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# Investigation on the regeneration characteristics of LiCl solution with PVP and MWNTs

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**Abstract**

The falling film regeneration performance of a plate type regenerator with the adding of surfactant PVP and MWNTs was experimentally studied. The steady nanofluid contained MWNTs was fabricated firstly. The regeneration characteristics of $LiCl/H_2O$ solution, $LiCl/H_2O$-PVP solution and $LiCl/H_2O$-MWNTs nanofluid were studied and compared under various experimental conditions. The experimental results show that the regeneration effectiveness of $LiCl/H_2O$-PVP solution and $LiCl/H_2O$-MWNTs nanofluid have an improvement of 24.2% and 23.9% respectively compared with that of $LiCl/H_2O$ solution. The improvement results from the increment of wetting area and decrement of falling film thickness. However, the addition of MWNTs into $LiCl/H_2O$-PVP solution has negligible influence on the regeneration performance.



*Keywords:* PVP; MWNTs; regeneration; falling film; contact angle

## 1. Introduction

The regenerator is one of the key components in a liquid desiccant cooling system (LDCS) which is a promising alternative for traditional vapor compression air conditioning due to its promising energy conservation potential and flexible control ability of temperature and humidity [1]. To further improve the heat and mass transfer characteristics of regeneration process, previous researchers have put forward different methods including both the physical and chemical ways. As the most direct way, surface modification has been widely adopted. Some special structures, plate-fin plate [2], super hydrophilic coating plate [3] for example, were tried and investigated. To make a summary, the surface improvement method intends to change the flow pattern of falling film on regenerator to obtain more turbulent flow and greater heat and mass transfer contact area. Other methods, such like adding surfactant or nanoparticles into solution, focused on the modification of liquid desiccant itself rather than the configuration of components in the LDCS [4, 5].

The definition for nanofluid is the steady lyosol contained nanoparticle with the size less than 100nm [6]. Kang et al. [7] researched the absorption characteristics of $LiCl/H_2O$ solution by adding Fe and carbon nanotubes. Kim et al. [8] conducted similar study by adding of $SiO_2$ nanoparticle. MWNTs was added into $LiCl/H_2O$ solution by Wen et al. [9] to study the falling film dehumidification experimentally.

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The present study firstly fabricated the stable nanofluid by adding PVP and mechanical methods. Then, comparative experiments were carried out to study the regeneration performance of $LiCl/H_2O$ solution, $LiCl/H_2O$-PVP solution and $LiCl/H_2O$-MWNTs nanofluid.

## 2. Experimental method

### *2.1. Nanofluid fabrication and stability analysis*

In order to get stable nanofluid, the surfactant PVP, mechanical stirring and ultrasonic vibration were used during fabrication. The detailed dispersion processes are shown in Fig. 1. The concentration of PVP is 0.4 wt% in present study. The particle distribution of $LiCl/H_2O$-MWNTs nanofluid was measured by a Mastersizer 3000 laser diffraction particle size analyzer. The distribution results are shown and compared in Fig. 2. It is clear that no particle aggregation occurs by comparing the particle distribution curves of 0 and 60 days. As a result, it is rational to say that the MWNTs have been steadily dispersed into the $LiCl/H_2O$ solution and the $LiCl/H_2O$-MWNTs nanofluid is appropriate for the following experiments.

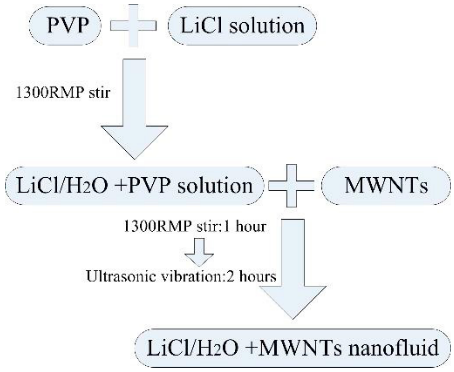


Fig.1. Dispersion processes of LiCl/H2O-MWNTs nanofluid

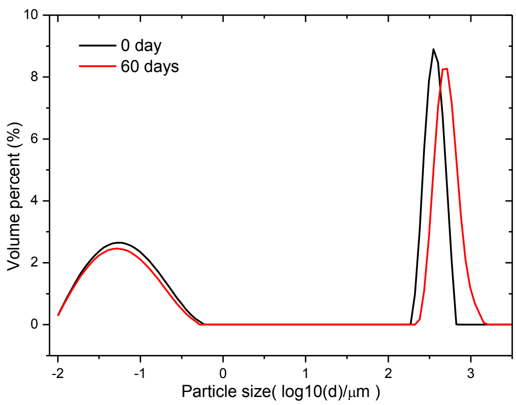


Fig. 2. Particle distribution of the LiCl/H2O-MWNTs nanofluid

### *2.2. Experimental system description*

An experimental system shown in Fig. 3 was designed and built to study the regeneration performance. Three loops, namely solution loop, air loop and hot water loop, are involved in the system. All loops are insulated from the ambient environment by neoprene foam. The specifications of the system can refer to our previous study [10].

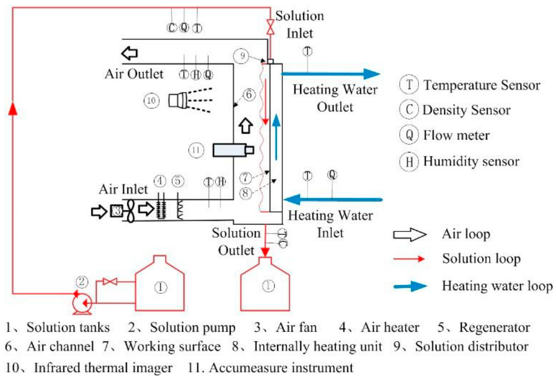


Fig. 3. Schematic diagram of the test bench

### 2.3. Regeneration performance index and experimental system validation

The regeneration effectiveness shown in Equation 1 is selected to evaluate the regeneration performance.

$$\xi = \frac{d_{a,out} - d_{a,in}}{d_{a,e} - d_{in}} \tag{1}$$

The uncertainties of different parameters are determined by the accuracies of sensors and the uncertainty propagation method [11]. All uncertainties are calculated and listed in Table 1.

Table. 1. The uncertainties of different parameters

| Parameter | Uncertainty | Parameter | Uncertainty |
|---|---|---|---|
| Temperature/ $T$ | ± 0.1$K$ | Solution density/ $\rho_s$ | ± 1$kg/m^3$ |
| Air relative humidity/ $\varphi$ | ± 2.5% | Solution concentration/ $X_s$ | 0.2% |
| Solution flow rate/ $G_s$ | ± 3% | Air absolute humidity/ $d$ | 2.8% |
| Cooling water flow rate/ $G_w$ | ± 3% | Regeneration rate/ $\Delta m$ | 5.2% |
| Air flow rate/ $G_a$ | ± 2.2% | | |

The heat conservation equation shown in Equation 2 is checked and the validation results are illustrated in Fig. 4. Almost all the absolute differences of enthalpies are less than 25%. As a result, the rationality of the experimental system is demonstrated.

$$G_s(h_{s,o} - h_{s,i}) = G_w(h_{w,i} - h_{w,o}) + G_a(h_{a,i} - h_{a,o}) \tag{2}$$

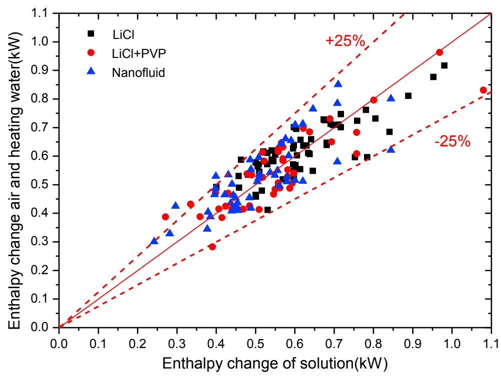


Fig. 4. Validation results of the energy balance

## 3. Regeneration results and discussion

### 3.1. Influence of solution temperature

The effect of solution temperature on regeneration performance is presented in Fig. 5. It is clear that the regeneration effectiveness decreases with solution temperature for all three solutions. Both the regeneration effectiveness for LiCl/$H_2O$-PVP solution and nanofluid have a distinct improvement compared with the LiCl/$H_2O$ solution.

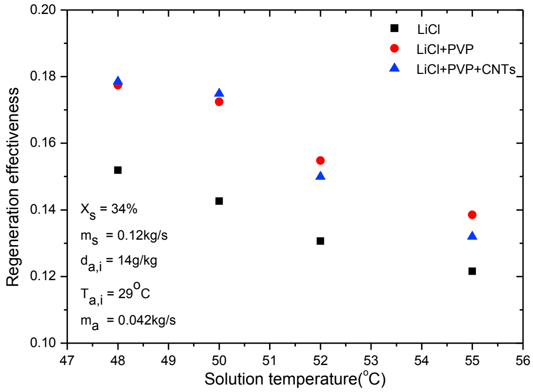


Fig. 5. Influence of solution temperature on regeneration effectiveness

### 3.2. Influence of solution flow rate

The effect of solution flow rate on regeneration characteristics is given in Fig. 6. The regeneration effectiveness maintains around 14.3%, 17.6% and 17.5% for solutions under various flow rates. This is caused by the unimportant effect of solution flow rate on mass transfer coefficient. A relative improvement of 23.1% and 22.4% in terms of regeneration effectiveness for LiCl/$H_2O$-PVP solution and nanofluid is observed.

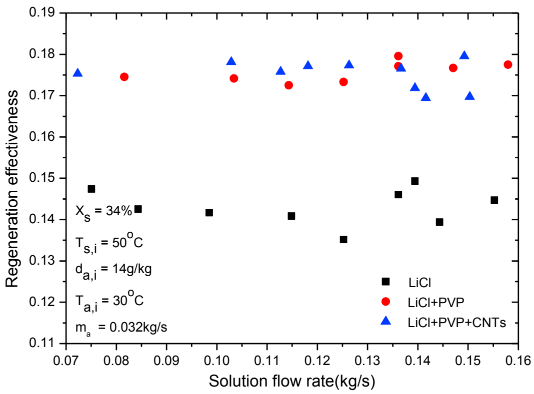


Fig. 6. Influence of solution flow rate on regeneration effectiveness

### 3.3. Influence of air humidity

From Fig. 7, we can see the regeneration effectiveness shows an obvious declining trend with air humidity which is caused by the decrement of mass transfer driving force. When the air humidity has an increment, the mass transfer driving force which is the difference between the air humidity and equivalent water vapor content at the surface of solution has a decrement correspondingly. In line with the previous observations, the regeneration effectiveness for the modified two solution improves obviously compared with the ordinary liquid desiccant.

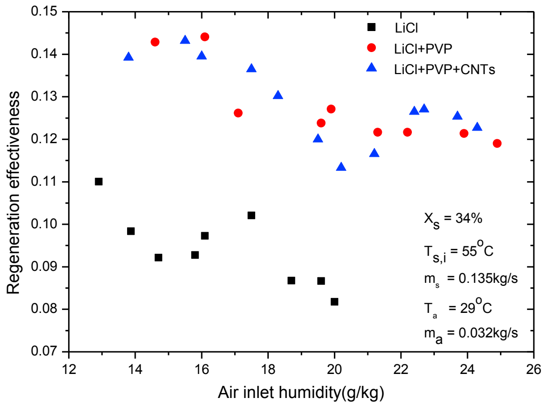


Fig. 7. Influence of air humidity on regeneration effectiveness

### 3.4. Discussion

Averagely speaking, the relative enhancement for regeneration effectiveness are 24.2% and 23.9% for LiCl/$H_2O$-PVP solution and LiCl/$H_2O$-MWNTs nanofluid respectively. The improvement results from the increment of wetting area and decrement of film thickness. The wetting area increases from 0.172m$^2$ for ordinary solution to 0.209m$^2$ and 0.210m$^2$ for the other two modified solution. Greater wetting area corresponds to bigger regeneration rate. A reduction of nearly 0.1mm for both the two modified solutions from 0.681mm to 0.583mm and 0.577mm is observed in the experiments. The decrement of film thickness can result to the increment of heat transfer efficiency between solution and hot water and regeneration effectiveness as well.

## 4. Conclusion

The present study investigated the regeneration performance of LiCl/$H_2O$ solution, LiCl/$H_2O$-PVP solution and LiCl/$H_2O$-MWNTs nanofluid experimentally. Some conclusions are drawn as follows:

(1) The regeneration effectiveness decreases with solution temperature and air inlet humidity. However, it maintains nearly unchanged under various solution flow rates.

(2) An average relative enhancements of 24.2% and 23.9% for regeneration effectiveness are obtained for the two modified solutions. However, the effect of adding 0.1 wt% MWNTs into solution on regeneration effectiveness is negligible.

(3) The improvement can be attributed to the increment of wetting area and decrement of falling film thickness.

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