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Experimental and theoretical research on the electrical conductivity of a liquid desiccant for the liquid desiccant air-conditioning system: LiCl aqueous solution

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ABSTRACT

At present, the energy consumption in buildings occupies a large proportion of total energy use, and air-conditionings cost a large proportion of energy in the buildings. The liquid desiccant air-conditioning system has a good energy saving potential and the electrodialysis (ED) regeneration is a reliable choice for the liquid desiccant regeneration. In order to establish the energy consumption model and the performance coefficient model of liquid desiccant air-conditioning system based on ED regeneration using LiCl, experimental and theoretical research on the electrical conductivity of LiCl aqueous solution with a lot of concentrations and temperatures was conducted in this paper. The results show that when polynomial degrees of the mass concentration and the temperature of the LiCl aqueous solution are both 3, the electrical conductivity model for the LiCl aqueous solution is most suitable as its simplicity and high accuracy. Moreover, when the concentration is 36% and the temperature is 22 °C, the liquid desiccant cooling system has the maximum COP of about 5. Finally, a case study of a small office room was conducted, and the result shows that the liquid desiccant cooling system based on electrodialysis regeneration has a good energy-saving potential.

Étude expérimentale et théorique de la conductivité électrique d'un déshydratant liquide pour les systèmes de conditionnement d'air à déshydratant liquide : Solution aqueuse de LiCl

Mots-clés: Déshydratant liquide; Régénération électrodialytique; Solution aqueuse de LiCl; Conductivité électrique; Modèle de performance

1. Introduction

At present, the energy consumption in buildings occupies a large proportion of the total energy use (U.S. Energy Information Administration, 2010). Air-conditionings cost a large proportion of energy in the buildings, especially when the outside air is quite wet. At present, the vapor compression cooling system is widely used for the cooling and dehumidification demand of the buildings, which needs to cool the air below its dew point for dehumidification demand and causes energy waste as the air needs to be reheated to meet the temperature demand (Yang et al., 2016a, 2016b).

The liquid desiccant air-conditioning system does not need to reheat the air after the dehumidification process, which has a good energy saving potential (Ahmed et al., 2017; McNevin and Harrison, 2017; Zhang et al., 2017). As the key component, the heat and mass transfer characteristic of the dehumidifier will highly affect the performance of the liquid desiccant air-conditioning system. The internally-cooled liquid desiccant dehumidifier was developed

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Nomenclature

A	effective membrane area (m^2)
C	concentration (%)
C_{add}	the concentration increase (%)
COP	performance coefficient
COP_{vc}	performance coefficient of the vapor compression cooling system
F	Faraday constant (C/mol)
h_d	specific enthalpy of the air after dehumidification process (kJ/kg)
h_i	specific enthalpy of the required indoor air (kJ/kg)
h_o	specific enthalpy of the outdoor air (kJ/kg)
I	current of the ED regenerator (A)
L	thickness of one cell (mm)
m_a	mass flow of air (kg/s)
m_{reg}	flow rate of the regenerate desiccant (kg/s)
$m_{reg,ED}$	the flow rate of in the regenerate cells of one ED regenerator (kg/s)
M_d	molecular weight (g/mol)
N	number of cell pairs
P_{EDR}	energy consumption of the ED regenerator (W)
P_{vc}	energy consumption of the vapor compression cooling system (W)
$Q_{cooling}$	energy consumption for cooling the air (W)
Q_{rc}	refrigerating capacity (J)
Q_{reheat}	energy consumption for the air reheat (W)
r_w	latent heat of water vaporization (kJ/kg)
R	resistance (Ω)
t_{reg}	the temperature of the regenerate desiccant (°C)
T	the temperature of the LiCl aqueous solution (°C)
U	voltage of the ED regenerator (V)
z	valence
$\triangle m_w$	moisture transfer in dehumidifier (g/s)
ζ	current efficiency (%)
ρ	electrical conductivity (mS/cm)
ω_a	the humidity ratio of air (kg/kg)

Subscripts

am	anion-exchange membrane
blank	electrode compartments
cell	one cell pair
cells	cell pairs
cm	cation-exchange membrane
diu	a dilute cell
desiccant	the liquid desiccant in one cell of the ED regenerator
EDR	the ED regenerator
reg	a regenerate cell
reg,i	desiccant at the entrance of regenerate cells
reg,o	desiccant at the exit of regenerate cells

to improve the dehumidification performance and can help the liquid desiccant to keep the low temperature (Zhang et al., 2013; Luo et al., 2014, 2017). Luo et al. (2017) established a model for an internally-cooled dehumidifier with CFD technology, the study demonstrated the necessity of considering the variable properties of desiccant solution during the simulation.

The energy consumption of the liquid desiccant air-conditioning system mainly relies on the regeneration process of the desiccant solution. Qi et al. (2014) conducted the simulation of the solar-assisted LDAC (SLDAC) in commercial buildings in five cities of four main climate regions, results showed that the system's performance was seriously affected by the ratios of building's sensible and latent cooling load. Bouzenada et al. (2016) studied the effects of location and solar thermal collector design on the performance of a liquid desiccant air conditioner (LDAC). The results indicated that the overall average COP for the LDAC unit was measured at 0.44. She et al. (2014, 2015) proposed a new energy-efficient refrigeration system subcooled by the liquid desiccant dehumidification and evaporation, results showed that a significantly higher COP was achieved. However, the liquid desiccant thermal regeneration needs to cool the liquid desiccant before entering the dehumidifier, which leads to the energy waste and the more complicated system.

Besides thermal regeneration, electrodialysis (ED) regeneration (Onorato et al., 2017; Chehayeb et al., 2017; Ali et al., 2018) is also a reliable choice for the liquid desiccant regeneration. Li and Zhang (2009,2012) and Li et al. (2011) developed a photovoltaic-electrodialysis (PV-ED) regeneration system which designed an ED stack as the regenerator. Moreover, there are many experimental and theoretical researches on the ED regeneration systems (Cheng et al., 2013, 2017a, 2017b; Qing and Wenhao, 2017; Guo et al., 2016; Al-Jubainawi et al., 2017). Cheng et al. (2017a, 2017b) experimentally studied the performance of an ED regenerator with 25 cells and the result shows that the low temperature is very important for liquid desiccant to have high dehumidification capacity, and the liquid desiccant will have little temperature increase during the regeneration process when 5A of current is applied in ED regeneration. Guo et al. (2016) and Al-Jubainawi et al. (2017) conducted experiments using an ED system with ten cell pairs of ion-exchange membranes and performed numerical simulation with COMSOL Multiphysics.

The present theoretical research on the ED regeneration is mainly focused on the current efficiency model (based on the experimental data) (Cheng et al., 2013; Guo et al., 2016) and the mass transfer model (Al-Jubainawi et al., 2017). The present research (Cheng et al., 2013) for the energy consumption model of ED regenerator is not quite exact as the voltage of ED regenerator can only be briefly acquired based on experimental data. The liquid desiccant resistance occupies the most resistance of ED regenerator, which depends on the electrical conductivity of the liquid desiccant. Seldom researches (M. Conde Engineering, 2012; CRC, 1989) were focused on the electrical conductivity of the liquid desiccant used in the liquid desiccant air-conditioning system as the high concentration. M. Conde Engineering (2012) studied the relationship between LiCl solution electrical conductivity and its temperature and concentration, but only the model of LiCl solution electrical conductivity varied with its temperature under several constant concentrations and the model of LiCl solution electrical conductivity varied with its concentration under several constant temperatures were acquired, as the lack of experimental data. So it's hard to use these models to establish the resistance model of ED regenerator as the solution temperature and concentration are both changed in the regeneration process.

In order to establish the performance coefficient model of liquid desiccant air-conditioning system based on ED regeneration using LiCl, this paper will do experimental research on the electrical conductivity of LiCl aqueous solution with a lot of concentrations and temperatures. In the experiment, the mass concentration of the LiCl aqueous solution is among 20% and 40% as the LiCl aqueous solution with this concentration range is usually used in the liquid desiccant air-conditioning system (Liu et al., 2011). Based on most experimental data, the LiCl solution electrical conductivity model will be acquired and be validated. Finally, the performance coefficient model of the liquid desiccant cooling system based on ED regeneration will be achieved and the effect of LiCl solution temperature and concentration on the performance of the system will be researched.

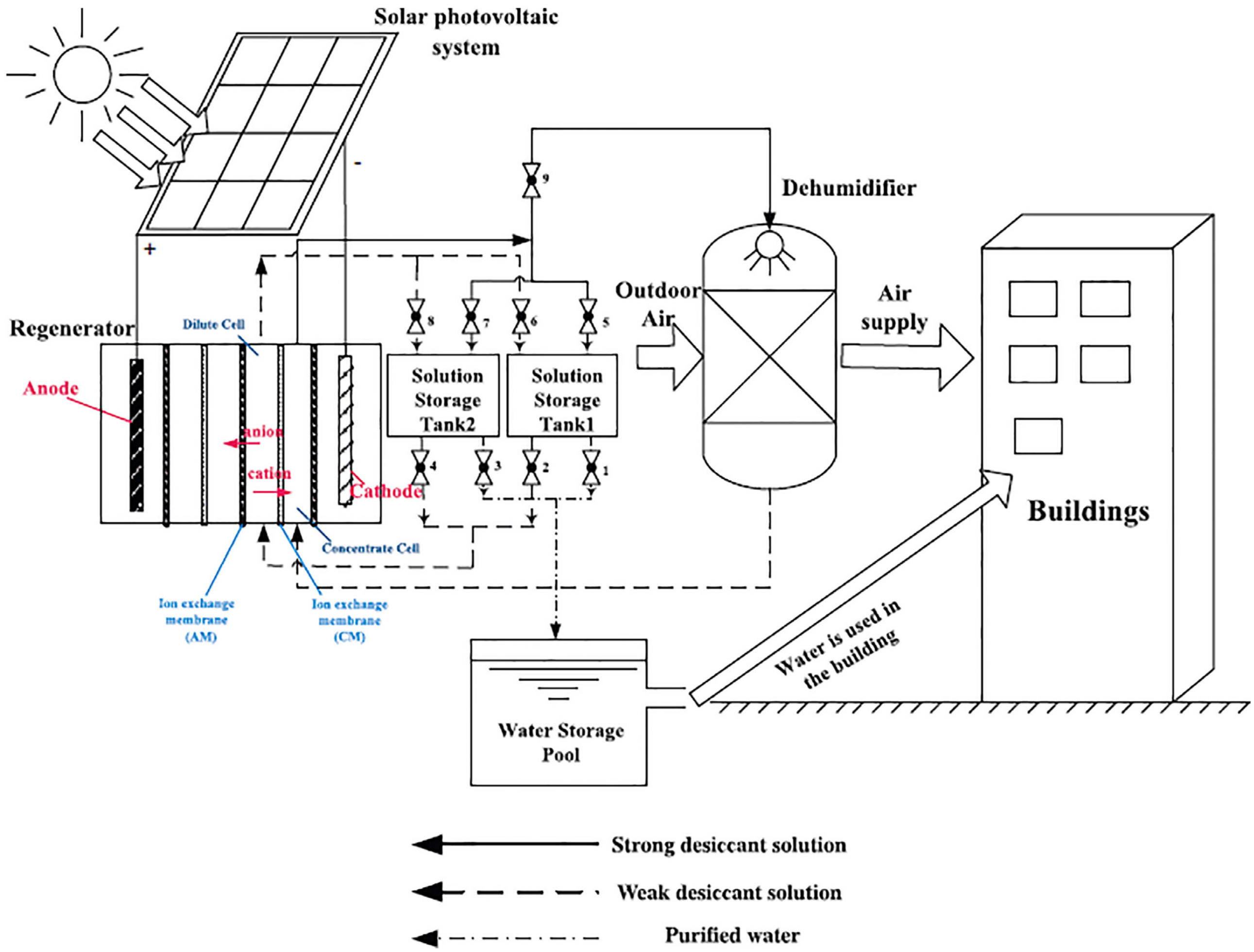


Fig. 1. PV-ED-LDCS (Li and Zhang, 2009).

2. Material and method

2.1. System description of the liquid desiccant cooling system based on ED regeneration

A typical liquid desiccant cooling system based on PV-ED regeneration (PV-ED-LDCS) (Li and Zhang, 2009) is depicted in Fig. 1. The weak desiccant solution is sent from the dehumidifier to the regenerator. The regenerator in PV-ED-LDCS is basically an ED stack (or some ED stacks), which consists of a multitude of cells placed in parallel between two electrodes. In alternating cells the desiccant solution is concentrated and diluted, respectively. By this way, the weak desiccant solution will be regenerated and sent to the solution storage tank. Finally, strong desiccant solution can be acquired and sent to the dehumidifier.

2.2. Principle of ED regeneration

Fig. 2 shows a typical ED regenerator for the liquid desiccant air-conditioning system using LiCl solution, which is combined with regenerate cells (b in Fig. 2), dilute cells (a in Fig. 2), an anode cell (e in Fig. 2) and a cathode cell (f in Fig. 2).

The ED regenerator is driven by a rectifier. In the ED regenerator, cation-exchange membranes and anion-exchange membranes are placed alternately between the cathode and the anode. The Cl^-s and the Li^+s in the cells of ED regenerator will move to the anode and the cathode respectively under an electrical field. In the migration process, the Li^+s will pass through the cation-exchange membrane and be retained by the anion-exchange membrane. Likewise the Cl^-s will pass through the anion-exchange membrane and be retained by the cation-exchange membrane. Finally, the concentration of LiCl solution in regenerate cells of ED regenerator will increase, and that in dilute cells will decrease. As a result, the strong LiCl solution can be acquired from regenerate cells of ED regenerator.

2.3. Theoretical analysis of the system

2.3.1. Energy consumption of the ED regenerator

The energy consumption of ED regenerator mainly relies on the operational current and voltage of the ED regenerator:

$$P_{EDr} = IU = I^2 R_{EDr} \tag{1}$$

The current efficiency is a key parameter to evaluate the regeneration performance of the ED regenerator (Chehayeb et al., 2017; Li and Zhang, 2009; Cheng et al., 2013):

$$\zeta = \frac{zFm_{reg}(C_{reg,o} - C_{reg,i})}{INM_d} \tag{2}$$

The resistance of the ED regenerator is given by the sum of the total cell pair resistance and the active resistance of the electrode compartments, also known as blank resistance (Tufa et al., 2016):

$$R_{EDr} = R_{cells} + R_{blank} \tag{3}$$

As there are a high number of cell pairs in the ED regenerator, the effect of blank resistance can be negligible (Tufa et al., 2016),

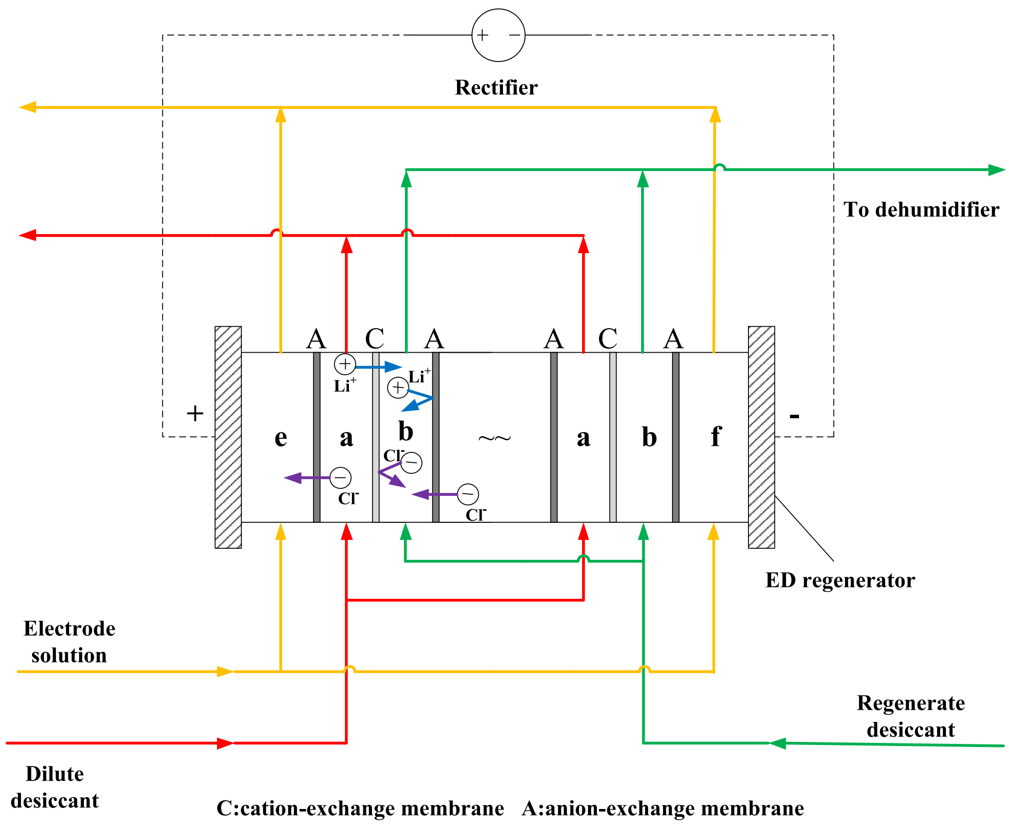


Fig. 2. A typical ED regenerator using LiCl solution.

the resistance of the ED regenerator can be simplified as:

$$R_{EDr} = R_{cells} = NR_{cell} = N(R_{cm} + R_{am} + R_{reg} + R_{diu}) \quad (4)$$

The energy consumption of the ED regenerator can be calculated by combining Eqs. (1), (2) and (4):

$$P_{EDr} = \left[\frac{zFm_{reg}(C_{reg,o} - C_{reg,i})}{\zeta M_d}\right]^2 \frac{(R_{cm} + R_{am} + R_{reg} + R_{diu})}{N} \quad (5)$$

2.3.2. Performance coefficient of the system

The liquid desiccant cooling system usually uses a dehumidifier to get dry air and then use a water evaporator to control the temperature and humidity of the air (Cui et al., 2016), so the refrigerating capacity of the liquid desiccant cooling system can be considered as the evaporative heat absorption of water in the water evaporator (Li and Zhang, 2012; Li et al., 2015, 2016):

$$Q_{rc} = r_w \Delta m_w \quad (6)$$

For LiCl solution, the correlation of moisture removal rate can be expressed from a reference (Liu et al., 2011), which uses Celdek structured packing with the specific surface area of 396 m^2/m^3 in the dehumidifier and the experimental module size ($H \times L \times W$) is 550 × 330 × 350 mm^3:

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

The refrigerating capacity of the liquid desiccant cooling system using LiCl solution can be calculated by combing Eqs. (6) and (7):

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

The performance coefficient of the liquid desiccant cooling system using LiCl solution can be given by combing Eqs. (5) and (8):

$$COP = \frac{Q_{rc}}{P_{EDr}} = \frac{9.4542 \times 10^8 \times m_a^{0.406} \omega_a^{2.2478} m_{reg}^{0.6499} t_{reg}^{-2.3911} C_{reg,o}^{1.7919} r_w}{\left[\frac{zFm_{reg}(C_{reg,o} - C_{reg,i})}{\zeta M_d}\right]^2 \frac{(R_{cm}+R_{am}+R_{reg}+R_{diu})}{N}} \quad (9)$$

2.4. Experimental setup

2.4.1. Material

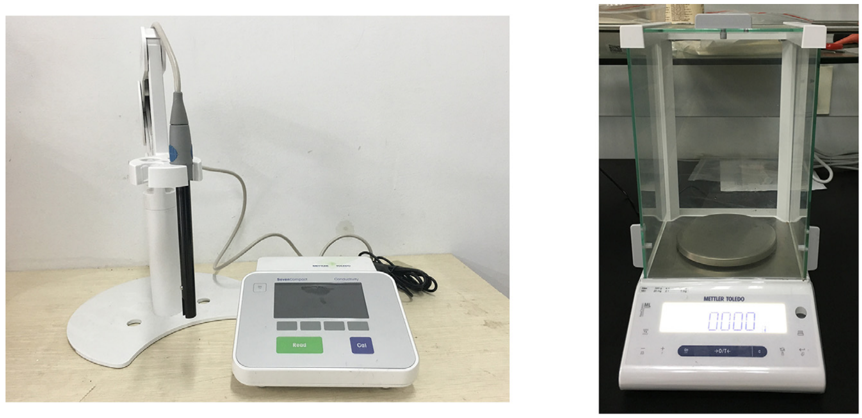
In the experiment, the LiCl (CAS NO. 7447-41-8) was supplied from the Shanghai Aladdin Bio-chem Technology Company. The purity of the LiCl was higher than 99.0%. Moreover, a Millipore Synergy water purification system was used to supply the pure water for the preparation of the LiCl aqueous solution.

2.4.2. Measuring instruments

In the experiment, a precision conductivity meter (Mettler Toledo S230-K, shown in Fig. 3(a)) with an application range of 0.001 µS/cm–1000 mS/cm was used to measure the electrical conductivity and the temperature of the LiCl aqueous solution, whose electrical conductivity accuracy is ±0.5% and temperature accuracy is ±0.1 °C. Moreover, a Mettler Toledo microbalance with an accuracy of 0.001 g (shown in Fig. 3(b)) was used to prepare the LiCl aqueous solution.

2.4.3. Experimental protocol

In the experiment, the conductivity of the LiCl aqueous solution was measured with 9 different mass concentrations (20%, 22.5%, 25%, 27.5%, 30%, 32.5%, 35%, 37.5% and 40%). The initial LiCl solution has a high temperature as the dissolution process releases large thermal energy. The conductivity and temperature readings were taken at time intervals (one minute) with the cooling of the LiCl solution.



(a) The Mettler Toledo conductivity meter (b) The Mettler Toledo microbalance

Fig. 3. Experimental instrument.

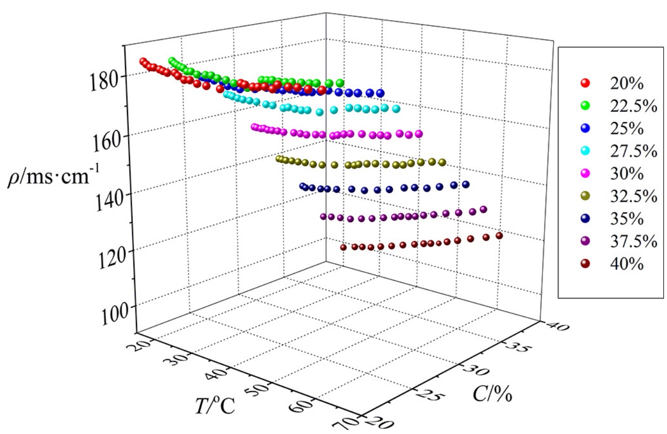


Fig. 4. Experimental results of the LiCl aqueous solution electrical conductivity.

2.5. Fitting method

In this paper, based on the experimental results, the polynomial regression method was used to achieve the mathematical model of the electrical conductivity for the LiCl aqueous solution correlated with the mass concentration and the temperature of the LiCl aqueous solution. In the fitting process, the polynomial degrees of the mass concentration and the temperature of the LiCl aqueous solution were varied from 2 to 5, respectively. As a result, 16 different mathematical models of the electrical conductivity for the LiCl aqueous solution were acquired and all of them would be compared with the fitting goodness.

3. Correlation of electrical conductivity for the LiCl aqueous solution

3.1. Experimental results

Fig. 4 shows the experimental results of the electrical conductivity of the LiCl aqueous solution for the nine different mass concentrations.

Fig. 4 shows that for the LiCl solution with the mass concentration from 20% to 30%, the LiCl solution electrical conductivity changes slightly with the temperature. For the mass concentration from 32.5% to 40%, the electrical conductivity of the LiCl aqueous solution increases with the temperature, and the increase speed of the electrical conductivity increases with the concentration. When the temperature of the LiCl aqueous solution is constant, for the mass concentration from 20% to 40%, the electrical conductivity of the LiCl aqueous solution decreases with the increase of the concentration, and the decrease speed of the electrical conductivity is small with the concentration from 20% to 25%, which turns to large with the concentration from 25% to 40%.

As the variation of the LiCl solution electrical conductivity with the concentration from 20% to 25% is different from that with the concentration from 25% to 40%, the experimental data of the LiCl aqueous solution with the concentration of 22.5% and 32.5% is used to validate the mathematical model and other experimental data (the LiCl aqueous solution concentration of 20%, 25%, 27.5%, 30%, 35%, 37.5% and 40%) is used to simulate the mathematical model.

3.2. Fitting goodness analysis

In this section, the fitting goodness of the 16 different mathematical models of the electrical conductivity for the LiCl aqueous solution is analyzed. In the analysis process, m is the polynomial degree of the LiCl aqueous solution temperature and n is the polynomial degree of the LiCl aqueous solution concentration.

Fig. 5 shows the sum of squares due to error (SSE) and the root mean squared error (RMSE) of the mathematical models varied with m and n. The smaller SSE and RMSE mean the higher goodness of the mathematical model. Fig. 5 shows that the mathematical model will be better with the increase of n, the SSE and the RMSE of the mathematical model are very high when n is 2. Then, the SSE and the RMSE decrease slightly with the increase of n when n varies from 3 to 5. On the other hand, the effect of the variation of m on the SSE and the RMSE is less than that of n. When m is 2, the SSE and the RMSE of the mathematical model are larger than that when m is 3, while the SSE and the RMSE of the mathematical model are almost the same when m varies from 3 to 5.

Fig. 6 shows the R-square and the Adjusted R-square of the mathematical models varied with m and n. The larger R-square and Adjusted R-square mean the higher goodness of the mathematical model. Fig. 6 also shows that the mathematical model of the electrical conductivity for the LiCl aqueous solution will be better when n varies from 2 to 3, the R-square and the Adjusted R-square of the mathematical model are very low when n is 2, which means the mathematical model has a bad goodness when n is 2. Then, the effect of n on the R-square and the Adjusted R-square of the mathematical model is very small when n varies from 3 to 5. On the other hand, the effect of the variation of m on the R-square

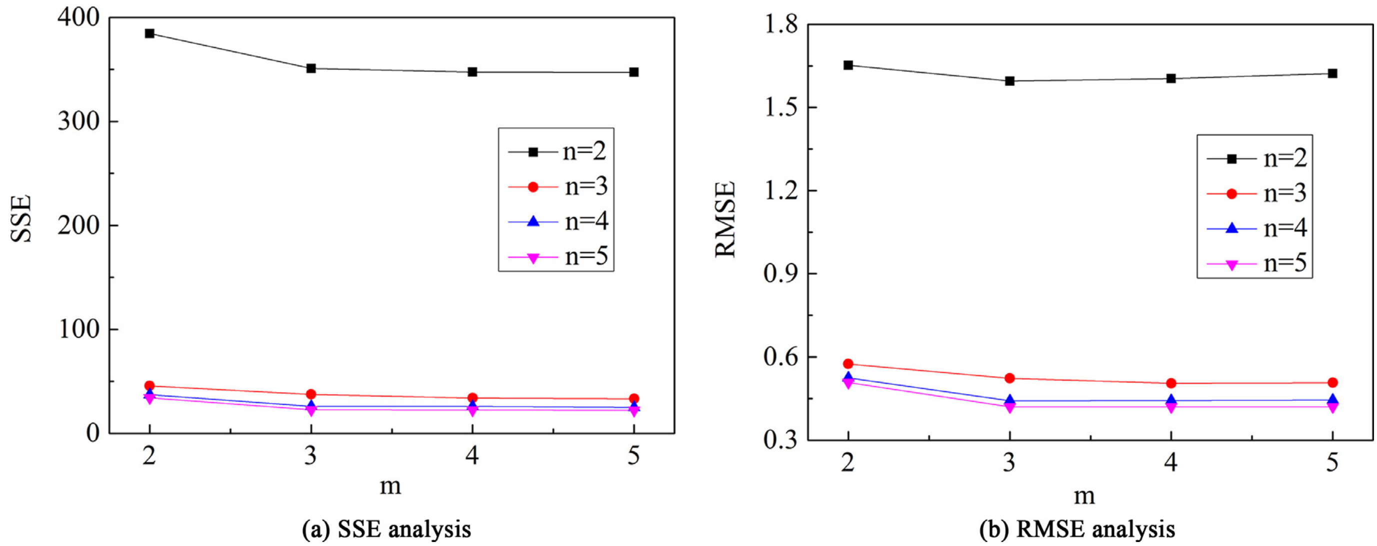


Fig. 5. SSE and RMSE of the mathematical models.

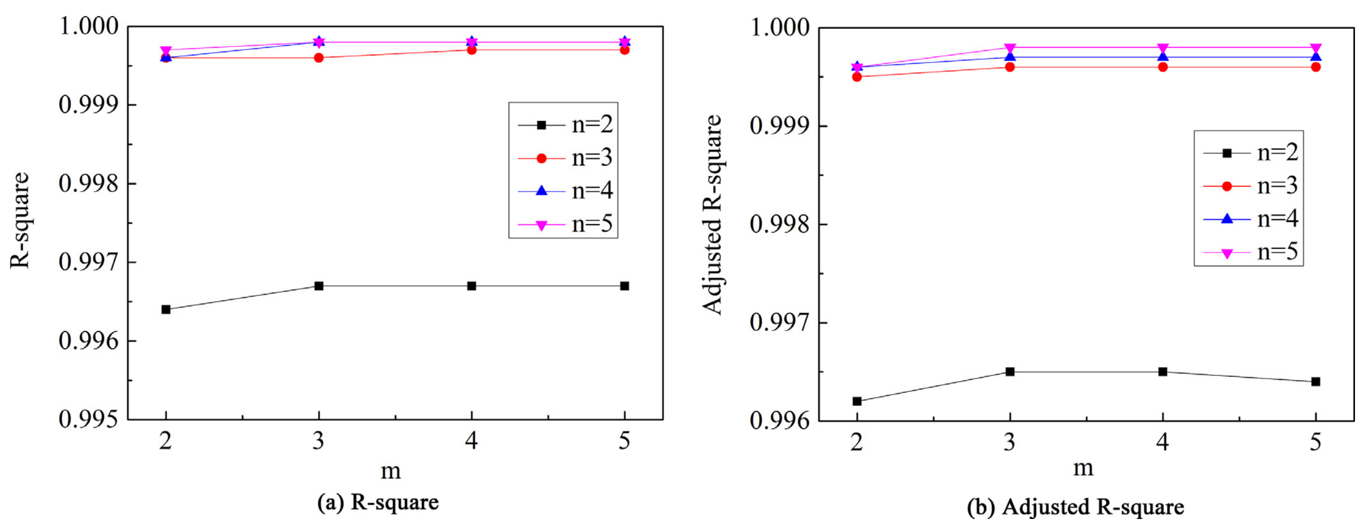


Fig. 6. *R*-square and Adjusted *R*-square of the mathematical models.

and the Adjusted *R*-square is much less than that of *n*, which can be ignored when *m* varies from 3 to 5.

According to the results shown in Figs. 5 and 6, higher values of *m* and *n* will lead to a higher goodness of the mathematical model, and the mathematical model goodness is poor when *m* is 2 or *n* is 2. As a result, only the polynomial degrees of the LiCl aqueous solution temperature and concentration varied from 3 to 5 respectively are considered in the following validation process.

3.3. Model validation

3.3.1. Model validation based on the experimental data with the concentration of 22.5% and 32.5%

In this section, the experimental data of the LiCl solution with the concentration of 22.5% and 32.5% is used to validate the nine different mathematical models (*m* and *n* varied from 3 to 5 respectively). The comparison results of the experimental electrical conductivity with the predicted values are shown in Fig. 7. There are three mathematical models having the absolute differences between experimental values and predicted values below 1%, including *m* is 3 and *n* is 5, *m* is 4 and *n* is 5, *m* is 5 and *n* is 5. But one problem is that the mathematical model will be more complicated with the increase of the sum of *m* and *n*, so besides the three mathematical models with the absolute difference below 1%, the simplest mathematical model when *m* is 3 and *n* is 3 is also considered in the following validation with other researchers' experimental data.

3.3.2. Model validation based on other researchers' experimental data

In this section, four different mathematical models of the LiCl aqueous solution electrical conductivity (*m* is 3 and *n* is 3, *m* is 3 and *n* is 5, *m* is 4 and *n* is 5, *m* is 5 and *n* is 5) are validated with some other researchers' experimental data (M. Conde Engineering, 2012; CRC, 1989). The comparison results of the experimental electrical conductivity with the predicted values are shown in Fig. 8. For the four different mathematical models, the absolute differences are all below 9%. The results show that among the four mathematical models, the simplest one (*m* is 3 and *n* is 3) has almost the same absolute difference with other three complicated mathematical models. As a result, among all mathematical models, the model when *m* and *n* are both 3 is most suitable to describe the correlation of electrical conductivity for the LiCl aqueous solution as its simplicity and high accuracy.

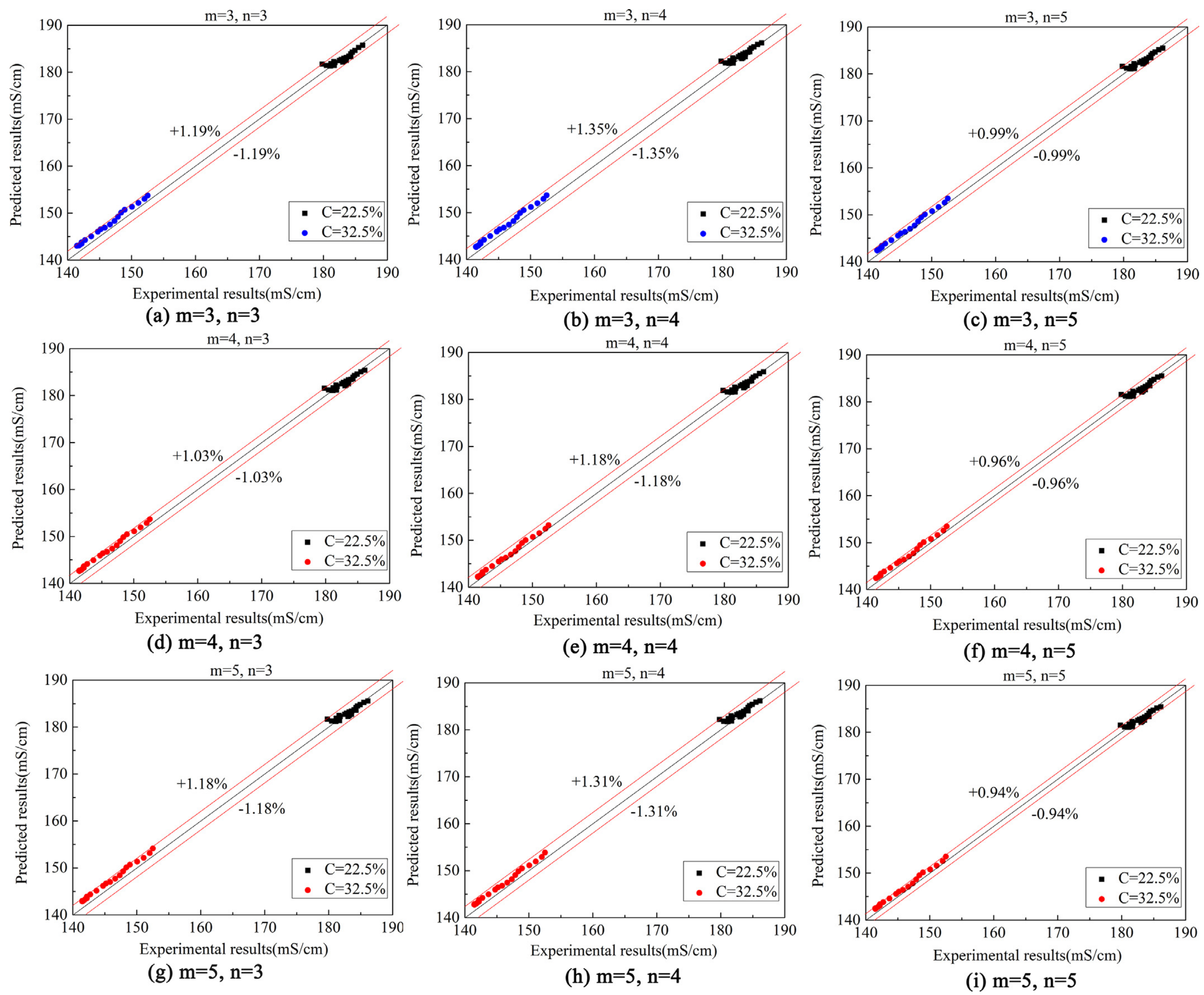


Fig. 7. Validation based on the experimental data with the concentration of 22.5% and 32.5%.

3.4. Correlation description

As the mathematical model when m is 3 and n is 3 is used to describe the correlation, the correlation of the electrical conductivity for the LiCl aqueous solution is expressed as:

$$\begin{aligned}\rho =&160.5+3.058\times\frac{T-38.59}{12.75}-28.96\times\frac{C-29.51}{6.534}\\&+0.9381\times\left(\frac{T-38.59}{12.75}\right)^2\\&+1.906\times\frac{T-38.59}{12.75}\times\frac{C-29.51}{6.534}-6.32\times\left(\frac{C-29.51}{6.534}\right)^2\\&-0.3259\times\left(\frac{T-38.59}{12.75}\right)^3\\&-0.2426\times\left(\frac{T-38.59}{12.75}\right)^2\times\frac{C-29.51}{6.534}+0.3203\times\frac{T-38.59}{12.75}\\&\times\left(\frac{C-29.51}{6.534}\right)^2+2.091\times\left(\frac{C-29.51}{6.534}\right)^3\end{aligned}\tag{10}$$

Based on the mathematical model of the LiCl aqueous solution electrical conductivity, the electrical conductivity of the LiCl aqueous solution varied with the solution temperature and concentration is shown in Fig. 9.

4. Performance of the liquid desiccant cooling system based on ED regeneration

4.1. Simulation preparation

In the following simulation, the dehumidifier in the liquid desiccant cooling system adopts the Celdek structured packing with the specific surface area of 396 m^2/m^3 and the module size ($H\times L\times W$) of $550\times330\times350$ mm^3 (Liu et al., 2011). Moreover, the ED regenerator in the liquid desiccant cooling system adopts a membrane stack consists of 25 cell pairs (Qing and Wenhao, 2017), which uses AMV anion-exchange membrane and CMV cation-exchange membrane (both supplied by AGC). Meanwhile, the effective membrane size is 175*120 mm, the thicknesses of regenerate room and dilute room in the multi-function liquid desiccant regenerator are both 1 mm. The parameters of membranes are shown in Table 1.

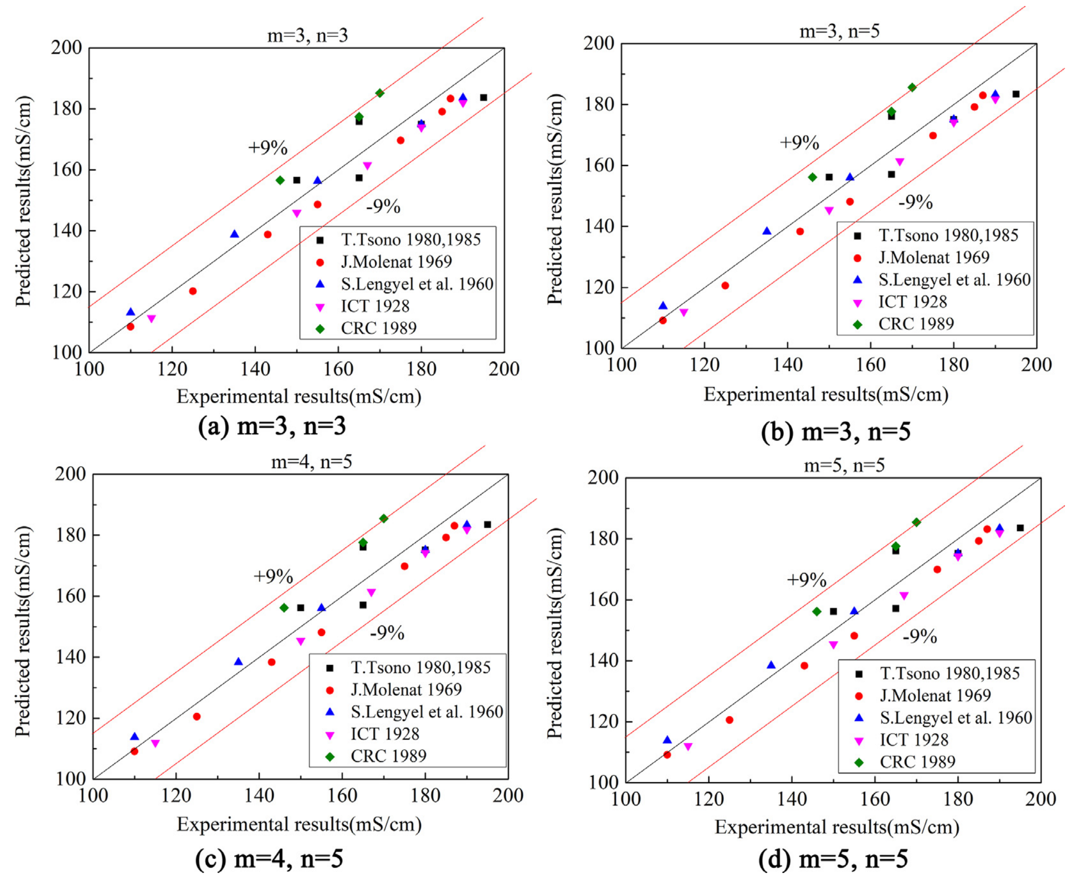


Fig. 8. Model validation based on other researchers' experimental data.

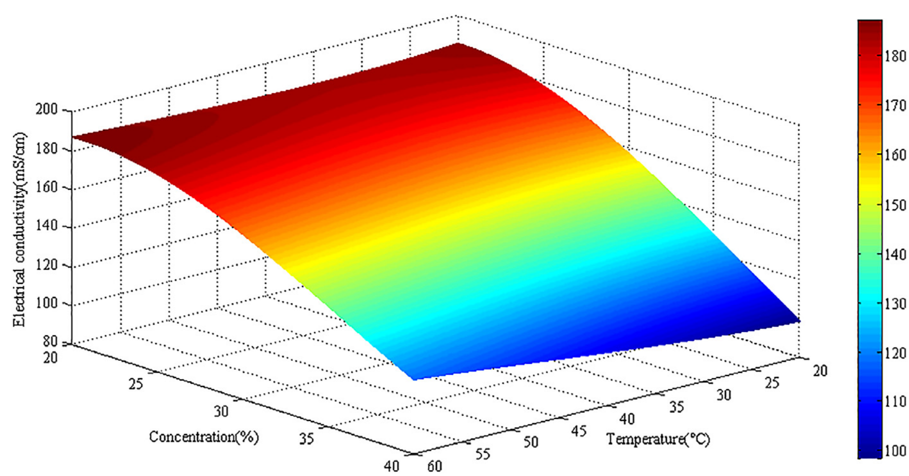


Fig. 9. The LiCl aqueous solution electrical conductivity varied with temperature and concentration.

Table 1
Parameters of membranes (Qing and Wenhao, 2017).

Membrane	Characteristic	Thickness	Resistance	Transport number
CMV	Standard	130 µm	3 Ω cm^2	>0.96
AMV	Standard	130 µm	2.8 Ω cm^2	>0.96

For one cell pair in the ED regenerator, the resistance of the liquid desiccant in the regenerate cell or dilute cell is:

$$R_{desiccant} = \frac{L}{\rho A} \quad (11)$$

The parameters for the following simulation are listed in Table 2. As the flow rate of the LiCl solution in the regenerate cells is 15 g/s in Qing and Wenhao (2017), it is assumed that 20 ED regenerators mentioned in Qing and Wenhao (2017) are used to regenerate the LiCl solution for the dehumidifier mentioned in Liu et al. (2011). As a result, the performance coefficient of the liquid desiccant cooling system can be described as:

$$COP = \frac{9.4542 \times 10^8 \times m_a^{0.406} \omega_a^{2.2478} m_{reg}^{0.6499} t_{reg}^{-2.3911} C_{reg,o}^{1.7919} r_w}{20 \times \left[\frac{zFm_{reg,ED}C_{add}}{\zeta M_d}\right]^2 \frac{(R_{cm}+R_{am}+\frac{L}{\rho_{reg}A}+\frac{L}{\rho_{diu}A})}{N}} \quad (12)$$

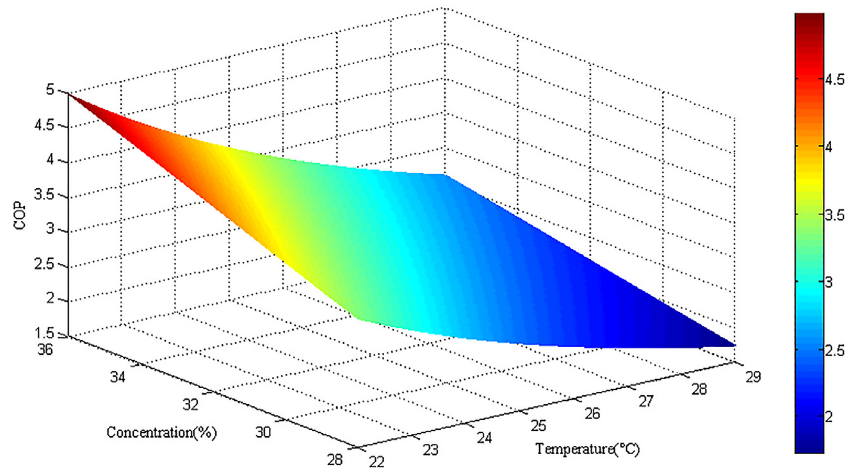


Fig. 10. Effect of LiCl solution concentration and temperature at the exit of regenerate cells on the COP.

Table 2
General parameters in the simulations.

Parameters		Specification
z	1	LiCl is applied
F(C/mol)	96,485	
M_d(g/mol)	42.5	LiCl is applied
L(mm)	1	Qing and Wenhao (2017)
A(m^2)	0.021	Qing and Wenhao (2017)
N	25	Qing and Wenhao (2017)
r_w(kJ/kg)	2257.2	Latent heat of water vaporization
m_a(kg/s)	0.3	Liu et al. (2011)
ω_a(g/kg)	16.5	Liu et al. (2011)
$m_{reg,\ ED}$(kg/s)	0.015	Qing and Wenhao (2017)
ζ(%)	50	Qing and Wenhao (2017)
m_{reg}(kg/s)	0.3	Liu et al. (2011)
C_{add}(%)	0.3	Qing and Wenhao (2017) and Liu et al. (2011)

In the following simulation, Eqs. (10) and (12) are used to analyze the effect of the concentration and the temperature of the LiCl solution on the performance coefficient of the liquid desiccant cooling system.

4.2. Effect of concentration and temperature on the performance coefficient

In this simulation, the effect of the concentration and the temperature of the LiCl solution at the exit of regenerate cells on the performance coefficient of the liquid desiccant cooling system based on ED regeneration is analyzed and shown in Fig. 10.

Fig. 10 shows that the performance coefficient will decrease with the increase of the LiCl solution temperature and the decrease of the LiCl solution concentration at the exit of regenerate cells of the ED regenerator. When the concentration is 36% and the temperature is 22 °C, the liquid desiccant cooling system has the maximum COP of about 5. Moreover, it shows that the effect of the temperature on the performance coefficient is larger than that of the concentration.

4.3. Discussions

The LiCl solution temperature and concentration will affect both the dehumidification performance and the ED regeneration performance of the liquid desiccant cooling system. The higher LiCl solution temperature will lead to the decrease of the performance coefficient. The higher LiCl solution concentration will lead to the increase of the performance coefficient. Moreover, the effect of the LiCl solution temperature on the performance coefficient is larger than that of the LiCl solution concentration, which means keeping the low LiCl solution temperature should be most important to improve the performance of the liquid desiccant cooling system based on ED regeneration.

In order to compare the performance of the vapor compression cooling system and the liquid desiccant cooling system based on electrodialysis regeneration, a small office room with two people is analyzed. Based on Chinese standard, fresh air of 60 m^3/h is considered in this room and a vapor compression cooling system with COP of 3.5 is used for cooling in this room. It is assumed that the dry-bulb temperature of outdoor air is 35 °C, and the relative humidity of outdoor air is 70%. At the meantime, the dry-bulb temperature of indoor air is 27 °C, and the wet-bulb temperature of indoor air is 19 °C. The electric energy consumption of the vapor compression cooling system is calculated by Eq. (13), and the result shows that the vapor compression cooling system needs 0.628 kW h, and the liquid desiccant cooling system based on electrodialysis regeneration needs 0.283 kW h, which means the liquid desiccant cooling system based on electrodialysis regeneration has a good energy-saving potential in the building.

$$P_{vc} = Q_{cooling} + Q_{reheat} = m_a\left(\frac{h_o - h_d}{COP_{vc}} + h_i - h_d\right) \tag{13}$$

On the other hand, there are some shortages in the simulation of this paper. In this paper, the current efficiency adopts a constant value in the simulation, which varies based on the operational condition actually. Moreover, the dehumidifier and ED regenerator models from other papers were used in the simulation part, and 20 ED regenerators were used to meet the liquid desiccant requirement of the dehumidifier, however, lower number and larger scale ED regenerators will be used in the actual liquid desiccant air-conditioning system, which may lead to a higher regeneration efficiency of ED regenerator and need to be verified with the experiment. In the future, the ED regeneration experiment for the LiCl solution with a large range of concentration will be conducted and a liquid desiccant cooling experimental system based on ED regeneration will be established to validate the performance coefficient model acquired in this paper.

5. Conclusion

Experimental and theoretical research on the LiCl solution electrical conductivity with a lot of concentrations and temperatures was conducted in this paper. The results can be concluded as:

(1) The mathematical model of the LiCl solution electrical conductivity when polynomial degrees of the mass

concentration and the temperature are both 3 is most suitable as its simplicity and high accuracy.

(2) The performance coefficient will increase with the decrease of the LiCl solution temperature and the increase of the LiCl solution concentration.

(3) When the LiCl solution concentration is 36% and the LiCl solution temperature is 22 °C, the liquid desiccant cooling system has the maximum COP of about 5.

(4) The effect of the LiCl solution temperature on the performance coefficient of the liquid desiccant cooling system based on ED regeneration is larger than that of the LiCl solution concentration.

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