Study Analysis of Solution Equilibrium Concentration as Evaluation Index of Liquid Desiccant Dehumidification System

Guangkai Zhang¹, Jingchao Xie¹, Boyao Du¹, Jiaping Liu¹
¹ Beijing Key Laboratory of Green Built Environment and Energy Efficient Technology, Beijing, China

Abstract
Since the mass concentration of the solution is a feedback parameter that is difficult to obtain directly, the research parameters for liquid desiccant system process optimization are primarily based on parameters that are easy to measure, such as flow rate, temperature and humidity, and the research on equilibrium point concentration is less. Based on multiple linear regression, the solution equilibrium point concentration was used as an evaluation index, and the equilibrium point concentration regression model was established to explore the relevant factors affecting the system equilibrium point concentration and analyze the equilibrium point concentration variation rule under the influence of various significant factors. The results show that the influence of humidity is the greatest, and the absolute value of the standardized regression coefficient is 0.7204 (0.7160). When the air temperature, dehumidification, and regeneration solution temperature increase by 1.0 °C, the equilibrium point concentration increases by 0.28 %, 0.21 %, and 0.49 %, respectively, which is favorable to the equilibrium point concentration. For every 1.0 g/kg increase in air moisture content and every 1.0 kg/s increase in dehumidified airflow rate and regenerated airflow rate, the equilibrium point concentration decreases by an average of 0.69 %, 13.01 % and 1.60 %, respectively, which is unfavorable to the increase of equilibrium point concentration.

Highlights
- Consider the usability of the solution concentration
- Establishing a computational model for equilibrium point concentration
- Give the variation law of the equilibrium point concentration

Introduction
With the unique advantages of air wet load treatment, the versatility and flexibility in energy utilization and the value in low carbon energy saving (Li, 2003), liquid desiccant dehumidification system (LDDS) is gradually being applied and promoted (Tu, 2010; Li, 2017; Mohammada, 2016).

The general LDDS mainly comprises a dehumidifier, regenerator and corresponding matching cold and heat sources. The research on LDDS has been mainly focused on the heat mass transfer characteristics of air-solution contact (Liu, 2008; Gao, 2012; Peng, 2016; Fang, 2021), the selection and application of matching cold and heat sources (Sun, 2019; Zhang, 2021; Alosaimy, 2011; Cheng, 2014; Guo, 2016), the development and performance testing of dehumidification solution (Xu, 2019; Jiang, 2019; Shen, 2016; Rafei, 2016) and the structure optimization of dehumidifier and regenerator (Lee, 2016; Gao, 2013; Bansal, 2011). Besides, some scholars analyzed the optimization of the process of LDDS. For example, Qu (2021) studied the dehumidification effect of the solution under different solution dehumidification processes and got the conclusion that the process is the core factor in determining the dehumidification effect; Yang (2020) explored the influence of system operation pressure on dehumidification performance, and the results showed that with the growth of operation pressure, the system dehumidification performance improved significantly; Qian (2014) found that different air and solution state parameters have different effects on dehumidification amount and efficiency.

During the process optimization, solution mass concentration is a very critical dynamic parameter, and the variation of solution mass concentration has a significant effect on the system performance. Fang (2020) found in a numerical study of the moisture transfer characteristics of a membrane dehumidifier that among all operating parameters, air inlet temperature and solution flow rate have limited effect on the total resistance, while solution concentration has a significant effect on the resistance: increasing the solution concentration and decreasing the solution temperature can significantly reduce the resistance to moisture transfer; Guan (2020) optimized the heat pump-driven solution dehumidification air conditioning system by considering the optimal solution concentration. For dehumidification only, the optimal solution concentration was found to minimize compressor energy consumption. For cooling and dehumidification, an energy-saving strategy was developed to achieve the required solution concentration. The study found that when only dehumidification was required, the optimal solution concentration was achieved by using all condensing heat to heat the solution for regeneration.
However, for cooling and dehumidification requirements, the required equilibrium solution concentration was lower than the optimal solution concentration. To achieve the required concentration, excess condensing heat could be removed by replenishing water into the regenerator or adding an auxiliary condenser; Xia (2015) theoretically analyzed the effect of branch flow rate on the equilibrium concentration difference in the solution humidification system, and the results showed that: with the increase of the solution branch flow rate, the equilibrium concentration difference between concentrated and dilute solutions decreases; Bouzenada (2017) was found that, for LiCl solutions, a decrease in concentration affects the hygroscopicity and water vapor partial pressure of the solution; the desiccant contact angle at the liquid/air interface has a significant effect on the film wetting area, and the film wetting area affects the mass transfer performance of the system; Qi (2015) in the study for solution dehumidifier/regenerator found that the contact angle of LiCl and LiBr solutions on the stainless steel surface increased with the increase of solution concentration. The above study shows that the solution mass concentration has a non-negligible role in optimizing the process and can effectively improve the performance of the LDDS.

The solution mass concentration is a crucial parameter for liquid desiccant dehumidification systems, but it is difficult to obtain directly. Previous studies have focused on easily measured parameters such as air, solution flow rate, temperature, and moisture content, or explored system circulation structure. Fewer studies have examined the effects of changes in dynamic equilibrium point concentration parameters during combined system operation. However, the equilibrium point concentration plays a significant role in the system's performance, affecting energy consumption, heat and mass transfer performance, and liquid change cycle. Therefore, exploring the relevant factors affecting the equilibrium point concentration to understand its change law is essential for process optimization.

This study uses a fork-flow adiabatic liquid desiccant dehumidification system with LiCl as the circulating dehumidification solution. The solution equilibrium concentration is used as an evaluation index of the LDDS. A dehumidifier/regenerator circulation model is established to calculate the equilibrium point concentration. The relationship between the system equilibrium point concentration and its influencing factors is analyzed using multiple linear regression. The influence trend of each significant factor on the change law of equilibrium point concentration is explored. A regression equation for solution equilibrium point concentration is provided as a reference for process optimization of LDDS.

**Methods**

**Equilibrium point concentration**

The LDDS relies on the liquid desiccant for dehumidification, and the solution enters the regenerator for regeneration after dehumidification. In the transient cycle before reaching the steady state, the mismatch between the dehumidification amount \(ADA\) of the dehumidification process and the absolute regeneration amount \(ARA\) of the regeneration process leads to the dynamic change of the mass concentration of the solution. When the absolute dehumidification amount and the absolute regeneration amount are equal, the system reaches a steady state, and at this time, the mass concentration of the solution remains balanced.

\[
ADA = M_{\text{in},D} \cdot (\omega_{\text{in}} - \omega_{\text{out}}) \quad (1)
\]

\[
ARA = M_{\text{in},R} \cdot (\omega_{\text{in}} - \omega_{\text{out}}) \quad (2)
\]

As shown in Figure 1, the system reaches a steady state when \(ADA = ARA\). At this time, the instantaneous solution mass concentration at any point of the system remains constant, the along-range solution mass concentration from point \(p\) to point \(p_1\) remains constant \((\xi_p = \xi_{p_1})\), and the long-range solution mass concentration from point \(q\) to point \(q_1\) remains constant \((\xi_q = \xi_{q_1})\). The solution equilibrium concentration at the outlet of the dehumidifier and regenerator is taken as the solution equilibrium point concentration for this study.

**Heat and mass transfer model**

The heat and mass exchange process between the solution and the air is shown in Figure 2, with the dehumidifier/regenerator unit having a height of \(H\), a width of \(W\) and a thickness of \(L\).

The energy conservation equation and the mass conservation equation are as follows.

\[
\frac{\partial (m_x \cdot h_x)}{\partial z} \, dz + \frac{\partial (m_x \cdot h_x)}{\partial x} \, dx = 0 \quad (3)
\]

The amount of change in moisture in the air is equal to the change in mass of the solution:

\[
\frac{\partial (m_x \cdot \omega_x)}{\partial z} \, dz + \frac{\partial m_x}{\partial x} \, dx = 0 \quad (4)
\]
The mass of the solute remains constant:

\[ d(m_s \cdot \xi) = 0 \]

(5)

The energy transfer and mass transfer equations for the air side are as follows.

\[
\begin{align*}
\frac{d h_a}{dz} &= \frac{NTU \cdot Le}{L} \left[ (h_a - h_c) + \left( \frac{1}{Le} - 1 \right) (\omega_a - \omega_a) \right] \\
&+ c_{pa} T_a d\omega_a + c_{pa} \omega_a dT_a \\
\frac{d\omega_a}{dz} &= \frac{NTU \cdot (\omega_a - \omega_a)}{L} 
\end{align*}
\]

(6)

(7)

The following equations define NTU and Le.

\[
NTU = \frac{k_{st} A_s L W H}{M_s}
\]

(8)

\[
Le = \frac{f_{st}}{k_{st} \cdot c_{pa}}
\]

(9)

**Algorithm for equilibrium point concentration**

According to the calculation model to find the equilibrium point concentration of the solution, the algorithm flow is shown in Figure 4, and the calculation steps are as follows.

1. Enter the air and solution inlet state parameters (to simplify the calculation, set the air and solution inlet parameters as fixed values without considering the temperature of the hot and cold sources); enter the structure parameters of the dehumidifier/regenerator as fixed parameters.

2. The dehumidifier and regenerator read the input parameters, and the dehumidifier model performs calculations to obtain the dehumidification solution outlet parameters \( \xi_{D, out} \) and ADA.

3. Let the regenerator inlet solution mass concentration equal the dehumidifier outlet solution mass concentration (\( \xi_{R, in} = \xi_{D, out} \)).

4. The regenerator model is calculated using the inlet parameters to obtain the regeneration solution outlet parameters \( \xi_{R, out} \) and ARA.

5. If ADA-ARA \( \leq 0.1 \) g/s is valid, output \( \xi_{D, out} \) and \( \xi_{R, out} \). At this time, \( \xi_{D, out} = \xi_{R, out} \) and the cycle ends; if the judgment formula is not valid, make \( \xi_{D, in} = \xi_{D, out} \) in the input parameters, and repeat (1)~(5) until the judgment formula is valid.

**System model verification**

The experimental results of Chen (2016) were used for model validation. Model accuracy is assessed by the absolute mean deviation AAD, as defined in equation (10):

\[
AAD = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{x_i, calculate - x_i, experiment}{x_i, experiment} \right| \times 100\% \quad (10)
\]

The solution outlet concentration was selected as the validation index. As shown in Figure 3, the absolute mean deviation AAD is 3.2 %, and the maximum deviation does not exceed 6.0 %, indicating that the model has good accuracy.

**Figure 2: Element control body model.**

**Figure 3: Result comparison.**

**Figure 4: Calculation process of equilibrium point concentration.**
Multiple linear regression scheme for equilibrium point concentration

The general form of the multiple linear regression model is \( Y = f(x_1, x_2, \ldots, x_n) \), as shown in equations (11) and (12), with the equilibrium point concentration of the system as the dependent variable and the air temperature, air moisture content, air mass flow rate at the inlet of the dehumidifier, air mass flow rate at the inlet of the regenerator, solution temperature at the inlet of the dehumidifier, solution temperature at the inlet of the regenerator, solution mass flow rate, and initial concentration of the solution as the independent variables to establish the multiple linear regression equation. Since the direct linear relationship between the solution flow rate and the equilibrium point concentration is insignificant, the solution flow rate is pretreated to improve the equation fit.

\[
\xi_p = a_0 + \alpha_1 T_{a,in} + \alpha_2 \omega_{a,in} + \alpha_3 T_{s,in,D} + \alpha_4 T_{s,in,R} + \alpha_5 \xi_{initial} + \alpha_6 M_{a,in,D} + \alpha_7 M_{a,in,R} + a_9 (M_s - 0.45)^2 + \epsilon
\]

\[
\xi_q = b_0 + \beta_1 T_{a,in} + \beta_2 \omega_{a,in} + \beta_3 T_{s,in,D} + \beta_4 T_{s,in,R} + \beta_5 \xi_{initial} + \beta_6 M_{a,in,D} + \beta_7 M_{a,in,R} + \beta_9 (M_s - 0.45)^2 + \epsilon
\]

As shown in Table 2, the selection of air state parameters refers to the *The Wheather Data for HVAC Design in Extreme Hot-humid Climate Zone*. The selection is based on the dominant humidity level and the range of outdoor calculation parameters that do not guarantee 50 hours per year on average. Subsequently, the relevant parameters are input into the equilibrium point concentration calculation process to obtain regression analysis data, which are statistically analyzed using Stata software.

### Table 2: Equilibrium point concentration calculation parameters.

<table>
<thead>
<tr>
<th>Air state parameters</th>
<th>Solution state parameters</th>
<th>Flow parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{a,in} )/°C</td>
<td>( \omega_{a,in} )/(kg/kg)</td>
<td>( T_{s,in,D} )/°C</td>
</tr>
<tr>
<td>28.0–33.0 0.027</td>
<td>22.5 60 30 0.35 0.65 0.45</td>
<td></td>
</tr>
<tr>
<td>30.5 0.0235–0.0315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.5 0.027</td>
<td>22.5 60 30 0.35 0.65 0.45</td>
<td></td>
</tr>
<tr>
<td>30.5 0.027</td>
<td>22.5 60 30 0.35 0.65 0.45</td>
<td></td>
</tr>
<tr>
<td>30.5 0.027</td>
<td>22.5 60 30 0.35 0.65 0.45</td>
<td></td>
</tr>
<tr>
<td>30.5 0.027</td>
<td>22.5 60 30 0.35 0.65 0.45</td>
<td></td>
</tr>
<tr>
<td>30.5 0.027</td>
<td>22.5 60 30 0.35 0.65 0.45</td>
<td></td>
</tr>
<tr>
<td>30.5 0.027</td>
<td>22.5 60 30 0.35 0.65 0.45</td>
<td></td>
</tr>
</tbody>
</table>

**Results**

After conducting OLS regression using Stata, the White test and variance inflation factor (VIF) were used to check for heteroskedasticity and multicollinearity in the regression process. The results showed that the VIF was <1.5 after using OLS regression, indicating a small effect of multiple cointegrations. However, heteroskedasticity was present with a White test \( P<0.05 \). Therefore, Stock and Watson (2011) recommend using "OLS + robust standard error" in most cases to reduce the impact of heteroskedasticity on the regression. The final regression results are shown in Table 3.

The regression model results for the equilibrium point concentration are as follows.

\[
\xi_p = 8.1951 + 0.2902 T_{a,in} - 680.8333 \omega_{a,in} + 0.2178 T_{s,in,D} + 0.4876 T_{s,in,R} - 0.0002 \xi_{initial} - 13.1 M_{a,in,D} - 1.6143 M_{a,in,R} - 23.2298 (M_s - 0.45)^2
\]

\[
\xi_q = 7.4871 + 0.2973 T_{a,in} - 679.951 \omega_{a,in} + 0.21 T_{s,in,D} + 0.5024 T_{s,in,R} + 0.0004 \xi_{initial} - 12.5929 M_{a,in,D} - 1.6786 M_{a,in,R} - 26.3555 (M_s - 0.45)^2
\]

The regression results show that the equation is significant overall \( P<0.05 \) and has a good fit. The variables can be divided into core explanatory variables and control variables based on the significance of the regression coefficients. The effects of air temperature, air moisture content, dehumidifier inlet air mass flow rate, regenerator inlet air mass flow rate, dehumidifier inlet solution temperature, regenerator inlet solution temperature, and solution mass flow rate on the equilibrium point concentration are very significant and are considered core explanatory variables. The effect of initial solution concentration on the equilibrium point concentration is not significant and is considered a control variable.

To investigate the significant factors' degree of influence on the equilibrium point concentration, the data were standardized to obtain the standardized regression coefficients. The absolute value of the standardized regression coefficient indicates the degree of influence. According to Table 3, the air moisture content has the most significant influence on the equilibrium point concentration among all factors and air state parameters. The regenerator inlet solution temperature has the greatest influence on the equilibrium point concentration among solution state parameters. The dehumidifier inlet air mass flow rate has the most significant influence on...
the equilibrium point concentration among flow parameters.

Table 3: Results of equilibrium point concentration regression.

<table>
<thead>
<tr>
<th>Equilibrium point concentration</th>
<th>Variables</th>
<th>Regression coefficient</th>
<th>Robust standard errors</th>
<th>t</th>
<th>Standardized regression coefficients</th>
<th>$R^2_{\text{adjusted}}$</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{a,in}$</td>
<td>0.2902***</td>
<td>0.0127</td>
<td>22.77</td>
<td>0.1594</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sigma_{a,in}$</td>
<td>-680.8333***</td>
<td>12.2035</td>
<td>-55.79</td>
<td>-0.7204</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core explanatory variables</td>
<td>$T_{a,in,D}$</td>
<td>0.2178***</td>
<td>0.0019</td>
<td>114.86</td>
<td>0.1197</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$T_{a,in,R}$</td>
<td>0.4876***</td>
<td>0.0130</td>
<td>37.48</td>
<td>0.5538</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_{a,in,D}$</td>
<td>-13.100***</td>
<td>1.3827</td>
<td>-9.47</td>
<td>-0.3631</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_{a,in,R}$</td>
<td>-1.643***</td>
<td>0.0298</td>
<td>-54.13</td>
<td>-0.0447</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$(M_{a} - 0.45)^2$</td>
<td>-23.2298***</td>
<td>1.0269</td>
<td>-22.62</td>
<td>-0.1148</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control variables</td>
<td>$\xi_{\text{Initial}}$</td>
<td>-0.0002</td>
<td>0.0015</td>
<td>-0.14</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\alpha_0$</td>
<td>8.1951***</td>
<td>1.0613</td>
<td>7.72</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$T_{a,in}$</td>
<td>0.2973***</td>
<td>0.0127</td>
<td>23.32</td>
<td>0.1625</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sigma_{a,in}$</td>
<td>-679.9510***</td>
<td>11.7703</td>
<td>-57.77</td>
<td>-0.7160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core explanatory variables</td>
<td>$T_{a,in,D}$</td>
<td>0.2100***</td>
<td>0.0012</td>
<td>174.04</td>
<td>0.1148</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$T_{a,in,R}$</td>
<td>0.5024***</td>
<td>0.0133</td>
<td>37.75</td>
<td>0.5494</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_{a,in,D}$</td>
<td>-12.5929***</td>
<td>1.2986</td>
<td>-9.70</td>
<td>-0.3474</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M_{a,in,R}$</td>
<td>-1.6786***</td>
<td>0.0439</td>
<td>-38.25</td>
<td>-0.0463</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$(M_{a} - 0.45)^2$</td>
<td>-26.3555***</td>
<td>0.5389</td>
<td>-48.90</td>
<td>-0.1298</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control variables</td>
<td>$\xi_{\text{Initial}}$</td>
<td>0.0004</td>
<td>0.0014</td>
<td>0.31</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\beta_0$</td>
<td>7.4871***</td>
<td>1.0566</td>
<td>7.09</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** p<0.01, ** p<0.05, * p<0.1

Discussion

To analyze the effect of one variable factor on the equilibrium point concentration's variation pattern, the other parameters were held constant. As the control variables did not significantly affect the equilibrium point concentration, the analysis focused on the effect of core explanatory variables.

Influence of air state parameters

As shown in Figure 5, when the air temperature increases from 28 °C to 33 °C, $\xi_p$ increases from 26.4 % to 27.8 % and $\xi_q$ increases from 26.8 % to 28.2 %. In the temperature range, the equilibrium point concentration increases approximately linearly as the inlet air temperature increases and the equilibrium point concentration increases by 0.28 % on average for each 1 °C increase in air temperature. As shown in Figure 6, when the air moisture content was increased from 0.023 kg/kg to 0.031 kg/kg, $\xi_p$ decreased from 29.7 % to 24.1 % and $\xi_q$ decreased from 30.0 % to 24.5 %. The equilibrium point concentration decreased linearly with the increase in air humidity, and the equilibrium point concentration decreased by 0.69 % on average for each 1 g/kg increase in humidity.

Figure 5: Influence of $T_{a,in}$

Figure 6: Influence of $\sigma_{a,in}$
Influence of solution state parameters

As shown in Figures 7 and 8, when the inlet solution temperature of the dehumidifier was increased from 20 °C to 25 °C, $\xi_p$ increased from 26.6 % to 27.7 % and $\xi_a$ increased from 27.1 % to 28.1 %; when the inlet solution temperature of the regenerator was increased from 55 °C to 65 °C, $\xi_p$ increased from 24.6 % to 29.5 % and $\xi_a$ increased from 24.9 % to 29.9 %. The equilibrium point concentration increased linearly with the increase in solution temperature. However, the degree of influence differed in different solution states: the equilibrium point concentration increased by 0.21 % on average for each 1 °C increase of dehumidification solution, and 0.49 % for each 1 °C increase in regeneration solution.

![Figure 7: Influence of $T_{in,D}$](image)

![Figure 8: Influence of $T_{in,R}$](image)

Influence of flow parameters

As shown in Figure 9, the equilibrium point concentration gradually decreases with the air mass flow rate increase. When the dehumidified air mass flow rate increases from 0.2 kg/s to 0.5 kg/s, $\xi_p$ decreases from 29.6 % to 25.6 %; $\xi_a$ decreases from 29.9 % to 26.1 %; for every 1.0 kg/s increase of mass flow rate, the equilibrium point concentration decreases by 13.01 %; when the regenerated air mass flow rate increases from 0.5 kg/s to 0.8 kg/s, $\xi_p$ decreases from 27.4 % to 26.9 % and $\xi_a$ decreases from 27.8 % to 27.3 %; and the equilibrium point concentration decreases by 1.60 % for every 1.0 kg/s increase in mass flow rate. The change in equilibrium point concentration is steeper for dehumidified air mass flow rate and slower for regenerated air mass flow rate for the same magnitude of air mass flow rate increase.

![Figure 9: Influence of air mass flow](image)

As shown in Figure 10, with the increase of the solution mass flow rate, the equilibrium point concentration shows a trend of increasing and then decreasing and reaches a peak at the solution mass flow rate equal to 0.45 kg/s: 27.2 % for $\xi_p$ and 27.6 % for $\xi_a$. This indicates that when the mass flow rate of dehumidified and regenerated air is certain, an optimal value exists for the corresponding solution mass flow rate. When the solution mass flow rate is less than 0.45 kg/s, the system regeneration recovery capacity is stronger than the dehumidification capacity, and the equilibrium point concentration increases with the increase of mass flow rate. On the other hand, when the solution mass flow rate is higher than 0.45 kg/s, due to the fixed size of the equipment, even if the solution flow rate regeneration volume will not have a significant increase, the system regeneration recovery capacity is gradually more minor than the dehumidification capacity, and the equilibrium point concentration increases with the mass flow rate.

![Figure 10: Influence of $M_s$](image)

Based on the results above, increasing the air mass flow rate is not beneficial for increasing the equilibrium point concentration. However, maintaining the solution flow rate within a specific range is favorable. Therefore, optimizing the solution flow rate while keeping the air flow rate constant is more effective for achieving the objective of increasing the equilibrium point concentration.

Conclusion

Based on multiple linear regression, this study investigated the relationship between equilibrium point concentration and its influencing factors in a solution dehumidification system. A regression model for equilibrium point concentration was obtained, and the importance and variation of each significant factor on
equilibrium point concentration were analyzed. The applicability of the equilibrium point concentration model was reflected by changing the air state parameters, solution state parameters, and flow parameters, providing a reference for process optimization of LDDS. The main conclusions are as follows.

(1) The equilibrium point concentration regression model had good significance. The model regression significance parameters P<0.05, the adjusted goodness of fit is greater than 0.99, and the regression significant (P<0.01) factors are: air temperature and moisture content, dehumidifier/regenerator inlet air mass flow rate, dehumidifier/regenerator inlet solution temperature, solution mass flow rate, as the core explanatory variables; solution initial concentration is not significant (P>0.1), as the control variables.

(2) The absolute value of the standardized regression coefficient of moisture content of dehumidified (regenerated) air is 0.7204 (0.7160), which is the air state parameter and the most influential factor on the equilibrium point concentration among all factors. The most influential factors in the solution state and flow parameters are the regenerator inlet solution temperature and dehumidification inlet air mass flow rate, with the absolute values of the standardized regression coefficients of 0.5358 (0.5494) and 0.3631 (0.3474), respectively.

(3) The equilibrium point concentration increases with the growth of air temperature and solution temperature: for every 1 °C rise in air temperature, dehumidification solution and regeneration solution, the equilibrium point concentration increases by 0.30%, 0.21% and 0.49%, respectively, on average; it decreases with the growth of air moisture content and mass flow rate: for every 1 g/kg rise in air moisture content, the mass flow rate of dehumidification and regeneration air increases by 0.05 kg/s. The equilibrium point concentration decreases by 0.68%, 0.65% and 0.08% on average, respectively; with the increase of solution mass flow rate, the equilibrium point concentration shows a trend of rising and then decreasing and reaches the peak when the solution mass flow rate equals to 0.45 kg/s.

(4) To improve the equilibrium point concentration in extremely hot and humid climate zones, the optimization goal can be achieved by increasing the regeneration side inlet air temperature and solution temperature. When the air and solution state parameters remain unchanged, optimizing flow parameters involves determining the optimal solution flow rate while keeping airflow constant.

Limitation
This study has potential limitations. Although the regression model obtained had good significance, there may still be some degree of error in the model due to limitations in data collection or analysis.

Acknowledgments
This study was financially supported by the National Natural Science Foundation of China (Project No. 52178061) and the Key Program of the National Natural Science Foundation of China (Project No. 51838011). These supports are gratefully acknowledged.

Nomenclature

AAD — average absolute deviation, %
Aₘ — effective heat and mass transfer specific surface area, m²/m³
ADA — absolute dehumidification amount, kg/s
ARA — absolute regeneration amount, kg/s
cₚₑ — water vapor specific heat at constant pressure, kJ/(kg °C)
cₑₑ — specific heat of dry air at constant pressure, kJ/(kg °C)
f — heat transfer coefficient, W/(m²·k)
H — height, m
h — specific enthalpy, kJ/kg
k — mass transfer coefficient, g/(m²·s)
L — thickness, m
Le — Lewis number (dimensionless)
M — ass flow rate, kg/s
m — micro-element mass flow rate, kg/s
NTU — number of transfer unit (dimensionless)
T — temperature, °C
W — width, m
ω — Humidity content, kg/kg
ξ — solution mass concentration, %

Subscripts
a — air
D — Dehumidifier
e — Equivalent solution
in — input
out — output
p — equilibrium point of dehumidifying solution
q — equilibrium point of regenerated solution
R — regenerator
s — solution

References


