전기투석을 이용한 염화나트륨 용액 탈염과 모델링

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Desalting of sodium chloride solution using electrodialysis and its modelling

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1. Introduction

Electrodialysis is an electrochemical separation process in which electrically charged membranes and electrical potential are used to separate ionic species from an aqueous solution and other uncharged components. Electrodialysis is used widely for desalination of brackish water and recovery of acids [1].

The purposes of this study are to determine model parameters, to predict desalting performance, and finally to evaluate process economics through a numerical analysis by using a rate equation of ion transfer.

2. Theory

The rate of ion transfer is proportional to the current applied for electrodialysis system and given by

$$\frac{-d}{dt}(CV) = \eta \frac{IN}{zF} = \eta \frac{NAi}{zF} \quad \text{------- Eq. (1)}$$

where C is the sodium chloride concentration in the feed (M), V the volume of the feed solution (L), η the current efficiency, N the number of cell pair, I the current (A), z the charge of the ion, F the Faraday constant (C/eq) and A the area of each membrane (㎠). The current efficiency is a ratio of the amount ions transferred to the total charge supplied, which depends on the properties of membranes and solutions [2].

For the constant current electrodialysis operation, the time profile of the concentration of charged species, the feed volume and membrane area can be determined by Eq. (1) since, under electrical field, ions transport through the ion exchange membranes accompanying the solvent, referred to as electroosmosis [2].

3. Experimental

An electrodialysis unit, electrodialyzer (TS-2-10, Tokuyama, Japan) was used to determine the limiting current density and to carry out desalting experiments. It consisted of a membrane stack with five cell pairs in which CMX and AMX were arranged alternatively. The effective area of membranes was 200 cm^2. The electrical current was supplied by a power supply (Agilent, USA). Temperature of solutions was kept at 25℃ by a water bath (Jeio Tech. VTRC-620, Korea). Platinum wires were inserted in electrodialysis stack to measure cell voltages.

For the determination of limiting current density, the applied current was increased stepwise, while keeping the sodium chloride concentration constant, and the current was measured. The dilute and concentrate solution were circulated from the same reservoir through the dilute and concentrate compartments in the cell.

The initial concentrate solution was 3.0 L of 0.1 M NaCl and dilute solution 3.0 L of 0.01 M NaCl for desalting experiment. The initial current density was 10 mA/cm^2. A conductivity meter (Orion, model 250A, USA) and pH meter (Cole-Parmer, USA) were immersed for the measurement of the conductivity and pH in both concentrate and diluate reservoirs. The volume change in the reservoirs were recorded with time to determine water transport index in desalting experiment of sodium chloride solution.

4. Results and Discussion

Fig.1 shows the linear correlation between limiting current density and sodium chloride concentration. At the limiting current density, ion concentration at the membrane surface falls to zero due to severe limitation in their diffusion to the membrane surface and consequently the resistance increases sharply. If the electrodialysis is operated at a current density beyond the limiting value, the current efficiency significantly decreases, and excessive energy is also dissipated for splitting water [3]. It is expected that a feasible range of sodium chloride concentration would be determined for a given operating current density from Fig. 1. Desalting experimental results were compared with model equations for 34 min, i.e. during the operation at a current density below the limiting current density.

Water transport index (L/mol) is the amount of water transferred per unit amount of sodium chloride transferred and can be expressed as follows.

$$\omega = \frac{\Delta V}{\Delta (CV)} \quad \text{------- Eq.(2)}$$

Water transport index and current efficiency with time were numerically calculated at each time step by using Eq. (1),(2) and the experimental results of concentration and volume in desalting experiment. They are obtained from electrodialysis results (concentration and volume changes). Average water transport index was found to be 0.2291 L/mol and average current efficiency 0.965 for 34 min.

Concentrations and volumes obtained by a numerical analysis of the given model were compared with the corresponding experimental data as shown in Fig. 2. Model predictions were in good agreement with the experimental data.

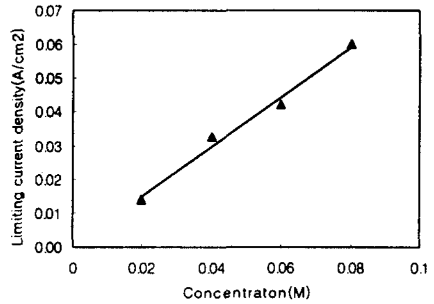

Fig. 1. Limiting current density vs sodium chloride concentration.

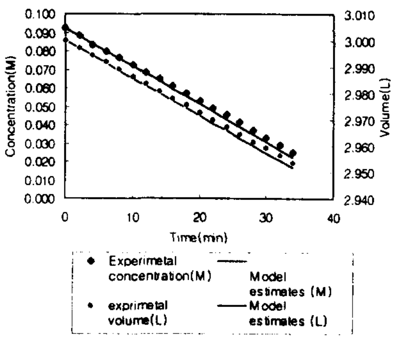

Fig. 2. Simulation of concentration and volume in desalting electrodialysis experiment.

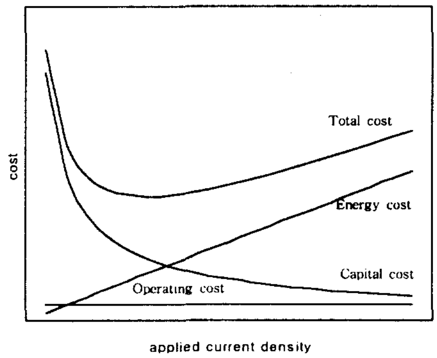

Fig. 3. Simulation of process cost with current density

The capital cost was calculated from membrane area obtained in Eq(1) and the energy cost from resistance obtained from the concentration change. The total desalination cost was obtained by summing capital, energy and operating costs. The process costs were presented in Fig. 3. The result shows that an optimum current density exists to minimize the total cost and the model enables to predict the optimum current density.

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