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To cite this article: Ruiqi Song *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **562** 012102

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# Study on the Physical Properties of LiCl Solution

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**Abstract.** In the process of dehumidification of the solution, dehumidifier contacts with air directly to achieve the purpose of dehumidification, which is a very important part of air conditioning dehumidification system. Under different working conditions, the basic physical parameters of the liquid desiccant will change, which will have an important impact on the efficiency and performance of dehumidification. LiCl solution is widely used as a desiccant with many advantages such as high efficiency and safety. In this paper, the basic physical parameters of LiCl solution with high accuracy are summarized. Empirical formulas of saturation temperature, surface tension, density, dynamic viscosity, thermal conductivity, specific heat and dilution enthalpy of LiCl solution are summarized. The relationship between different physical properties and temperature, pressure and solution concentration is drawn. The corresponding data tables and graphs are drawn under different working conditions. This conclusion has developed a new idea for the research of desiccant solution, which provides a basis for follow-up research and in-depth research.

## 1. Introduction

In recent years, with the energy crisis and people's demand for high-quality living environment, temperature and humidity independent control air-conditioning system has attracted much attention from domestic and foreign researchers[1-2]. The temperature and humidity independent control air conditioning system is divided into two parts as a whole, one is the cooling part; the other is the dehumidification part[3].Solution dehumidification is a process of adjusting the humidity of air using a salt solution having a humidity control function. The pressure difference between the partial pressure of water vapor of the treated air and the vapor pressure of the surface of the moisture absorption solution is used as the driving force for moisture transfer [4-5]. After desiccation agent by absorbing moisture in the air, reduce the concentration of, dehumidifying diminished capacity, we must return to the regenerator for regeneration solution[6-8]. At present, solution regeneration methods include electrodialysis [9-10], membrane regeneration [11] and packing regeneration. Electrodialysis and membrane regeneration require more complex processes and cost, so they have not been widely used. Packing device can be used for solution regeneration and dehumidification. It has simple structure and high performance. At present, its common form is: spraying the solution on the filler at atmospheric pressure, heating the solution, evaporating the water in the solution and increasing the solution concentration[12].Because the dehumidification and regeneration process of the solution depend on the surface vapor pressure of the solution, the physical and chemical properties of the solution dehumidifier determine whether the dehumidification and regeneration process can be carried out and the efficiency of the process. Studies have shown that [13] salt solution is less corrosive to pipelines and other equipment, and is not easily volatilized into the air to cause indoor air pollution, it is a better dehumidification solution. Zhao Yun et al. showed that[14] at the same solution temperature and concentration, the lithium chloride solution has a lower vapor partial pressure than the lithium bromide

solution and the calcium chloride solution, and the dehumidification performance is better. Therefore, the study of the properties of LiCl solution is particularly important. In this paper, the physical properties of the solution during the regeneration of LiCl solution and the effects of different working conditions on the physical properties of the solution were studied.

**2. Basic Properties of LiCl Solution**
Lithium Chloride has the chemical formula LiCl and has a molecular weight of 42.39. The anhydrous LiCl is a colorless cubic crystal having a relative density of 2.068 g/cm$^3$, a melting point of 605 °C and a boiling point of 1382 °C. Soluble in water, soluble in alcohol, ether. Deliquescent in the air. The aqueous solution is alkaline. LiCl has an excellent moisture absorption effect, and even if the environmental moisture content is extremely low, one LiCl molecule can absorb 1000 times its own mass [15]. Compared to water at the same temperature, water vapor partial pressure is lower than the surface of the solution LiCl. Therefore, under the action of the pressure difference, the LiCl solution absorbs the water vapor in the air, thereby achieving the purpose of dehumidification. After the LiCl solution absorbs water, the concentration gradually decreases, and the moisture absorption capacity gradually decreases. In order to make the LiCl solution reusable, it can be regenerated to increase the concentration of the solution. The core of the regeneration process is to increase the water vapor partial pressure difference between the solution and the air. As the pressure difference increases, the regeneration process is easier. However, the concentration of LiCl solution cannot be increased indefinitely. When the concentration of the solution is supersaturated, the excess solute will crystallize. It has been shown in the literature [16] that the concentration of LiCl solution is 30% to 40%, which has strong moisture absorption ability.

As a dehumidifying agent, LiCl solution is weak in corrosiveness to pipelines, equipment, etc., easy to obtain, more environmentally friendly, and has high cost performance and dehumidification efficiency [17]. Studies have shown that [18-19], LiCl and LiBr solutions have strong moisture absorption capacity, both used widely as desiccants, but the LiCl solution works best. Liu et al [20] In the comparative strength of the dehumidification performance of LiCl and LiBr process, using the method of controlling variable, to ensure that the solution temperature and water vapor partial pressure consistent, was compared at the same mass flow rate of both the amount of dehumidification The results show that the mass transfer performance of LiCl solution is better than LiBr. Koronaki et al [21]. Compared the three solutions of CaCl$_2$, LiCl and LiBr under the same working conditions. Under the same concentration, the dehumidification and efficiency of LiCl solution were better than those of the other two dehumidifiers.

**3. Physical Properties of LiCl Solution**

*3.1. Saturated Temperature of LiCl Solution*
The saturation temperature of a solution refers to the highest temperature that can be reached under a certain pressure, and it has a one-to-one correspondence with the saturated vapor pressure of the solution. In this paper, Baker [22] and Gibbered [23] are used to give the empirical formula of saturated vapor pressure. Using MATLAB to solve the equations in reverse, the saturation temperature is obtained. The applicable temperature range of the formula is 0-100 °C, and the mass fraction of LiCl solution is 0-0.5.

$$\pi \equiv \frac{p_{\text{sol}}(\xi,T)}{p_{\text{H}_2\text{O}}(T)} = \pi_{25} f(\xi,\theta) \tag{1}$$

$$f(\xi,\theta) = A + B\theta \tag{2}$$

$$A = 2 - \left[1 + \left(\frac{\xi}{\pi_0}\right)^{\pi_1}\right]^{\pi_2} \tag{3}$$

$$B = \left[ 1 + \left( \frac{\xi}{\pi_3} \right)^{\pi_4} \right]^{\pi_5} - 1 \tag{4}$$

$$\pi_{25} = 1 - \left[ 1 + \left( \frac{\xi}{\pi_6} \right)^{\pi_7} \right]^{\pi_8} - \pi_9 e^{-\frac{(\xi - 0.1)^2}{0.005}} \tag{5}$$

$$\theta = \frac{t}{T_c} \tag{6}$$

$T_c$ is the critical temperature of water, 647.3 K; $t$ is the saturation temperature of the solution; $\xi$ is the mass fraction of the solution; $\sigma_{H_2O}$ is the surface vapour pressure of pure water, kPa; $\sigma_{sol}$ is the surface vapour pressure of the solution, kPa. The correlation coefficient is shown in Table 1.
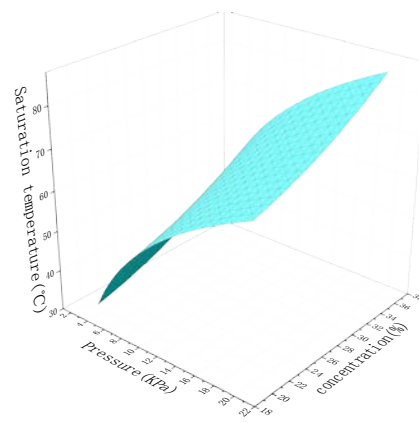
**Table 1.** Calculation coefficient of saturation temperature

| $\pi_0$ | $\pi_1$ | $\pi_2$ | $\pi_3$ | $\pi_4$ | $\pi_5$ | $\pi_6$ | $\pi_7$ | $\pi_8$ | $\pi_9$ |
|------|------|------|------|------|------|------|------|------|------|
| 0.28 | 4.3 | 0.6 | 0.21 | 5.1 | 0.49 | 0.362 | -4.75 | -0.4 | 0.03 |

According to the above empirical formula, the variation curve of the saturation temperature of the solution with different pressures is obtained. The variation of the solution saturation temperature with concentration and pressure is shown in Fig.1.
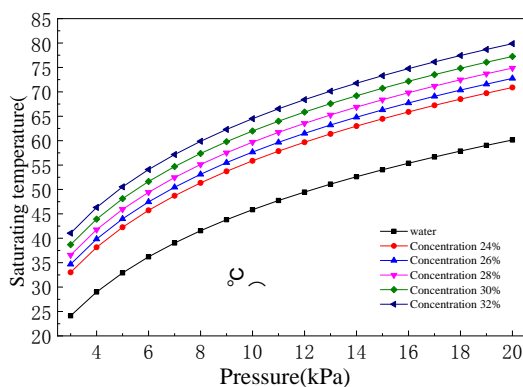


(a) Plan                                  (b) Three-dimensional graph

**Figure 1.**The relationship between the saturation temperature of LiCl solution and the pressure and concentration: (a) Plan; (b) Three-dimensional graph

*3.2. Surface Tension of LiCl Solution*

Surface tension is a force acting on the surface of a liquid. When the surface area of a liquid is reduced, the force for forcing it to shrink is called surface tension. The interface between gas and liquid phase is also called the surface layer. The liquid internal molecules are more and dense, while the molecules outside the surface side are sparse, resulting in a difference in the distance between the inner and outer molecules, thus creating surface tension.

This paper uses the empirical formulas of Palitzsch[24] and IAPWS[25].

$$\sigma_{sol}(\xi, \theta) = \sigma_{H_2O}(\theta)(1 + \sigma_1 \xi + \sigma_2 \xi \theta + \sigma_3 \xi \theta^2 + \sigma_4 \xi^2 + \sigma_5 \xi^3) \tag{7}$$

$$\sigma_{H_2O}(\theta) = \sigma_0 [1 + b(1 - \theta)](1 - \theta)^\mu \tag{8}$$

$$\theta = \frac{t}{T_c} \tag{9}$$

$T_c$ is the critical temperature of water,647.3K; $t$ is the temperature of the solution, K; $\xi$ is the mass fraction of the solution; $\sigma_{H_2O}$ is the surface tension of pure water, mN·m$^{-1}$; $\sigma_{sol}$ is the surface tension of the solution, mN·m$^{-1}$. Other required parameters are shown in Table 2.

**Table 2.** The coefficient of the formula of the surface tension of LiCl solution

| $\sigma_1$ | $\sigma_2$ | $\sigma_3$ | $\sigma_4$ | $\sigma_5$ | $\sigma_0$ | $b$ | $\mu$ |
|---|---|---|---|---|---|---|---|
| 2.757115 | -12.0113 | 14.75182 | 2.443204 | -3.14774 | 235.8 | 0.625 | 1.256 |

According to the above empirical formula, the curve of the surface tension of the solution at different concentrations as a function of the solution temperature can be obtained. The change of surface tension will affect the evaporation speed of water in the solution, which can provide a basis for the later experimental rules. The variation law and calculation results are shown in Figure2.
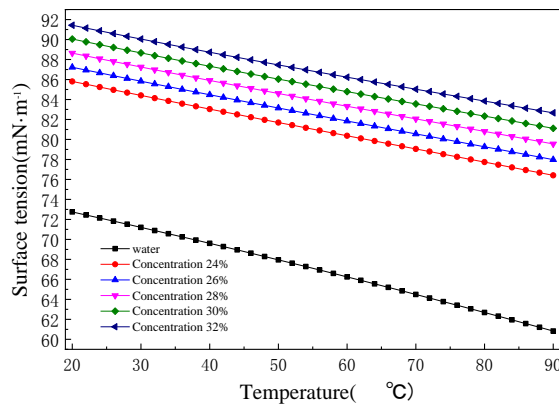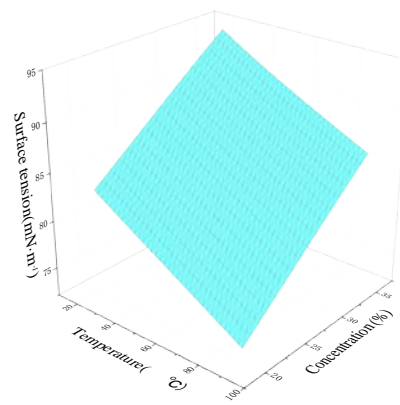


|          (a) Plan          |   (b) Three-dimensional graph   |

**Figure 2.** The relationship between the surface tension of LiCl solution and the temperature and concentration: a Plan; b Three-dimensional graph

### 3.3. Density of LiCl Solution

The density of the LiCl solution is related to the temperature and concentration, and the higher the concentration of the LiCl solution, the higher the density. In this paper, the density calculation method of LiCl solution is calculated by the empirical formula given by Gibson [26]. The applicable concentration range for this formula is 0-0.56.

$$\rho_{sol}(\xi,T) = \rho_{H_2O}(T)\sum_{i=0}^{3}\rho_i\left(\frac{\xi}{1-\xi}\right)^i \tag{10}$$

$$\rho_{H_2O}(\tau) = \rho_{c,H_2O}\left(1 + B_0\tau^{1/3} + B_1\tau^{2/3} + B_2\tau^{5/3} + B_3\tau^{16/3} + B_4\tau^{43/3} + B_5\tau^{110/3}\right) \tag{11}$$

$$\tau = 1 - \frac{t}{T_c} \tag{12}$$

$T_c$ is the critical temperature of water, 647.3K; $t$ is the temperature of the solution, K; $\xi$ is the mass fraction of the solution; $\rho_{H_2O}$ is the density of pure water, kg•m$^{-3}$; $\rho_{sol}$ is the density of the solution, kg•m$^{-3}$. Other required parameters are shown in Table 3.

According to the above empirical formula, the variation of the density of the solution at different concentrations with the solution temperature was obtained. The change law and calculation results are shown in Figure 3.

**Table 3.** The coefficient of the LiCl solution density formula

| $\rho_0$ | $\rho_1$ | | $\rho_2$ | | $\rho_3$ |
|---|---|---|---|---|---|
| 1 | 0.540966 | | -0.303792 | | 0.100791 |
| $B_0$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
| 1.993772 | 1.098521 | -0.50945 | -1.76191 | -45.9005 | -723692 |
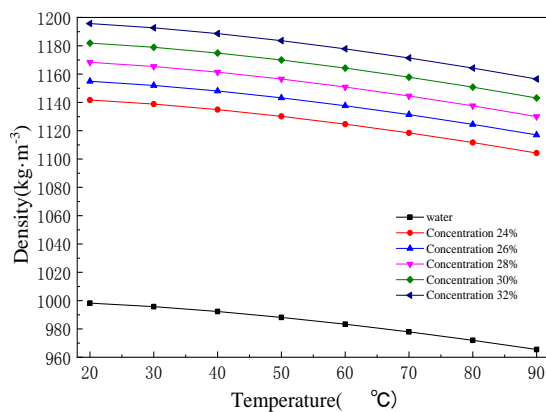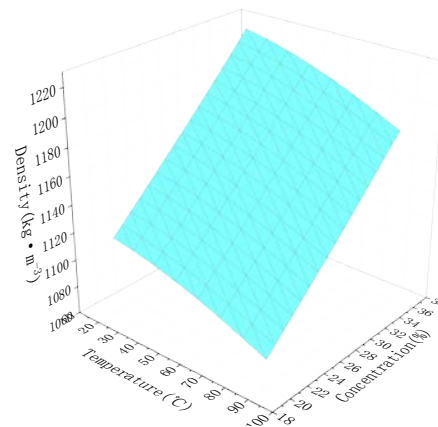


(a) Plan                                          (b) Three-dimensional graph

**Figure 3.** The relationship between the density of LiCl solution and temperature and concentration: a Plan; b Three-dimensional graph

### 3.4. Thermal Conductivity of LiCl Solution

The thermal conductivity of LiCl solution is less studied at this stage, and the data provided is not accurate enough, which may be related to the test method chosen by the researcher. The calculation methods of Riedel [27] and Uemura [28] are used in this paper, and the formula is applicable from 10 °C to 90 °C.

$$\alpha_R \equiv \frac{\lambda_{H_2O}(t) - \lambda_{sol}(t, \xi)}{\zeta_{eq}} \tag{13}$$

$$\zeta_{eq} = \frac{\xi \times \rho_{sol}(t, \xi)}{M} \tag{14}$$

$$\alpha_R = \alpha_0 + \alpha_1 \xi \tag{15}$$

$t$ is the temperature of the solution, K; $\xi$ is the mass fraction of the solution; $\lambda_{H_2O}$ is the thermal conductivity of pure water, W·m$^{-1}$·K$^{-1}$; $\lambda_{sol}$ is the thermal conductivity of the solution, W·m$^{-1}$·K$^{-1}$; M is the molar mass of LiCl, g; $\alpha_0 = 0.010896$, $\alpha_1 = -0.01179$.

$$\Lambda_{H_2O}(\theta) = \Lambda_0(\tau) \bullet \Lambda_1(\delta, \tau) \tag{16}$$

$$\Lambda_0(\tau) = \left[ \tau^{0.5} \sum_{i=0}^{3} n_i^0 \tau^i \right]^{-1} \tag{17}$$

$$\Lambda_I(t) = \exp\left[\delta \sum_{i=0}^{4} \sum_{j=0}^{5} n_{ij}(t-1)^i (\delta-1)^j\right] \tag{18}$$

$\Lambda = \lambda / \lambda^*$ , $\delta = \rho / \rho^*$ , $\tau = T^* / T$ , $\lambda$ and $\lambda^*$ are the thermal conductivity and critical thermal conductivity of water, respectively, $W \cdot m^{-1} \cdot K^{-1}$; $\rho$ and $\rho^*$ are the density and critical density of water, respectively, $kg \cdot m^{-3}$; $T$ and $T^*$ are the temperature and critical temperature of water, respectively, °C; Other required parameters are shown in Tables 4 and 5.

**Table 4.** Coefficient of thermal conductivity of LiCl solution

| $n_0^0$ | $n_1^0$ | $n_2^0$ | $n_3^0$ |
|---|---|---|---|
| 1 | 6.978267 | 2.599096 | -0.99825 |

**Table 5.** Coefficient of thermal conductivity of LiCl solution

| $j$ | $n_{0j}$ | $n_{1j}$ | $n_{2j}$ | $n_{3j}$ | $n_{4j}$ |
|---|---|---|---|---|---|
| 0 | 1.329305 | 1.701836 | 5.224616 | 8.712768 | -1.8526 |
| 1 | -0.40452 | -2.21568 | -10.1241 | -9.50006 | 0.934047 |
| 2 | 0.244095 | 1.651106 | 4.987469 | 4.378661 | 0 |
| 3 | 0.018661 | -0.76736 | -0.27298 | -0.91784 | 0 |
| 4 | -0.12961 | 0.372833 | -0.43083 | 0 | 0 |
| 5 | 0.04481 | -0.11203 | 0.133385 | 0 | 0 |

According to the above empirical formula, the curve of the thermal conductivity of the solution at different concentrations with the solution temperature is obtained. The variation law and calculation results are shown in Fig. 4.
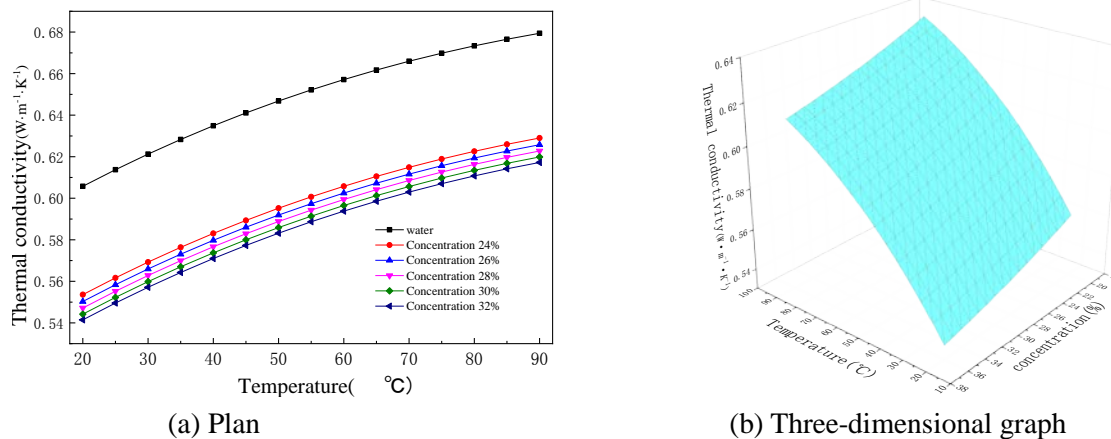


(a) Plan                                          (b) Three-dimensional graph

**Figure 4.** The relationship between the thermal conductivity of LiCl solution and the temperature and concentration: a Plan; b Three-dimensional graph

*3.5. Specific Heat of LiCl Solution*
LiCl solution has many researches on specific heat. In this paper, the calculation formulas of Sato[29] and Angell[30] are used to carry out theoretical calculations.

$$Cp_{sol}(t, \xi) = Cp_{H_2O}(t) \times (1 - f(\xi) \times f_2(t)) \tag{19}$$

$$Cp_{H_2O}(\theta) = A + B\theta^{0.02} + C\theta^{0.04} + D\theta^{0.06} + E\theta^{1.8} + F\theta^{8} \tag{20}$$

$$f_1(\xi) = A\xi + B\xi^2 + C\xi^3 \tag{21}$$

$$f_2(\theta) = F\theta^{0.02} + G\theta^{0.04} + H\theta^{0.06} \tag{22}$$

$$\theta \equiv \frac{t}{228} - 1 \tag{23}$$

$t$ is the temperature of the solution, K; $\xi$ is the mass fraction of the solution; $Cp_{H_2O}$ is the specific heat of pure water, kJ·kg$^{-1}$·K$^{-1}$; $Cp_{sol}$ is the specific heat of the solution, kJ·kg$^{-1}$·K$^{-1}$; Other required parameters are shown in Table 6.

**Table 6.** Coefficient of specific heat formula for LiCl solution

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| 1.4398 | -1.24317 | -0.1207 | 0.12825 | 0.62934 | 58.5225 | -105.634 | 47.7948 |

According to the above empirical formula, the change curve of specific heat of solution with solution temperature at different concentrations is obtained. The variation law and calculation result are shown in Fig. 5.
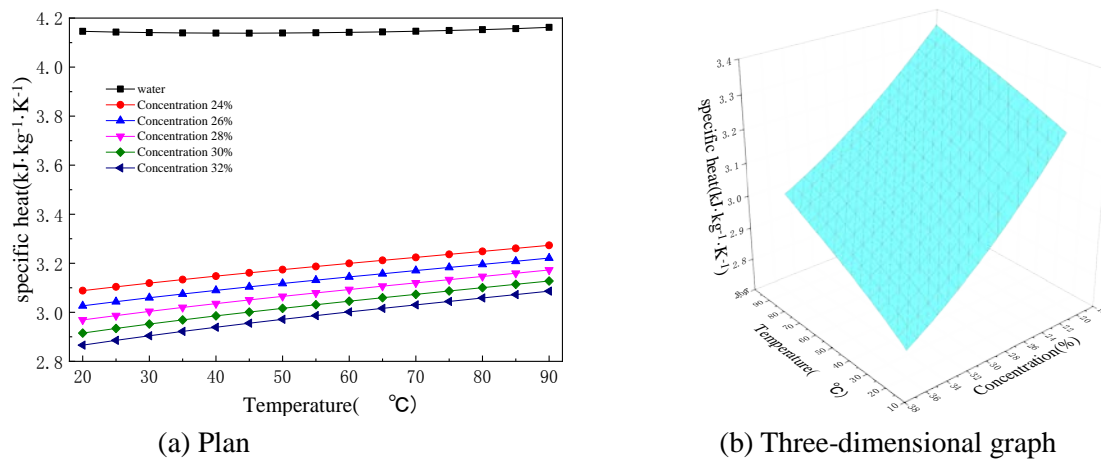


(a) Plan                                                                (b) Three-dimensional graph

**Figure 5.** The relationship between the specific heat of LiCl solution and the temperature and concentration: a Plan; b Three-dimensional graph

*3.6. The Enthalpy Formula for LiCl Solution*
Under a certain temperature and pressure, a certain amount of the solute of the composition of $r_1$ is added to the solution of the solvent B, and a pure solvent is added to dilute it to the solution constituting $r_2$. The enthalpy change of the process is called the dilution of the B solution from $r_1$ to $r_2$.

The calculation formulas of Johnson [31] and Lange [32] are used in this paper.

$$\Delta h_d = \Delta h_{d,0} \left[ 1 + \left( \frac{\zeta}{H_1} \right)^{H_2} \right]^{H_3} \tag{24}$$

$$\zeta = \frac{\xi}{H_4 - \xi} \tag{25}$$

$$\Delta h_{d,0} = H_5 + H_6\theta \tag{26}$$

$$\theta = \frac{t}{T_c} \qquad (27)$$

$T_c$ is the critical temperature of water, 647.3 K; $t$ is the saturation temperature of the solution; $\xi$ is the mass fraction of the solution; $\Delta h_d$ is the dilution enthalpy of LiCl solution, kJ·kg$^{-1}$·K$^{-1}$; Other required parameters are shown in Table 7.

**Table 7.** The coefficient of the enthalpy formula for LiCl solution

| $H_1$ | $H_2$ | $H_3$ | $H_4$ | $H_5$ | $H_6$ |
|---|---|---|---|---|---|
| 0.845 | -1.965 | -2.265 | 0.6 | 169.105 | 457.85 |

Dilution enthalpy is an important physical parameter that reflects the change in heat required for solution changes with concentration and temperature. According to the above empirical formula, the variation curve of the dilution enthalpy of the solution with the solution temperature at different concentrations is obtained. The variation law and calculation result are shown in Fig. 6.
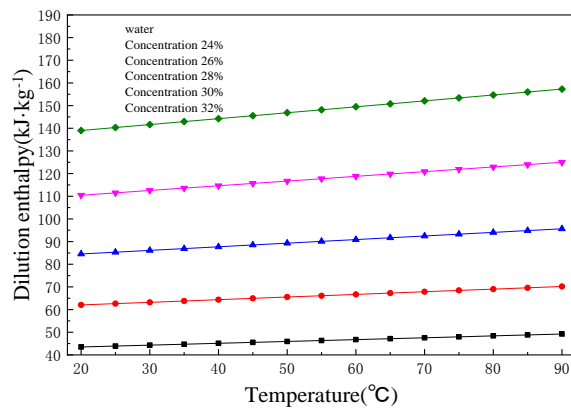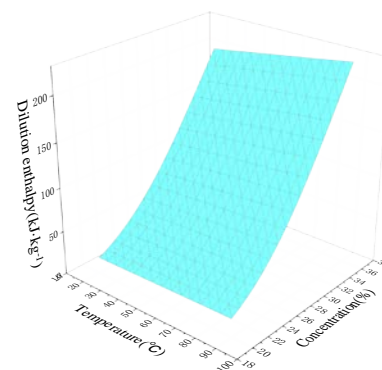


(a) Plan                                      (b) Three-dimensional graph

**Figure 6.** The relationship between the enthalpy of LiCl solution and temperature and concentration: a Plan; b Three-dimensional graph

## 4. Conclusion

This paper first reviews the basic properties of LiCl solution, and introduces its important role in the solution dehumidification system. As a widely used liquid dehumidifier, in addition to high moisture absorption efficiency, it also has a series of advantages such as environmental protection, safety and low corrosivity. . Since the dehumidification and regeneration processes of the solution depend on the surface water vapor partial pressure of the solution, it can be concluded that the physicochemical properties of the solution are the root cause of the efficiency of the dehumidification regeneration process and the efficiency of the process. Therefore, this paper summarizes the physical properties of the commonly used solution desiccant LiCl solution in the solution conditioning air conditioning system by consulting a large number of domestic and foreign literatures, including the physical properties of the most concerned aspects: saturation temperature, surface tension, density, Thermal conductivity, specific heat and dilution. It can be seen that the saturation temperature of the LiCl solution is proportional to the pressure at a certain concentration and proportional to the concentration of the solution when the pressure is constant. Its surface tension and density are inversely proportional to temperature and proportional to the solution concentration. The physical properties such as thermal conductivity, specific heat and dilution enthalpy are proportional to temperature and inversely proportional to solution concentration. At the same time, according to the empirical formula, the variation curves of various physical properties under different working conditions are obtained, and

the variation law is obtained, and the three-dimensional relationship diagram is drawn. The image stereoscopic provides reference for subsequent research.

In summary, the change of physical properties of LiCl solution under different working conditions is directly related to the effect of dehumidification and regeneration. It is of great significance for the study of physical properties of LiCl solution. This paper summarizes the most accurate basic physicochemical properties data before and after the country. Researchers who dehumidify the solution need only consult this article to obtain basic property data, which provides a basis for the selection of solution desiccant.

## 5. Acknowledgment

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