Advancement on mass transfer empirical models of electrodialysis regeneration for the liquid desiccant

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Abstract

Liquid desiccant dehumidification has a large energy-saving potential in severe humid area. Electrodialysis regeneration is a novel and reliable liquid desiccant regeneration method, which can use the solar energy through photovoltaic panels and avoid desiccant droplets carried by supplied air from the environment during the regeneration. The current utilization coefficient and concentration increment are important performance evaluation indexes to reflect the mass transfer characteristic of the electrodialysis regenerator, which are influenced by the liquid desiccant flow rate seriously. This paper aims to acquire the current utilization coefficient and the concentration increment models considering the liquid desiccant flow rate. The results show that the current utilization coefficient increases with increasing the desiccant flow rate within the desiccant concentration of 30 and 34%, while the increase of desiccant flow rate negatively affects the current utilization coefficient within the desiccant concentration of 38%. The current utilization coefficients are among 30 and 90% under experimental conditions. The concentration increment which is among 0.06 and 0.33% increases with increasing the operating current and decreases with increasing the liquid desiccant flow rate addition. The whole system coefficient of performance increases from 2.4 to 3.6 when the desiccant solution flow rate varies from 80 to 160 L·h⁻¹.

Keywords: Liquid desiccant; Regeneration; Electrodialysis; Current utilization coefficient; Concentration increment.

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1. Introduction

The comfortable and excellent air quality of indoor environment in buildings has become the important requirement nowadays. In buildings, the air-conditioning costs the large proportion of the total energy resources.^[1] At present, the vapor compression air-conditioning system is used to control the temperature and humidity of building indoor air, which decreases the air temperature for the air dehumidification and then reheats the air to meet the temperature requirement,^[2,3] resulting in the large consumption of fossil fuel and serious greenhouse gas emission.

The liquid desiccant air conditioning (LDAC) system can directly dehumidify indoor air as the desiccant solution can absorb vapor in air under the vapor pressure difference,^[4-6] which has a large energy-saving potential in severe humid area. In the LDAC system, the liquid desiccant regeneration device attributes to the main system energy consumption to

maintain the capacity for continuous dehumidification. Currently, there are different liquid desiccant regeneration ways in consideration.^[7-8] The conventional thermal regeneration includes condensing energy, solar energy and other thermal energy, among which the most popular one is the solar energy.^[9] However, the solar thermal energy depends on the weather, which may not meet the dehumidification demand continuously, especially with high air temperature or rainy day.^[10] On the other hand, the traditional thermal regeneration process needs liquid desiccant to contact outside environment air directly to acquire the high regeneration efficiency, while the desiccant droplets carried problem is difficult to be solved, which will affect room air quality and human healthy.^[11]

Electrodialysis (ED) had been used for sea water desalination, wastewater treatment, and ion separation applications, which can be driven by the solar energy through photovoltaic panels.^[12-14] The ED regenerator encourages the anions and cations transport toward opposite directions and pass through different selective membranes to achieve the concentration of desiccant solution increase in concentrate cells under the electrical field.^[15] ED regeneration is

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developed to regenerate liquid desiccant with solar energy under the hot and humid climate. When the environment air is hot and humid, liquid desiccant with high concentration is difficult to be regenerated with the conventional solar thermal regeneration method. In contrast, ED regeneration can acquire the strong liquid desiccant required in the dehumidifier even under the hot and humid climate, as this regeneration method does not need environment air. Then the weak liquid desiccant of the ED regenerator can be very easy to be regenerated by the conventional solar thermal regeneration method. Meanwhile, the problem of desiccant droplets corrosion can be avoided in the ED regenerator. Moreover, the ED regenerator can be operated with the relatively constant temperature, by this way the negative effect on the dehumidification process caused by the liquid desiccant temperature increment is eliminated.^[16]

For the LDAC system, several researches had been conducted on ED regeneration. The solar ED regeneration method for liquid desiccant was firstly put forward by Li and Zhang.^[17,18] Through the theoretical research, it was confirmed that solar ED regeneration has higher efficiency in comparison with the conventional thermal regeneration. Then ED regeneration driven by solar energy (photovoltaic) was gradually improved through several researches.^[19-21] Cheng et al.^[22] experimentally investigate the influence of concentration difference between dilute and concentrate desiccant solutions about the performance of ED regenerator, and the result shows that the concentration difference improvement has negative effect on the system performance. Han Wang et al.^[23] conducted the study on the electrical conductivity of LiCl solution with different concentrations and temperatures and obtained the accurate electrical conductivity model of LiCl solution.

The current utilization coefficient is important for the performance evaluation on the LDAC system based on ED regeneration, and it is also one of the important performance evaluation indexes to reflect the mass transfer characteristic of the ED regenerator.^[11,10,22-25] A simple current utilization coefficient model for LiCl solution was established by Cheng,^[11] which ignores the effect of liquid desiccant flow rate. As a result, the present current utilization coefficient model is not accurate enough to meet the demand of variable operational conditions as the variation of desiccant solution flow rate will change the flow state, thus affecting the mass transfer efficiency during the regeneration process. On the other hand, the concentration increment is also an important parameter, which had not been researched for the LDAC system models when LiCl solution is applied.

The novelty of this paper is:

- Develop the current utilization coefficient and the concentration increment empirical models of the ED regenerator considering liquid desiccant flow rate, which is beneficial to the application of ED regeneration in severe humid areas.
- Investigate the influence of liquid desiccant flow rate on the regeneration characteristic of the ED regenerator and the

LDAC system performance in depth, which is beneficial for the optimization design of electro dialysis regenerator in severe humid area.

2. Method

2.1 Experimental preparation

2.1.1 System and material

The ED experimental system in this work is displayed in Fig. 1 and Fig. 2(a). It shows that the system consists of three desiccant loops, including regenerate desiccant solution loop, dilute desiccant solution loop and electrode solution loop. In the experimental period, liquid desiccant solutions were pumped into different cells of the ED regenerator through three magnetic pumps, and the circulation flow rates in different loops were controlled by globe valves installed before flow meters.

Fig. 1 The principle of the experimental system.

In this experimental system, the core device is the ED regenerator (shown in Fig. 2(b)), which is supplied by Zhejiang Yi Di Co., Ltd (SAAS-S, 200×400 mm, 30 cell pairs). Membranes in the experimental system are AMV and CMV from Asahi Nitrate in Japan, whose characteristic is shown in Table 1. The electrode in the experimental system is coated with Titanium-Ruthenium.

Table 1. Membrane characteristics.

Membrane	Thickness (μm)	Resistance ($\Omega \cdot \text{cm}^2$)	Transport number
CMV	130	3	>0.96
AMV	130	2.8	>0.96

The liquid desiccant in this experiment is LiCl solution from the Nanjing Jin Liu Hua Glass Instruments Co., Ltd.

2.1.2 Measuring instruments

In this experiment, the liquid desiccant temperature is measured with T-type thermocouple and recorded by the data

collection equipment (Agilent 34970A). The mass concentration of the liquid desiccant is achieved through the density and temperature data.^[26] The real-time current and voltage can be acquired from the rectifier. The main instruments and their accuracies are summarized in Table 2.

Table 2. Instruments.

Name	Mode	Measurement range	Accuracy
Rectifier	HCP-DC	0-20A	±0.01A
Density meter	AU-120L	0.0001-99.9999g·cm ⁻³	0.0001g·cm ⁻³
Thermocouple	TC-TT-5M	-200-350°C	± 0.5°C
Flow meter	LFS15	16-160L·h ⁻¹	±5 L·h ⁻¹

2.1.3 Protocol

In the experiment, 27 experimental conditions were conducted to research the current utilization coefficient and the concentration increment of the ED regeneration for LiCl solution. Three initial mass concentrations (30, 34 and 38%) of the liquid desiccant and three operating current (3, 5, and 8 A) were conducted. Meanwhile, three flow rates (80, 120 and 160 L·h⁻¹) of the liquid desiccant were conducted in the experiment. During the experimental period, the liquid desiccant was sampled with intervals of six minutes from regenerate and dilute desiccant loops respectively for measuring their densities and temperatures.

(a) The experimental system and (b) ED regenerator
Fig. 2 Devices in the experiment.

2.2. Analytical methods

The current utilization coefficient is the key performance evaluation index of the ED regenerator,^[17, 27] which can be indicated as:

$$\eta_{ED} = \frac{zFm_{reg,ED} (C_{reg,o} - C_{reg,i})}{INM_d} \quad (1)$$

The concentration increment of regenerate desiccant solution during the regeneration process of the ED regenerator can be acquired from:

$$\Delta C = C_{reg,o} - C_{reg,i} \quad (2)$$

So the exiting concentration of the regenerate desiccant solution of the ED regenerator is:

$$C_{reg,o} = C_{reg,i} + \Delta C \quad (3)$$

The main energy consumption of the whole system can be expressed as Equation (4):^[11]

$$P = \left[\frac{zFm_{reg,ED} (C_{reg,o} - C_{reg,i})}{\eta_{ED} NM_d} \right]^2 N \left(R_{cm} + R_{am} + \frac{L}{\rho_{reg} A} + \frac{L}{\rho_{diu} A} \right) \quad (4)$$

The LiCl electrical conductivity can be acquired from Equation (5):^[23]

$$\begin{aligned} \rho = & 160.5 + 3.058 \times \frac{T - 38.59}{12.75} - 28.96 \times \frac{C - 29.51}{6.534} + 0.9381 \times \left(\frac{T - 38.59}{12.75} \right)^2 \\ & + 1.906 \times \frac{T - 38.59}{12.75} \times \frac{C - 29.51}{6.534} - 6.32 \times \left(\frac{C - 29.51}{6.534} \right)^2 - 0.3259 \times \left(\frac{T - 38.59}{12.75} \right)^3 \\ & - 0.2426 \times \left(\frac{T - 38.59}{12.75} \right)^2 \times \frac{C - 29.51}{6.534} + 0.3203 \times \frac{T - 38.59}{12.75} \times \left(\frac{C - 29.51}{6.534} \right)^2 \\ & + 2.091 \times \left(\frac{C - 29.51}{6.534} \right)^3 \end{aligned} \quad (5)$$

The system refrigerating capacity can be achieved from the water vaporization heat during the dehumidification process:^[18,28]

$$Q_o = r_w \Delta m_w \quad (6)$$

The moisture removal rate in the dehumidification process for the LiCl solution can be acquired from Equation (7):^[29]

$$\Delta m_w = 9.4542 \times 10^8 \times m_a^{0.406} \omega_a^{2.2478} m_{reg}^{0.6499} t_{reg}^{-2.3911} C_{reg}^{1.7919} \quad (7)$$

Based on Equations (6) and (7):

$$Q_o = 9.4542 \times 10^8 \times m_a^{0.406} \omega_a^{2.2478} m_{reg}^{0.6499} t_{reg}^{-2.3911} C_{reg}^{1.7919} r_w \quad (8)$$

As a consequence, the system performance coefficient can be given by combing Equations (4) and (8):

$$COP = \frac{9.4542 \times 10^8 \times m_a^{0.406} \omega_a^{2.2478} m_{reg}^{0.6499} t_{reg}^{-2.3911} C_{reg}^{1.7919} r_w}{\left[\frac{zFm_{reg,ED} (C_{reg,o} - C_{reg,i})}{\eta_{ED} NM_d} \right]^2 N \left(R_{cm} + R_{am} + \frac{L}{\rho_{reg} A} + \frac{L}{\rho_{diu} A} \right)} \quad (9)$$

The dehumidification efficiency and the income-cost coefficient can be achieved from:

$$\eta_{de} = \frac{\Delta m_w}{P} = \frac{9.4542 \times 10^8 \times m_a^{0.406} \omega_a^{2.2478} m_{reg}^{0.6499} t_{reg}^{-2.3911} C_{reg}^{1.7919}}{\left[\frac{zFm_{reg,ED} (C_{reg,o} - C_{reg,i})}{\eta_{ED} NM_d} \right]^2 N \left(R_{cm} + R_{am} + \frac{L}{\rho_{reg} A} + \frac{L}{\rho_{diu} A} \right)} \quad (10)$$

$$ICC = \frac{\Delta p}{P} = \frac{p_{air} - p}{\left[\frac{zFm_{reg,ED} (C_{reg,o} - C_{reg,i})}{\eta_{ED} NM_d} \right]^2 N \left(R_{cm} + R_{am} + \frac{L}{\rho_{reg} A} + \frac{L}{\rho_{diu} A} \right)} \quad (11)$$

(a) Initial concentration of 30%

(b) Initial concentration of 34%

(c). Initial concentration of 38%

Fig. 3 The average system current utilization coefficients with three initial concentrations

3. Experimental result and characteristic model

3.1 The current utilization coefficient correlation

In the experiment analysis process, the average values of the calculated current utilization coefficients are obtained to appraise the ED regenerator performance under specific operating conditions, which are shown in Fig. 3. In Fig. 3, the x-axis and y-axis represent operating current and desiccant flow rate respectively

Fig. 3(a) shows that with the initial LiCl solution concentration of 30%, the average current utilization coefficients under different operating conditions in the experiment are among 33.8 and 65.4%. It is shown that the average current utilization coefficient decreases with the operating current addition while increases with increasing the LiCl solution flow rate. The maximum average system current utilization coefficient is 65.4% with the operating current of 3 A and the LiCl solution flow rate of 160 L·h⁻¹. The minimum average system current utilization coefficient is 33.8% with the operational current of 8 A and the LiCl solution flow rate of 80 L·h⁻¹.

Fig. 3(b) shows that when the initial LiCl solution concentration is 34%, the average current utilization coefficients of all conditions in the experiment are among 44.9 and 65.9%, and its variation trend is the same with that when the initial LiCl solution concentration is 30%. The average system current utilization coefficient decreases with the operating current addition and increases with the LiCl solution flow rate improvement.

Fig. 3(c) shows that with the initial LiCl solution concentration of 38%, the average system current utilization coefficients of different operational conditions in the experiment are among 50.2 and 90.2%. Different with the variation trend when desiccant mass concentrations are 30 and 34%, the average system current utilization coefficient with the initial desiccant concentration of 38% decreases with the operating current addition and slightly decreases with the LiCl solution flow rate improvement. The maximum average system current utilization coefficient is 90.2% with the operating current of 3 A and the LiCl solution flow rate of 80 L·h⁻¹. The minimum average system current utilization coefficient is 50.2% with the operating current of 8 A and the LiCl solution flow rate of 160 L·h⁻¹.

According to Levenberg–Marquardt algorithm method, the poly 2D function is used in nonlinear curve fitting. The current utilization coefficient correlation model with the initial LiCl solution concentration of 30% is:

$$\eta_{ED} = 65.1057 - 5.86372 \times I + 0.0477 \times Q_v + 0.05737 \times I^2 + 2.69958 \times 10^{-4} \times Q_v^2 + 0.00935 \times IQ_v \quad (12)$$

The current utilization coefficient correlation model with the initial LiCl solution concentration of 34% is:

$$\eta_{ED} = 15.27173 - 0.97707 \times I + 0.73601 \times Q_v - 0.18756 \times I^2 - 0.00274 \times Q_v^2 + 0.01409 \times IQ_v \quad (13)$$

And the current utilization coefficient correlation model with the initial LiCl solution concentration of 38% is:

$$\eta_{ED} = 180.73326 - 24.79161 \times I - 0.58905 \times Q_v + 1.68421 \times I^2 + 1.79968 \times Q_v^2 + 0.05169 \times IQ_v \quad (14)$$

As a consequence, the current utilization coefficient at the same position in the three models is correlated and then substituted into the poly 2D function to acquire the integral model of the system current utilization coefficient:

$$\begin{aligned} \eta_{ED} = & 7301.4789 - 443.05362 \times C_{reg,i} + 6.72804 \times C_{reg,i}^2 - 957.36403 \times I \\ & + 58.62404 \times C_{reg,i} I - 0.89691 \times C_{reg,i}^2 I - 69.29079 \times Q_v \\ & + 4.19882 \times C_{reg,i} Q_v - 0.06292 \times C_{reg,i}^2 Q_v + 69.36416 \times I^2 \\ & - 4.29463 \times C_{reg,i} I^2 + 0.06615 \times C_{reg,i}^2 I^2 + 0.21186 \times Q_v^2 \\ & - 0.01261 \times C_{reg,i} Q_v^2 + 1.85309 \times 10^{-4} \times C_{reg,i}^2 Q_v^2 \\ & + 1.02121 \times IQ_v - 0.06454 \times C_{reg,i} IQ_v + 0.00103 \times C_{reg,i}^2 IQ_v \end{aligned} \quad (15)$$

Fig. 4 Comparison of the predicted system current utilization coefficient and experimental results.

The adjusted R-Square of the system current utilization coefficient correlation model is 80.741%. Fig. 4 shows the comparison of fitted system current utilization coefficients and experimental results. It can be concluded that the average absolute difference of current utilization coefficient experimental and predicted values is below $\pm 10\%$, which shows the accuracy of this current utilization coefficient model. As this current utilization coefficient model is based on experimental results, the using scope of this model is the concentration range of 30-38%, the mass flow rate range of 80-160 L/h and the current range of 3-8 A.

3.2 The concentration increment correlation

In this experiment, the concentration of exiting regenerated desiccant is calculated with Equation (3) based on the experimental data, meanwhile, average values of the calculated exiting regenerate desiccant concentration are obtained and shown in Fig. 5. Fig. 5 shows the average

concentration increment of regenerate desiccant in the experiment. Average concentration increments under all operating conditions in the experiment are among 0.06 and 0.33%. It is shown that the average concentration increment of regenerate desiccant solution increases with the operating current addition and decreases with the LiCl solution flow rate improvement. On the other hand, the average concentration increment of regenerate desiccant solution decreases with the LiCl solution initial concentration improvement. The maximum average concentration increment is 0.33% with the operating current of 8 A and the LiCl solution flow rate of 80 L·h⁻¹. The minimum average concentration increment is 0.06% as the operating current is 3 A and the LiCl solution flow rate of 160 L·h⁻¹.

Fig. 5 The average concentration increment in the experiment.

Fig. 6 Comparison of the predicted concentration increment and experimental results.

According to the Levenberg–Marquardt algorithm method, the concentration increment of regenerate desiccant solution model can be expressed as:

$$\Delta C = 1.028913 \times 10^6 \times C_{\text{reg},i}^{-3.45874} \cdot I^{0.59592} \cdot Q_v^{-1.01617} \quad (16)$$

Then the concentration of exiting regenerate desiccant can be obtained with Equation (3). As this model is based on experimental results, the using scope of this model is the concentration range of 30-38%, the mass flow rate range of 80-160 L/h and the current range of 3-8 A.

The adjusted R-Square of this average concentration increment of regenerate desiccant solution correlation model is 87.66%. Fig. 6 shows the comparison of the predicted concentration increment and experimental results. It can be concluded that average absolute difference among experimental concentration increments of regenerate desiccant solution and predicted values is also below $\pm 10\%$.

4. The regeneration characteristic and system performance evaluation

In this simulation section, whole system consumption, whole system *COP*, income-cost coefficient and system dehumidification efficiency are evaluated with Equations (4) and (9-11). In this simulation part, the ED experimental regenerator shown in this paper and the specific dehumidifier presented in the reference^[29] are conducted. However, just one ED experimental regenerator shown in this paper is not enough to satisfy the demand of dehumidifier presented in the reference [29]. Thus several same ED regenerators shown in this paper are conducted to provide strong Li Cl solution for the specific dehumidifier presented in the reference [29]. The simulation settings are listed in Table 3.

Table 3. General parameters.

Parameter	value	specification
Z	1	LiCl
$F(\text{C} \cdot \text{mol}^{-1})$	96485	
$M_d(\text{g} \cdot \text{mol}^{-1})$	42.5	LiCl
$L(\text{mm})$	1	experimental system
$A(\text{m}^2)$	0.048	experimental system
N	30	experimental system
$r_w(\text{kJ} \cdot \text{kg}^{-1})$	2257.2	
$m_a(\text{kg} \cdot \text{s}^{-1})$	0.3	[29]
$\omega_a(\text{g} \cdot \text{kg}^{-1})$	16.5	[29]
$m_{\text{reg}}(\text{kg} \cdot \text{s}^{-1})$	0.4	[29]
$t_{\text{reg}}(^{\circ}\text{C})$	30	experimental system

The system current utilization coefficient and the concentration increment of regenerate desiccant solution models are simulated with variable parameters shown in Table 4.

Table 4. Variable parameters.

Simulation	1	2	3
$C_{\text{reg},i}(\%)$	34	34	30-38
$I(\text{A})$	5	3-8	5
$Q_v(\text{L} \cdot \text{h}^{-1})$	80-160	120	120

4.1 The regeneration characteristic

Fig. 7 shows the influence of the LiCl solution flow rate on the current utilization coefficient and the concentration increment of regenerate desiccant solution. It shows that with the LiCl solution flow rate improvement, the system current utilization coefficient increases and the concentration increment of regenerate desiccant solution decreases. The current utilization coefficient varies from 52 to 64% and the concentration increment varies from 0.16 to 0.08% as LiCl solution flow rate increases from 80 to 160 L·h⁻¹.

Fig. 7 Effect of LiCl flow rate on current utilization coefficient and concentration increment.

Fig. 8 Effect of operating current on current utilization coefficient and concentration increment.

The influence of operating current on the system current utilization coefficient and the concentration increment of regenerate desiccant solution is shown in Fig. 8. It can be concluded that with the operating current improvement, the current utilization coefficient decreases while the concentration increment of regenerate desiccant solution increases. It shows that the system current utilization coefficient varies from 64 to 57% and the concentration increment of regenerate desiccant solution varies from 0.08 to 0.14% when the operating current increases from 3 to 8 A.

Fig. 9 Effect of initial concentration on current utilization coefficient and concentration increment.

Fig. 9 shows the effect of initial LiCl solution concentration on the current utilization coefficient and the concentration increment of regenerate desiccant solution. It shows that with the initial LiCl solution concentration improvement, the current utilization coefficient increases while the concentration increment decreases. The system current utilization coefficient varies among 52 and 68% and the concentration increment of regenerate desiccant solution varies among 0.16 and 0.07% when the initial concentration of the regenerate and dilute LiCl solutions increases from 30 to 38%.

4.2 System performance evaluation

The influence of LiCl solution flow rate on the system performance is analyzed with simulation 1 in the Table 4. Fig. 10(a) shows the effect of LiCl solution flow rate on the electrical energy cost and the COP of the whole system, and its influence on income-cost coefficient and dehumidification efficiency is displayed in Fig. 10(b).

Fig. 10(a) shows that with the LiCl solution flow rate improvement, the electrical energy cost of ED regenerator decreases and the system COP increases. The system electrical energy consumption varies from 1030 to 655 W and the system COP varies from 2.9 to 4.6 when the LiCl solution flow rate increases from 80 to 160 L·h⁻¹. The LiCl solution flow rate improvement will be beneficial to the current utilization coefficient because the large LiCl solution flow rate may destroy the ion diffusion boundary layers and accelerate the mass transfer. Although the electrical energy consumption of the single ED regenerator increases slightly with the LiCl solution flow rate improvement, there will be fewer number of ED regenerator operating simultaneously needed to meet the dehumidifier demand. Thus, the LiCl solution flow rate improvement will lead to the whole system electrical energy consumption reduction and increase the whole system COP.

It can be concluded from Fig. 10(b) that the income-cost coefficient and the dehumidification efficiency increase with

the LiCl solution flow rate improvement. The income-cost coefficient varies from 2.4 to 3.7 Pa·W⁻¹ and the system dehumidification efficiency varies from 4.7 to 7.3 kg·kWh⁻¹ when the LiCl solution flow rate increases from 80 to 160 L·h⁻¹.

In conclusion, with the LiCl solution flow rate improvement, the system dehumidification capacity will increase while the system energy consumption will decrease. As a consequence, the LiCl solution flow rate improvement is beneficial to the whole system performance.

(a) Energy consumption and COP

(b) Dehumidification performance

Fig. 10 Effect of LiCl solution flow rate on system performance.

4.3 Discussion

The results show that the current utilization coefficient increases with increasing the desiccant flow rate within the desiccant concentration of 30 and 34%, while the increase of desiccant flow rate negatively affects the current utilization coefficient within the desiccant concentration of 38%. This is an interesting phenomenon and it may be because of the high viscosity characteristic of LiCl solution with the

concentration of 38%, which should be further theoretically researched in the future work to explore the mass transfer characteristic of liquid desiccant with the extra high concentration in ED regeneration. Meanwhile, liquid desiccant nature modification should also be researched to reduce the effect of the high viscosity characteristic.

The result shows that the increase of LiCl solution flow rate will increase the performance coefficient of the liquid desiccant air-conditioning system based on ED regeneration, which will also decrease the energy consumption of the liquid desiccant air-conditioning system, so it's necessary to increase the liquid desiccant flow rate to improve the system performance. However, the increase of LiCl solution flow rate will decrease the concentration increment of the ED regenerator, so it's necessary to increase the cell pairs of the ED regenerator to meet the concentration requirement of dehumidification part. In the analysis of system energy cost, although the LiCl solution flow rate improvement will increase the electrical energy cost of single ED regenerator slightly, the ED regenerator number needed to meet the dehumidifier requirement will be reduced. Thus, the LiCl solution flow rate improvement is beneficial to energy consumption and COP. As a result, the LiCl solution flow rate should be designed to be maximized when the regenerated liquid desiccant can meet the dehumidification requirement. On the other hand, the electrical energy cost of solution pumps will increase with the LiCl solution flow rate improvement, which is ignored in this paper, so it's essential to advance the system model integrated with the pump energy cost based on the desiccant solution flow rate consideration in the future work. Besides, the liquid desiccant flow state in the compartment will be changed from laminar flow to turbulent flow and the pressure will be increased due to desiccant flow rate improvement, which will affect the mass transfer process.

5. Conclusion

Average current utilization coefficients are among 30 and 90% in this experiment. The current utilization coefficient increases with the LiCl solution flow rate improvement while decreases with the current addition with the initial LiCl solution concentration of 30 and 34%, while the LiCl solution flow rate improvement will decrease the current utilization coefficient with the initial concentration of 38%. Average concentration increments of regenerate desiccant solution are among 0.06 and 0.33% in the experiment. It is shown that the average concentration increment of regenerate desiccant solution increases with the operating current improvement and decreases with the LiCl solution flow rate improvement. On the other hand, the average concentration increment of regenerate desiccant solution of ED regenerator decreases with the initial LiCl solution concentration improvement.

In the simulation, the whole system COP varies among 2.4 and 3.6 with the LiCl solution flow rate varying from 80

to 160 L·h⁻¹. The liquid desiccant flow rate improvement is beneficial to the energy consumption and COP, so it should be designed to be maximized when the regenerated liquid desiccant solution can meet the dehumidification requirement.

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Support information

Not applicable

Conflict of Interest

There are no conflicts to declare.

Nomenclature

A	effective area of membrane (m ²)
C	concentration (%)
COP	coefficient of performance
F	Faraday number (96485 C·mol ⁻¹)
I	supplied current (A)
ICC	income-cost coefficient (Pa·W ⁻¹)
L	cell thickness (mm)
m_a	mass flow rate of air (kg·s ⁻¹)
m_{reg}	required mass flow rate of strong desiccant (kg·s ⁻¹)
$m_{reg,ED}$	mass flow rate of regenerate desiccant (kg·s ⁻¹)
M_d	molecular weight (g·mol ⁻¹)
N	number of membrane pairs
P	vapor pressure of liquid desiccant (Pa)
p_{air}	air vapor pressure (Pa)
P	energy consumption of ED regenerator (W)
Q_0	refrigerating capacity (J)
Q_v	volume flow rate of liquid desiccant (L·h ⁻¹)
r_w	latent heat of water vaporization (kJ·kg ⁻¹)
R	ED regenerator resistance (Ω)
t_{reg}	temperature of regenerate desiccant (°C)
T	temperature of LiCl aqueous solution (°C)
z	valence
Δm_w	moisture transfer in the dehumidifier (g·s ⁻¹)
η_{de}	system dehumidification efficiency (kg·kWh ⁻¹)
η_{ED}	current utilization coefficient (%)
P	electrical conductivity (mS·cm ⁻¹)
ω_a	the humidity ratio of air (kg·kg ⁻¹)
Subscripts	
Am	anion-exchange membrane
Cm	cation-exchange membrane

Diu	dilute desiccant
Reg	regenerate desiccant
reg,i	entering regenerate desiccant
reg,o	exiting regenerate desiccant

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