Desalination of salt solutions by means of circulating diffusion dialysis system using salinity gradient energy

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Abstract

In this paper, a novel desalination system called circulating diffusion dialysis (CDD) was set up by connecting two stacks using salt bridges, with the stacks consisting of cation- and anion-exchange membranes and three types of water flow channels of two salt solutions (HS: high salt concentration, LS: low salt concentration) and desalting water (DW) solution. By feeding 30,000 mg/dm³ NaCl as HS and various initial concentrations of NaCl as LS and DW to the CDD system, the salt concentration of DW decreased to less than 500 mg/dm³. In conclusion, we confirmed that the CDD system can desalinate saline water without applying any heat and electrical power from outside; but just by feeding salt solutions with different concentrations into the system.

Key Words: Renewable energy, Reverse electrodialysis, Electrodialysis, Ion exchange membrane, Desalination

1. Introduction

The production of fresh water by the desalination of seawater and brackish water is an important issue in many areas of the world. Thermal processes such as multistage flashing, reverse osmosis (RO) and electrodialysis (ED) used for water desalination have a negative impact on the environment due to their intensive energy consumption. Recently, there have been many reports on desalination technology using renewable energy such as the combination of RO-solar power, RO-wind power. However, both solar and wind power depend on weather and climate; therefore desalination using these energy sources is not suitable for continuous supply of fresh water. Reverse electrodialysis (RED) converts salinity gradient energy (SGE) between two salt solutions with different concentrations into electricity; hence, it is known as a renewable energy. Xu et al. proposed a power free desalination system (PFED) by ans of in-situ combination of RED unit as the energy donor and ED unit as the desalination part using electricity from RED. The combination system is very interesting; however, the system uses two pairs of electrodes that will decrease the energy conversion efficiency in the system and increase equipment cost.

In this paper, we propose a novel RED-based desalination system called circulating diffusion dialysis (CDD). Schematic diagram of the system is shown in Fig. 1. The system consists of two stacks connecting to each other with salt bridges to form a circulating ionic transport between the two stacks. The stacks consist of cation- and anion-exchange membranes (CEM and AEM, respectively), and water flow channels. Two salt solutions with different concentrations (here, we call the high- and low concentration salt solutions HS and LS, respectively) are fed to the water flow channels alternately. In this alternating sequence of HS and LS, one flow channel for HS is exchanged with the desalting water (DW) channel. The system can desalinate DW channel flow by using SGE between HS and LS flows. Compared with ED and PFED systems, CDD system does not use any expensive electrodes; hence, the energy obtained inside the CDD stack can be used directly for desalination of DW channel, thus it is expected to be a high efficiency and low cost desalination process using renewable energy.

2. Experimental

In this study, Neosepta® CMX and AMX (ASTOM Co., Ltd.) were used as CEMs and AEMs, respectively. A stack for the CDD system consisted of eight HS channels, ten FS channels and one DW channel. The effective membrane

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The concentration of DW as a function of time at various concentrations of LS were 20 dm³, respectively, and that of DW was 0.5 dm³. All the solutions were circulated between the CDD stack and each solution tank using magnet pumps (IWAKI Co., Ltd.). Flow rate was 1.5 dm³/min for HS, 3.0 dm³/min for LS and 0.5 dm³/min for DW. The concentration change with time was measured by a conductivity meter (CM-31P, TOADKK Co., Ltd.). The operation in all the desalination tests was terminated when the concentration of DW water became less than 500 mg/dm³.

Table 1 The initial concentration of LS and DW, $C_{int}$, desalination time period, $T_d$, and mean desalination rate, $r_d$

<table>
<thead>
<tr>
<th>$C_{int}$ [mg/dm³]</th>
<th>$T_d$ [min]</th>
<th>$r_d$ [g/(m²·min)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>65</td>
<td>0.44</td>
</tr>
<tr>
<td>2500</td>
<td>236</td>
<td>0.48</td>
</tr>
<tr>
<td>5000</td>
<td>625</td>
<td>0.41</td>
</tr>
<tr>
<td>7500</td>
<td>1225</td>
<td>0.32</td>
</tr>
</tbody>
</table>

volume of DW solution [dm³] (≈ 0.5 dm³), $S$ was effective area of the membranes [m²] ($≈ 88 \times 10^{-4}$ m²), $T_d$ was measurement time [min].

Table 1 shows the measurement time and mean desalination rate of the experiments at various initial concentrations of LS and DW.

$r_d$ increased with decreasing $C_{int}$, and had a maximum value at 2500 mg/dm³ of $C_{int}$. This will be due to the fact that: the energy for the desalination of DW to 500 mg/dm³ decreased with decreasing $C_{int}$ because the required energy for the DW desalination decreased with decreasing $C_{int}$, and the available SGE for the desalination also increased with decreasing $C_{int}$. On the other hand, the total electric resistance of the CDD system increased with decreasing $C_{int}$. Because of the trade-off relationship between the two factors, $r_d$ had a maximum value at 2500 mg/dm³ of $C_{int}$.

4. Conclusion

A CDD system was set up by connecting two stacks of CEMs, AEMs and water flow channels of HS, LS and DW using salt bridges. By feeding 30,000 mg/dm³ NaCl as HS and various initial concentrations of NaCl as LS and DW into the CDD system, the salt concentration of DW decreased to less than 500 mg/dm³, indicating that the CDD system can desalinate saline water without applying any heat and electrical power from outside; but just by feeding salt solutions with different concentrations into the system.

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References

2) Fabao Luo, Yaoming Wang, Chenxiao Jiang, Bin Wu, Hongyan Feng and Tongwen Xu, A power free electrodialysis (PFED) for desalination, Desalination, 404, 138-146 (2017)