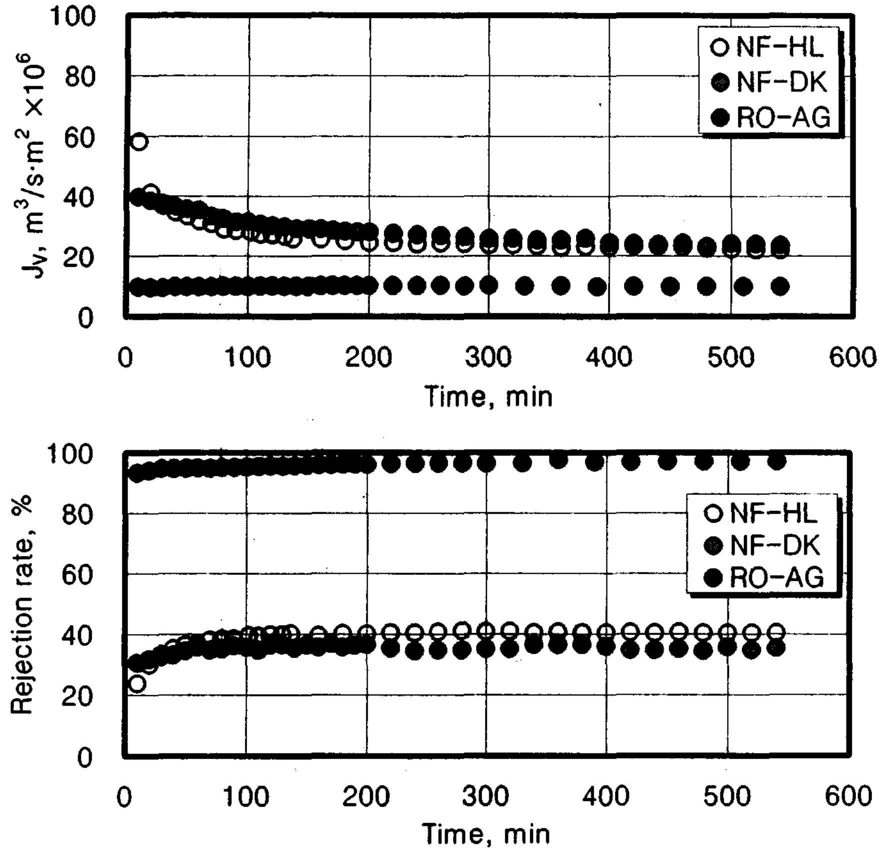

Fig. 1. Flux decline and rejection rate for three membranes.

Acknowledgement

This research was supported by the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce, Industry and Energy of the Korean Government

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