Demineralization by electrodialysis (ED) — separation performance and cost comparison for monovalent salts

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Abstract

The separation performance of K^+ ions from KCl solution has been investigated by electrodialysis at constant voltage mode of operation as a function of flow rate and voltage scanned. TS-1-10 model electrodialysis equipment (Tokuyama) modified with rotameters was employed in experimental runs. The efficiencies of each unsteady state run were evaluated as specific power consumption with the electrical energy consumed only in stack. The separation performance of K^+ ions was compared with that of Na^+ ions.

Keywords: Electrodialysis; Membrane; Desalination; Potassium; Sodium; Specific power consumption

1. Introduction

Electrodialysis (ED) is an electrochemical process for the separation of ions across charged membranes from one solution to another under the influence of electrical potential difference. This process has been widely applied to treat brackish water for potable use or to desalt and concentrate effluents for reuse [1,2].

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In a typical electrodialysis cell, a series of anion and cation exchange membranes are arranged in an alternating pattern between an anode and a cathode to form individual cells. When a DC potential is applied between two electrodes, the positively charged ions move to the cathode, passing through the negatively charged cation exchange membrane and are retained by the positively charged anion exchange membrane. On the other hand, the negatively charged ions move

to the anode, passing through the anion exchange membrane and are retained by the cation exchange membrane. At the end, ion concentrations increase in alternating compartments, with a simultaneous decrease of ions in other compartments [1,2]. Recently, we have reported the electrodialysis of NaCl solution at constant voltage mode of operation [3]. In this study, the separation performance of K^+ ions using 0.01 M KCl solution by electrodialysis has been studied. Effects of feed characteristics on the separation performance of K^+ ions from KCl solution have been evaluated. The results were compared with those obtained for Na^+ ions.

2. Experimental

TS-1–10 electrodialysis equipment (Tokuyama) modified with rotameters was employed for experimental studies. A schematic view of the experimental set-up is shown in Fig. 1. This equipment contains a stack with ten pairs of Neosepta® CMX (cation exchange) and AMX (anion exchange) membranes with the area of 1 dm². Three pumps have capacities of max. 1.8 L/min. A rectifier is provided to supply a DC power at constant voltage (max. 18 V) or constant current (max. 3 A). Three solution tanks (each 1 L) are
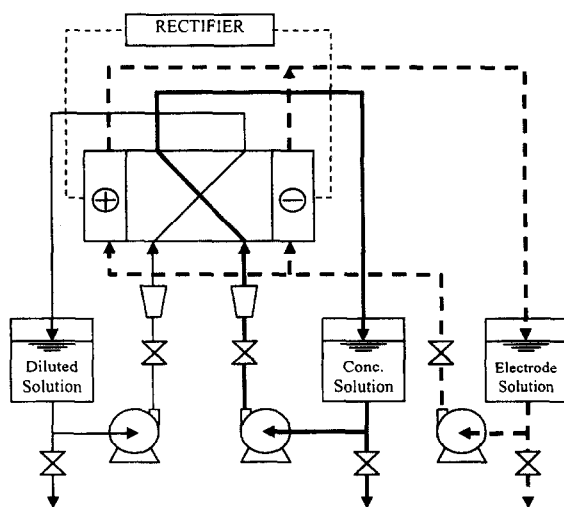

Fig. 1. Batch mode operation of electrodialysis system.

used for holding the dilute, the concentrated, and the electrode rinse solutions. The electrodes are platinum plated titanium (anode) and stainless steel (cathode) [4]. All tests were performed using KCl and NaCl solutions with the concentration of 0.01 M at room temperature using various potentials (3, 5, 10, 15 V) and flow rates (0.6, 1.2, 1.8 L/min) until the current measured dropped to 0.01A.

Concentrations of K^+ and Na^+ ions in the solutions were determined by AAS (Varian 10 Plus) while conductivities were measured by a conductometer (WTW-LF 330/SET).

3. Results and discussion

From the former studies, it was observed that the change in the concentration of electrode rinse stream was negligible, therefore only concentrated and dilute streams were monitored by K^+ ion concentration and conductivity. K^+ ion content of dilute stream was measured in certain time intervals and presented on charts, in dimensionless concentrations, defined as the ratio of concentration at any time to initial concentration. Histories of K^+ ion concentration at constant potentials are given in Fig. 2, whereas those at constant flow rates in Fig. 3. From both Figs. 2 and 3, it is seen that the operation time needed for reaching 0.01 A becomes shorter as the potential increases. Furthermore, Fig. 2 shows that the flow rate has negligible effect on both the dilution reached and the operation time followed. Nevertheless, the drastic effect of potential applied on both dilution and operation time is clearly seen in Fig. 3, such as the dilution ratio drops from around 0.4 to below 0.05 while the potential increases from 3 to 15 V.

A comparative study was performed using NaCl and KCl solutions at a flow rate of 1.8 L/min at 5 and 10 V. The results are plotted in Fig. 4. The effect of type of cationic species on operation time becomes smaller at 10 V.

Specific power consumption (SPC) for the separation of K^+ and Na^+ ions at constant voltage
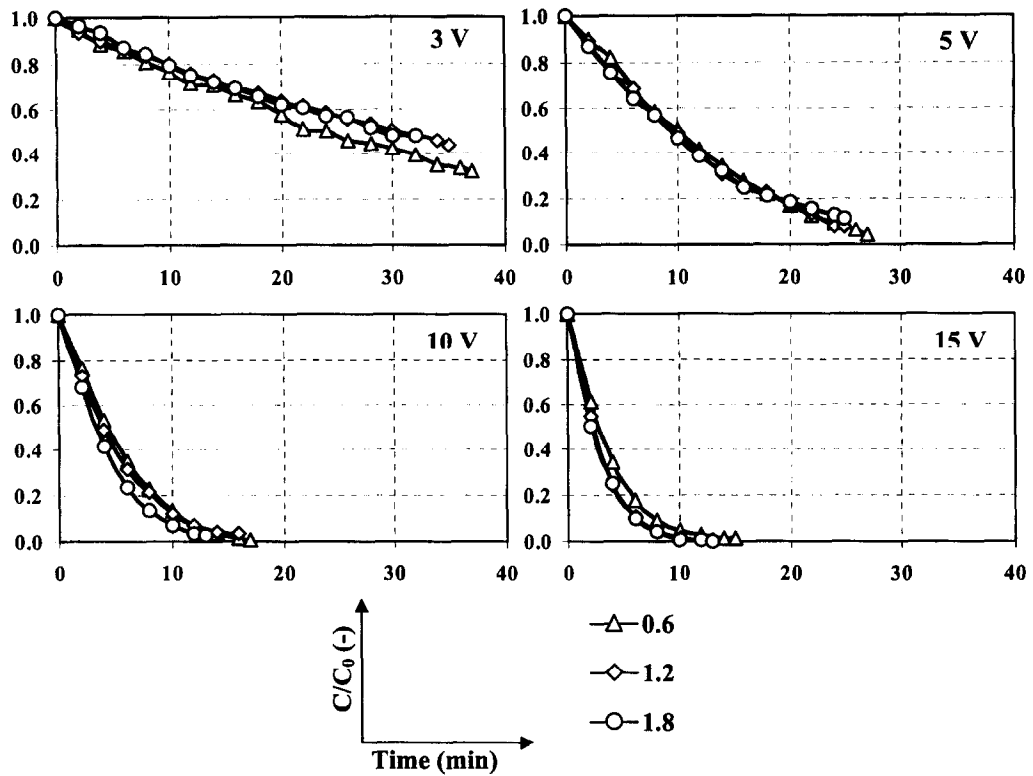
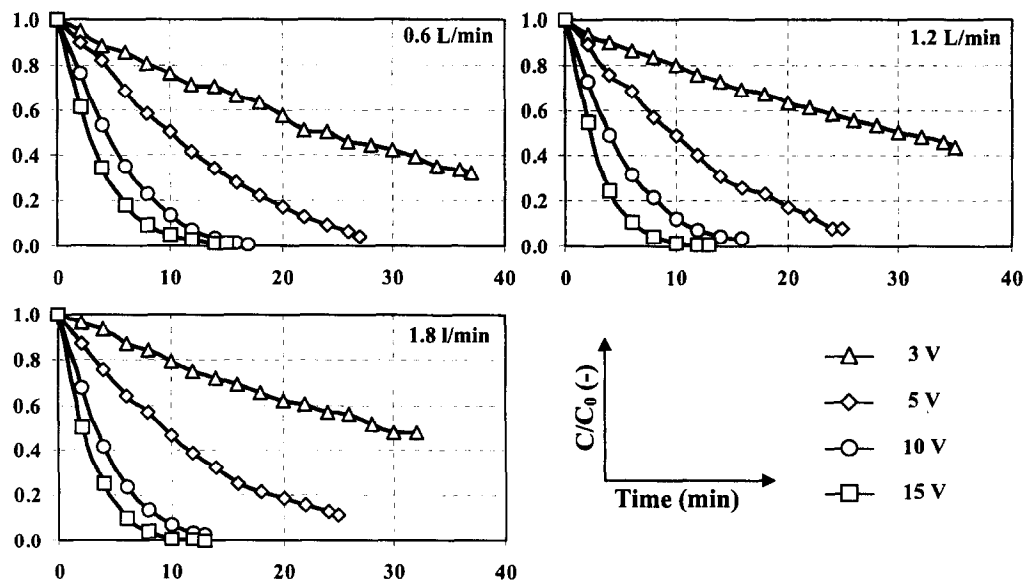Fig. 2. Experimental data for dimensionless concentration of K^+ ions vs. time with respect to flow rate.

Fig. 3. Experimental data for dimensionless concentration of K^+ ions vs. time with respect to potential.
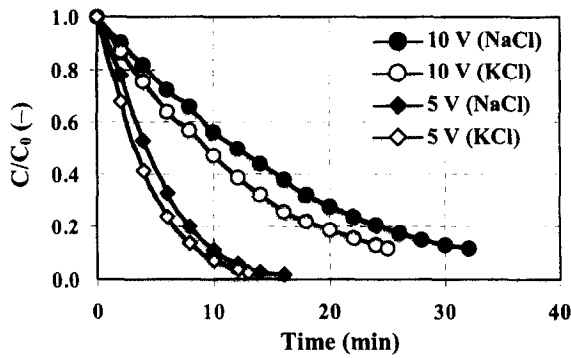
Fig. 4. Effect of potential on the separation performance of monovalent salts.
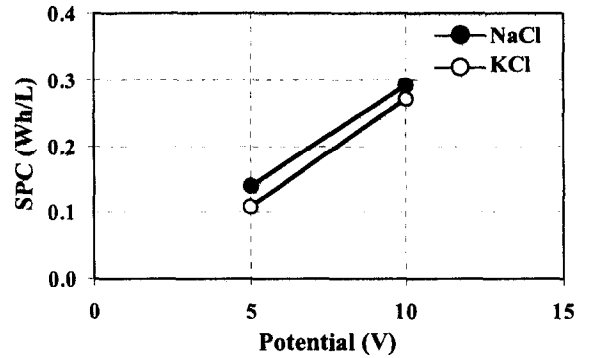

Fig. 6. SPC vs. potential plots for monovalent salts.

mode of operation was calculated within the operation time as follows:

$$\text{Specific power consumption (SPC)} = \frac{E \int_0^t I dt}{V_D} \quad (1)$$

The results are given in Fig. 5 as a function of flow rate and potential. It is clear that the potential applied greatly determines the SPC, whereas flow rate has negligible effect on it. As shown in Fig. 6, SPC data for both NaCl and KCl were similar.

4. Conclusions

A series of experiments was performed for removal of K$^+$ ions from 0.01 M KCl solution within the range of potentials and flow rates chosen in the ED system of TS-1-10 model electrodialyzer (Tokuyama). The operation time was short when a high potential was applied. Specific power consumption increased with an increase in potential applied although it was not sensitive to the change in flow rate. The difference in the separation performances of NaCl and KCl was small when potential increased from 5 to 10 V.
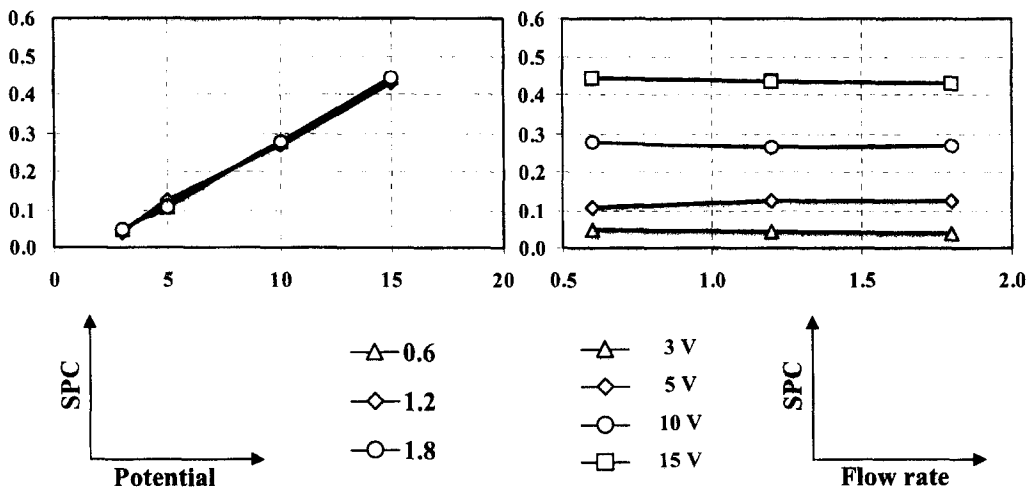

Fig. 5. Specific power consumption with potential (left) and flow rate (right) for K$^+$.

Symbols

E	–	Potential
I	–	Current
V	–	Volume
t	–	Time

Subscripts

D	–	Diluate

Acknowledgement

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