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한계전류밀도 이상에서 전기투석공정의 운전

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Operation of electrodialysis at over limiting current density

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1. Introduction

It is common knowledge that electrodialysis (ED) is increasingly of importance in various applications such as demineralization of whey, recovery of metals from metal plating rinse waters, recovery of inorganic and organic acids, separation of amino acids from a fermentation broth [1-5]. Nevertheless the wider spread of ED is prohibited by the cost of the stack. Since the ED process cost is depending on the membrane area, it is desired to operate at the highest practicable current density to get the maximum ion flux per unit membrane area. Operating current levels are, however, restricted by the limiting current density based upon concentration polarization phenomenon. It is traditionally believed that the limiting current density (LCD) is the maximum current allowed to operate an ED process, and the operation at the over LCD causes to diminish the process efficiency by an increase in the electrical resistance and the occurrence of water dissociation. However, it was observed from the previous studies [7-9] that the over LCD dominantly carried the electrolyte, and the loss of permselectivity or water dissociation are not responsible for the over LCD. This indicates that the membrane area required to remove salts for a given feed solution could be reduced with the increasing current density.

The purpose of this study is to investigate the feasibility of an ED operation at the over LCD. The feasibility was discussed in terms of current efficiency, salt removal efficiency, energy consumption, and water dissociation.

2. Experimental

Measurement of current-voltage (I-V) curves and ED experiments of NaCl solutions are obtained using a six- and five-compartment cell, respectively, with different membrane configurations as shown in Fig. 1. The effective area of the membrane was 25 ㎠. Two Ag/AgCl reference electrodes were used to measure the potential difference between membrane-solution interfaces. The membranes used in the experiments were the Neosepta CMX and the Neosepta AMX (Tokuyama Corp., Japan),

3. Results and Discussion

As shown in Fig. 2, three regions can normally be observed in the I-V curves: the first region of approximately ohmic behavior, the second region corresponding to the "plateau," followed by the third region of rapid current increase. According to the electroconvective transport mechanism at the over LCD region [6], the plateau length can be regarded as a minimum potential that can cause the electroconvective mixing in the diffusion boundary layer (DBL). In order to achieve a cost effective operation of ED, the plateau length of the current voltage curve for an ion-exchange membrane is required to be as short as possible to minimize the additional power consumption by the plateau length when the constant current density initially applied under the LCD becomes the over LCD as salt in a dilute compartment was depleted. Fig. 3 shows that the LCD has a proportional relationship with the concentration of the salt in the bulk phase. The higher LCDs for the AMX is due to the higher transport number of the counter ions (Na^{-} for the CMX and Cl^{-} for the AMX) in solution.

Batch ED of 0.1 M NaCl solution as a feed solution at various current densities were carried out to access the ED performances. Fig. 4 shows the energy consumptions calculated and plotted as a function of removal efficiency of NaCl. The energy consumptions increased exponentially with the removal efficiency because the electrical resistance in the dilute compartment increased with the removal efficiency. For a 0.1 M NaCl solution 6 mA/cm^2 is in the under LCD region for both the CMX and AMX, and 12 mA/cm^2 in the over LCD region for only the CMX, resulting in a higher energy consumption to overcome the additional potential corresponding to the plateau length for the CMX. It was noted that there were no significant differences in energy consumptions per unit mass transported between the current density of 18 and 24 mA/cm^2. This indicates that the ED operation at an over LCD is feasible without significant energy consumption. Fig. 5 shows the current efficiencies at different operating current densities as a function of salt removal efficiency. The current efficiencies did not changed significantly until most salts were removed, and decreased slightly from 0.96 to 0.93 with the increasing current densities. Assuming that the membrane permselectivities are not affected by the current density, the decrease in current efficiency resulted from the water dissociation, and it means that the amount of water dissociation is estimated to be less that 3 % of the total current supplied.

4. Conclusion

Operating of ED at the over LCD region is possible. Eventually, although the energy consumption required to transport ions increased in the over LCD region, operation of ED at the over LCD has advantages of decreasing the pumping cost and the reduction of membrane area required, resulting in the significant decrease in total ED stack cost.

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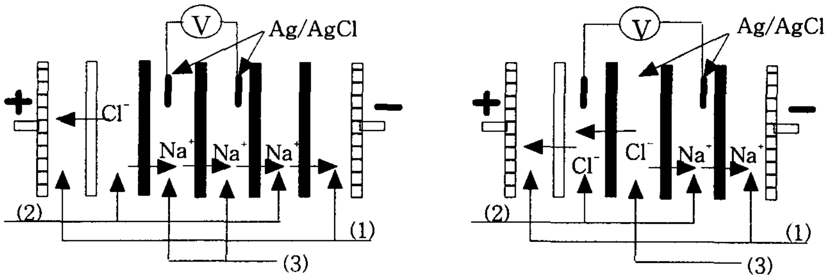

(a) (b)

Fig. 1. Schematic diagrams for (a) I-V curve measurement and (b) desalting experiments: (1) electrode solution (0.5 M Na2SO4), (2) 0.5 M NaCl (3) feed solutions (white square: AMX, black square: CMX).

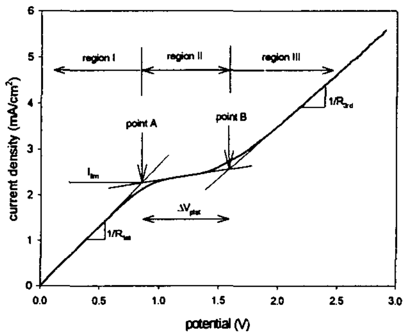

Fig. 2. Typical I-V curve for an ion-exchange membrane.

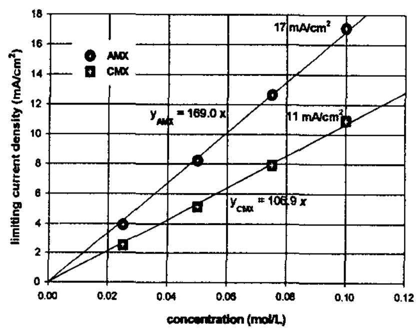

Fig. 3. LCDs obtained for the CMX and AMX as a function of NaCl concentration.

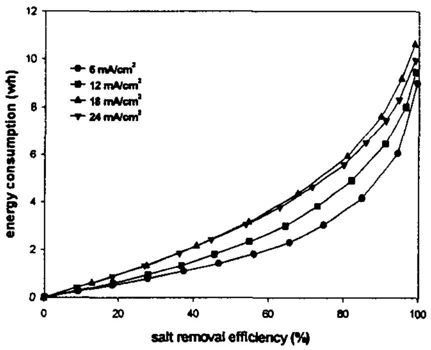

Fig. 4. Energy consumptions as a function of removal efficiency of NaCl at different current densities.

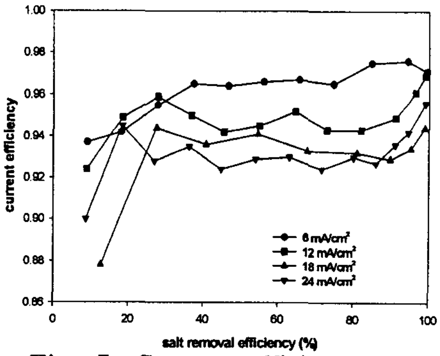

Fig. 5. Current efficiencies as a function of salt removal efficiency at various current densities.