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# Using electrodialysis for regeneration of aqueous lithium chloride solution in liquid desiccant air conditioning systems

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ABSTRACT

This study evaluates the potential of using electrodialysis (ED) technology to regenerate the aqueous lithium chloride (LiCl) solution, a commonly used liquid desiccant in liquid desiccant air conditioning (LDAC) systems. Experiments were performed using an ED system with ten cell pairs of ion-exchange membranes. A range of tests were carried out to examine the effects of the circulation flow rate, supplied current density, solution initial concentration and the concentration difference between the regenerated and spent solutions on the performance of ED for regenerating LiCl liquid desiccant solutions. The results showed that the regeneration capability of the ED stack decreased with the increase of the circulation flow rate. Regeneration performance in terms of the concentration enrichment increased as the supplied current density increased and the solution initial concentration decreased. It is also shown that the concentration difference between the regenerated and spent solutions is critical for the regeneration performance of ED. The ED stack can continuously increase the concentration of the regenerated solution when the concentration difference between the regenerated and spent solutions is below 5.86% (wt/wt), under the supplied current density of 57.1 mA/cm$^2$, circulation flow rate of 100 L/h, and the initial concentrations of the solutions in the regenerated and spent tanks of 28.77% and 23.96% (wt/wt), respectively. The current efficiency of the ED in two hours running for all experiments was in the range of 55.17–73.54%. The results obtained from this study would be useful for the ED regenerator design and system integration.



## 1. Introduction

Significant energy is consumed for building heating, cooling and dehumidification. Thus, building energy efficiency is essential to reduce global energy usage and greenhouse gas emissions. Over the last several decades, many efforts have been made on the development and application of various sustainable and low energy technologies for promoting building energy efficiency [1–3]. Among different technologies, liquid desiccant dehumidification has gained significant scientific attention due to a high energy saving potential [4–8]. Liquid desiccant technologies have started to find practical applications for cooling and dehumidification [9].

In a liquid desiccant air conditioning (LDAC) system, the regeneration of the liquid desiccant is a key process to maintain the capacity of the liquid desiccant for continuous dehumidification. Different regeneration methods have been studied for LDAC systems, including but not limited to thermal regeneration, ultrasonic regeneration, reverse osmosis regeneration and electrodialysis regeneration [10,11]. Thermal regeneration using solar energy, waste heat and heat pumps has been extensively studied. For instance, Elsarrag [12] examined a solar liquid desiccant regeneration system in terms of the liquid to air flow rate ratio, temperature and concentration of the liquid desiccant, and humidity ratio of the inlet air on the evaporation rate. Niu et al. [13] investigated the possibility to match liquid desiccant and heat pump in hybrid LDAC systems. The results showed that dynamic capacity matching among the dehumidifier, regenerator, evaporator and condenser can be achieved only through regulating the circulation flow rate, revolution of the compressor and air flow rate in the air cooled condenser simultaneously. Yamaguchi et al. [14] presented a hybrid liquid desiccant system, in which the absorber and regenerator were integrated with the evaporator and condenser of the heat pump, respectively. Their system could achieve a higher coefficient of performance by improving the isentropic efficiency of the compressor and the temperature efficiency of the solution heat exchanger. In thermal regeneration, the liquid desiccant is reactivated through a

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**Nomenclature**

| | |
|---|---|
| $a_0$–$a_5$ | coefficients |
| $F$ | Faraday number (96,485 C/mol) |
| $I$ | supplied current (A) |
| $M$ | molar mass (g/mol) |
| $m$ | mass (kg) |
| $N$ | number of membrane pairs |
| $n$ | number of independent measured variables |
| $t$ | temperature (°C) |
| $V$ | volume (L) |
| $x$ | independent measured variable |
| $y$ | calculated variable |
| $z$ | charge of ions |
| *Greek symbols* | |
| $\eta$ | current efficiency (%) |
| $\xi$ | concentration [% (wt/wt)] |
| $\rho$ | density (g/cm$^3$) |
| *Superscript* | |
| $k$ | time (s) |
| 0 | initial condition |
| *Subscript* | |
| $r$ | regenerated |
| $s$ | salt |

process in which the moisture is transferred to the scavenging air through heating the solution to a high temperature (e.g. 65 °C or higher). The desiccant must then be cooled down before entering the dehumidifier to achieve desirable dehumidification performance. Therefore, the efficiency of thermal regeneration is limited.

Yao [15] described the basic idea of a ultrasonic dehydrator for liquid desiccant regeneration. This non-thermal regeneration method can potentially improve the energy efficiency of the liquid desiccant dehumidification system due to the lower regeneration temperature. However, Yao [15] also acknowledged that the ultrasonic regeneration may bring environmental hazard issue and the energy savings due to the use of the ultrasonic regenerator for liquid desiccant were not reported. Al-Sulaiman et al. [16] studied the reverse osmosis (RO) process for regenerating calcium chloride liquid desiccant in a cooling system with two-stage evaporative coolers. It was pointed out that currently available RO membranes are not able to handle the high concentration of calcium chloride required in liquid desiccant applications.

Although the use of electrodialysis (ED) for liquid desiccant regeneration has only been recently explored [17–23], the benefits of integration of ED with LDAC systems have been demonstrated in the literature. ED has been primarily used for desalination, wastewater treatment, and ion separation applications in the chemical, food, and pharmaceutical industries [24–27]. Liquid desiccant regeneration by ED provides an opportunity to allow the system to operate at a low temperature and therefore reduce the need for cooling the desiccant. Using ED as a regeneration method was first proposed by Li and Zhang [17]. Through theoretical analysis, it was concluded that ED operation is more stable as the weather condition has limited impacts on the performance of the ED stack, as compared to thermal regeneration [28]. Single stage and double stage photovoltaics and ED driven regeneration for LDAC systems were proposed and the performance of the systems was evaluated through theoretical analysis [19,20]. It was concluded that the double-stage regeneration system can save more energy under the optimised working conditions than that of the single stage regeneration system. In order to improve the reliability and the performance of ED for liquid desiccant regeneration, a desiccant pre-treatment ED regeneration system was proposed in [18]. It was shown that this new system was more energy efficient than the photovoltaics and ED driven regeneration system. Cheng et al. [21] experimentally examined the effect of the flow rates of the regenerated and spent desiccant solutions on the current utilisation and mass transfer rate of the ED regenerator. However, the effects of other key operating parameters such as supplied current and solution initial concentrations on the ED regeneration performance have not been evaluated. Li et al. [29] investigated the salt mass transfer of ED for liquid desiccant regeneration and it was found that the current intensity is the key factor influencing the ED regeneration performance.

Literature data to date showed that ED is a promising technology for liquid desiccant regeneration in LDAC systems. Nevertheless, previous ED investigations for other applications (e.g. desalination and wastewater treatment) indicated that ED performance can be influenced by many parameters, such as the construction of the ED stack, the characteristics of the membranes used, the concentrations of the feed and product solutions, solution flow rate, and current density or electric potential [30–32]. As the concentration of liquid desiccants used in LDAC systems is much higher than that of the solutions used in other fields such as water desalination, the behaviour of ED working with liquid desiccants is expected to differ from that in other fields. Thus, it is essential to substantiate the effects of the above mentioned parameters on ED performance specific for liquid desiccant regeneration.

This study aims to elucidate the effects of the operating conditions including the circulation flow rate, supplied current density, initial concentrations of the regenerated and spent solutions, and the concentration difference between the regenerated and spent solutions on the performance of the ED for regeneration of liquid desiccant solutions. As LiCl is one of the widely used liquid desiccants and has a low equilibrium humidity ratio under wide operating conditions [33], LiCl is considered as the working solution in this study.

## 2. ED working principle, experimental setup and experimental protocol

### 2.1. Working principle of electrodialysis

ED is a separation process used to transport cations and anions through cation and anion exchange membranes respectively, under the influence of a supplied electric field [34,35]. In an ED stack, a set of cation and anion exchange membranes are arranged alternately between the anode and the cathode. An example of the ED stack with two cell pairs is illustrated in Fig. 1. When the solution (i.e. liquid desiccant) is fed into the main cells of the ED stack, due to different permeability of cation and anion exchange membranes, the cations ($Li^+$) can only pass through the cation exchange membranes and the anions ($Cl^-$) can only pass through the anion exchange membranes. As a consequence, the concentration of the liquid desiccant in some cell spaces will increase, while the concentration of the liquid desiccant in the adjacent cell spaces will decrease due to the ions movement. The concentrated liquid desiccant can then be used for dehumidification. In this process, the electrical rinsing solution (i.e. $Li_2SO_4$ used in this study) is used to support the electrical conductivity in the two electrode cells.

In the ED regeneration process, osmosis appears if there is a difference between the concentrations of the spent and regenerated solutions, which can lead to the water transfer from the spent to the regenerated solutions. In the meanwhile, the salt diffuses from the regenerated to the spent solutions due to the concentration