# Experimental investigation on mechanism of vacuum regeneration of LiCl solution

ZOU Tonghua [1,a], HOU Xiaobing[1,b] , CHANG Yafei [1.c], WANG Wei [1.d], WEI Dongxu[1,e]

[1]Tianjin University of Commerce,Tianjin Key Laboratory of Refrigeration Technology,Tianjin,China

[a]zthua@tjcu.edu.cn,[b]hxb2016@outlook.com,[c]172982776@qq.com,[d]wawe.520@qq.com,[e]weidongxu0932@163.com

**Keywords:**vacuum; vaporization; equivalent thickness

**Abstract.** The solution evaporation in a vacuum is faster than that at the atmospheric pressure, and the required temperature of heat source is relatively low, which can realize the energy conservation. Therefore, it is a subject worthy of investigating. In this experiment, the regeneration process of LiCl solution under vacuum was studied. The effect of equivalent thickness (7mm-16mm), pressure (6kPa-10kPa), temperature difference (10℃-16℃) and concentration (24%-30%) on the regeneration performance of the solution was studied, and the influence of different size of the evaporation bottle (spherical and tapered) on the performance of regeneration was also compared. It is resulted that all the effects from the equivalent thickness, pressure, temperature difference and solution concentration have two sides on the evaporation of LiCl solution. The degree of regeneration of LiCl solution shows a maximum point with the change of equivalent thickness. The research of the present paper also shows that the degrees of regeneration have similar variation trends using different shapes of evaporating bottles, but the trends occur in different pressure ranges. However, the shape of the evaporating bottles has little influence on the location of the maximum value of the regeneration degree. Also, it has little influence on the change tendency of the regeneration degree of LiCl solution with the solution concentration in the process of vacuum evaporation. In addition, the conical evaporation bottle is superior to spherical evaporation bottle in the process of vacuum evaporation regeneration of LiCl solution.

## Introduction

Solution dehumidification technology has been used in many applications, such as archives[1], textile mills, pharmaceutical factories, hospitals[2] and other industrial and large-scale public construction projects.The energy efficiency of the dehumidification system is low due to the high requirement of heat source grade when the dilute solution is regenerated after dehumidification.Therefore, the research of solution regeneration technology has attracted wide attention of scholars at home and abroad.

In the technology of solution regeneration, there are many factors affecting heat and mass transfer, and the law of heat and mass transfer is not easy to get accurately.Zuo Yuanzhi et al.[3] proposed a dual-effect solution regeneration system driven by solar trough collector and gas-fired boiler to realize boiling evaporation regeneration and non-boiling evaporation regeneration, and analyzed the influence of two imported conditions on its regeneration performance;Liu Xiaohua et al[4] used LiBr solution as moisture absorbent to test the dehumidification and regeneration performance of a structured packed cross-flow heat and mass exchange device, and put forward the independent driving force of heat and mass transfer;GaoWenzhong et al.[5] based on the actual solution dehumidification air conditioning system, it is proved that the temperature, concentration and moisture content of regenerated air have great influence on the concentration change of regenerated solution.MEHTA et al.[6] proposed a new type of heat pipe vacuum tube collector, in which the solution can boil in a higher temperature range. The collector can be used to regenerate the solution, and the all-day COP of the collector can be maintained at 0.82;Wen Xiantai et al.[7] proposed a heat source tower solution regeneration device based on air energy recovery, and theoretically analyzed the regeneration performance of the system. The results show that the inlet solution temperature of the condenser will affect the regeneration quantity, system COP and so on;Peng Donggen et al.[8] studied the heat and mass transfer coefficient of solution dehumidification /regeneration based on the consideration of thermal unbalance. The results showed that the temperature and concentration of solution affected the countercurrent heat and mass transfer coefficient of solution and air;LAZZARIN et al.[9] put forward the solution regeneration process with preheating and heating process driven by heat pump, and Qian Junfei et al[10] carried out an experimental study on the regeneration process of solar energy solution, and obtained the influence of important operating parameters of the system on the regeneration performance of solar solution.These studies prove that the heat and mass transfer process in the whole system is very complex and must be studied.

In this paper, an experimental study on the regeneration process of LiCl solution in vacuum was carried out. The influence of pressure and temperature difference on evaporation was studied with the evaporation of solution as the evaluation standard.

## Equipment of experiment

The experimental device mainly includes rotary evaporator, vacuum pump, low temperature liquid bath pot and evaporation bottle. The rotary evaporator mainly consists of heated water bath pot, operating panel, collecting bottle and water catcher.The physical diagram and schematic diagram of the test system are shown in figure 1.

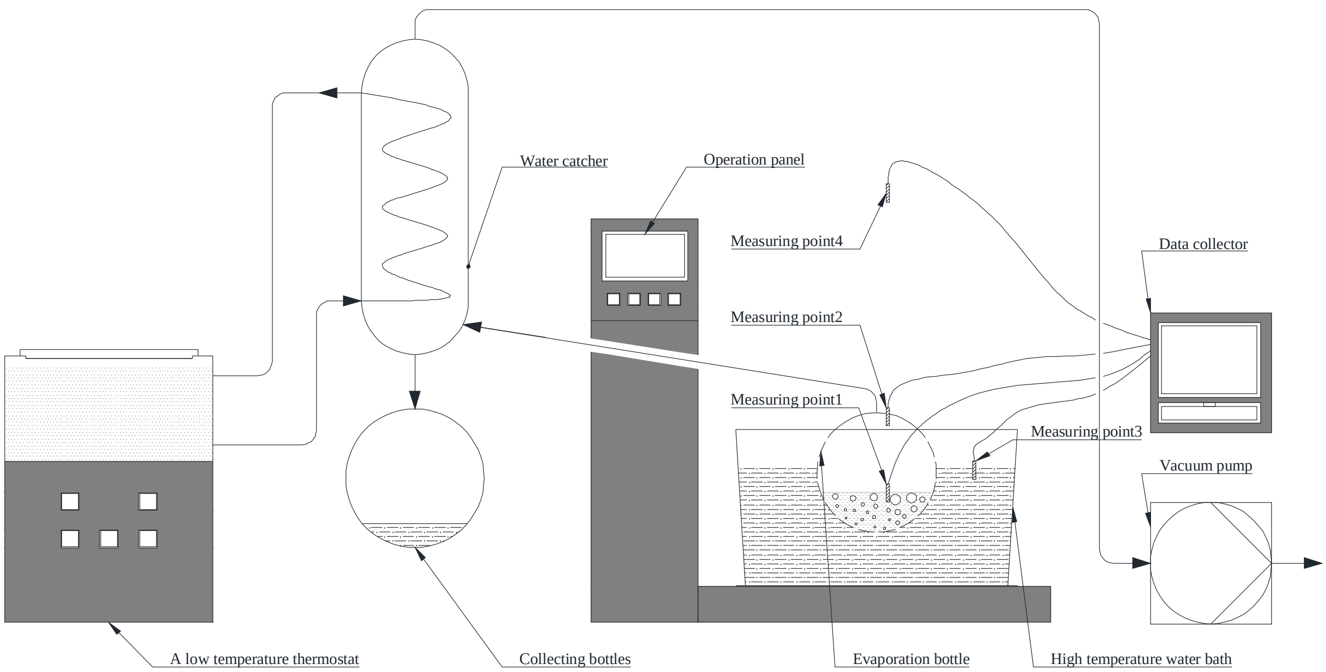


Fig. 1 Schematic diagram of test system

The left side is a low-temperature liquid bath pot, which is used to provide low-temperature liquid for the water catcher. In this experiment, alcohol is used in the low-temperature liquid bath pot; the water collector in the experiment, the collecting bottle and the evaporating bottle are all glass products. The collector is used to collect the condensed water from the collector, and the evaporator is used for the evaporation and regeneration of the LiCl solution. In this experiment, two kinds of evaporating bottles, one spherical and the other conical, are used, each of which has a volume of 500ml; the heated water bath pot is heated for the evaporator. The temperature of water can be set according to the experimental needs; the operating panel is mainly used to control the vacuum degree of the system and the start and stop of the vacuum pump; the test point 1, test point 2, test point 3 and test point 4 are four temperature measuring points. The temperature of LiCl solution, the temperature of gas in evaporation bottle, the temperature of water in heated water bath pot and the temperature of environment were measured respectively. The data of 4 measuring points were recorded by data collector in real time. The evaporation in the experiment is obtained from the total weight difference before and after the experiment of the electronic scale weighing evaporator and LiCl solution. The name of the measuring instrument used in this experiment, the model and accuracy are shown in Table 1.The LiCl solution used in this experiment is obtained by proportional ratio of anhydrous LiCl and pure water.

Table1 Relative parameters of test instruments

<table>
<tr><th>Projects</th><th>Instrument name</th><th>Model</th><th>Measuring range</th><th>Accuracy</th></tr>
<tr><td>Measurement of LiCl solution temperature</td><td rowspan="4">Thermocouple</td><td rowspan="4">TT-K-30-SLE</td><td rowspan="4">-267℃-260℃</td><td rowspan="4">±0.5℃</td></tr>
<tr><td>Measurement of gas temperature in evaporation bottle</td></tr>
<tr><td>Measurement of water temperature in a heated water bath</td></tr>
<tr><td>Measurement of environmental temperature</td></tr>
<tr><td>Data collector</td><td>YOKOGAWA Phn</td><td>GP10</td><td>--</td><td>--</td></tr>
<tr><td>Electronic scale</td><td>Electronic balance</td><td>YP10002</td><td>0-1000g</td><td>0.01g</td></tr>
</table>

## Method of experiment

### Scheme of experiment

Under different vacuum degrees, the concentration of LiCl solution, the temperature difference between hot water bath and evaporation bottle (replaced by temperature difference' in this paper) and the equivalent thickness of LiCl solution in evaporative bottle were changed, respectively. To study the effect of these factors on the experimental results, the equivalent thickness refers to the ratio of the volume of the LiCl solution to the heated area. The specific experimental scheme for spherical and conical evaporators is shown in Table 2.In order to further prove the credibility of the experimental results, A comparative test of pure water evaporation is also designed. The contrast test is carried out with spherical evaporation bottle. The detailed scheme of the contrast test is given in Table 3.

**Process of experiment**

The experimental equipment parameter setting: the low temperature liquid bath pot is set to -10 □, the heating water bath pot liquid level has been kept at about 60mm all the time, the rotational speed of the rotary evaporator is 0.

After the operation of the warm liquid bath pot and the heated water bath pot is stable, the LiCl solution is added to the evaporator, and the evaporation bottle is weighed and recorded. Then the evaporator is connected to the rotary evaporator. When the temperature of the LiCl solution reaches the boiling point under the experimental conditions, the vacuum pump is activated. When the pressure in the system has just reached the set value, the LiCl solution in the evaporator begins to boil and vaporize, and the evaporated water vapor enters the water trap along the pipeline, and the heat is condensed into a droplet in the collector, and then it enters the collector. This completes the whole process. At the end of each experiment, the evaporation bottle was removed, the water from the outer wall of the evaporator was erased, and the weight record was placed on the electronic balance. Then check the liquid level in the heated water bath pot and carry out other experiments according to the experimental plan.

Table 2 Experimental scheme (Difference in temperature)

| Influencing factors | Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Pressure(kPa) | 6 | 6 | 6 | 8 | 8 | 8 | 10 | 10 | 10 |
| Solutin concentration(%) | | | | | 30 | | | | |
| Difference in temperature(□) | 10 | 12 | 16 | 10 | 12 | 16 | 10 | 12 | 16 |
| Equivalent thickness(mm) | | | | | 13 | | | | |

Table 3 Experimental scheme for comparison of pure water (Difference in temperature)

| Infuencing factors | Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Pressure(kPa) | 6 | 6 | 6 | 8 | 8 | 8 | 10 | 10 | 10 |
| Difference in temperature(□) | 10 | 12 | 16 | 10 | 12 | 16 | 10 | 12 | 16 |
| Equivalent thickness(mm) | | | | | 13 | | | | |

**Standard evaluation**

In the experiment, the influence of pressure and temperature difference on evaporation was mainly studied.

The main purpose of this experiment is to study the effect of pressure and temperature difference on the regeneration of LiCl solution in a limited time. The "evaporation" referred to in this experiment is the average water evaporation of regenerated solution per unit volume per unit time.

The formula for calculating evaporation is as follows:

$$w=(m_i - m_0)/(V \cdot t)$$

In the formula $w$ is evaporation ,g·(L·min)$^{-1}$ ; $m_i$ is the total amount of evaporating bottle and adding LiCl solution before experiment ,g; $m_0$ is the total amount of evaporating bottle and residual LiCl solution after experiment ,g; $V$ is the volume of LiCl solution ,mL; $t$ is the time for each group of experiments ,min.

## Experimental data analysis

### Effect of pressure and temperature difference on evaporation

Spherical evaporation bottles during the experiment, the system pressure in the 6kPa~10kPa state, the solution evaporation of LiCl with temperature changes trend as shown in Figure 2; at 10 ℃~16 ℃ LiCl under the condition of solution evaporation with pressure change trend as shown in Figure 5. A contrast test in pure water system, the pressure in the 6kPa~10kPa state next, the evaporation of water per unit volume per unit time with the temperature change trend as shown in Figure 3; at 10 ℃ ~16 ℃ condition, evaporation of water per unit volume per unit time with pressure change trend as shown in Figure 6. The conical bottle evaporation experiment, system pressure in 6kPa~18kPa, evaporation of solution the amount of LiCl increased with the temperature change trend is shown in Figure 4; at 10 ℃~16 ℃ LiCl under the condition of solution evaporation with pressure change trend as shown in Figure 7.

**Trend of evaporation with temperature difference under different pressure**

In Figure 2, the trend of curve is composed of two reasons for the result of the interaction, the first is the temperature increases, boiling LiCl solution becomes more intense, the water vapor LiCl solution surface and air between partial pressure difference, which can promote the water evaporation trend, the second is with the rise in high temperature, boiling LiCl solution the bottle wall surface bubbles increased, evaporation increased, the bubble will increase the heat transfer block, block water evaporation trend. In 6kPa pressure, increased evaporation of LiCl solution with the temperature difference is first and then slow growth, rapid growth, due to the temperature from 12 ℃ to 16 ℃ in the process. The first reason for the increased importance, the more; in 8kPa pressure, the evaporation of LiCl solution with the temperature difference increased basically linear growth, because of increased temperature from 10℃ to 16 ℃ , two reasons of the importance of the proportion of basic nothing changes happened; At the pressure of 10kPa, the evaporation rate increases with the temperature difference first and then the increase is slow and then the rate of growth flattens out again to the "S", because of elevated temperature from 12 ℃ degrees to 14℃, the first reason for the increased importance of more elevated temperature from 14 ℃ to the process of 16℃, increased the importance of second reasons more. This indicates that temperature has two sides in the vacuum evaporation process of LiCl solution. In Figure 3, the reason of the change trend of the curve is consistent with that of Figure 2, but somewhat different curve trend, The reason is that in the process of temperature difference, the degree of interaction between the two causes is different from that in figure 2, so the effect of temperature difference on the vacuum evaporation of LiCl solution. In figure 4, each curve and corresponding to the shape of the curve in figure 2 is the same, but the degree of curvature of curve reduced, indicating that evaporation bottle structure size will affect both reasons in LiCl solution strength gap in the process of vacuum evaporation.

**Variation trend of evaporation rate with pressure under different temperature difference**

In figure 5, the curve trends are the result of two factors interacting ,One is that the higher the pressure, the higher the partial pressure of water vapor in the air, so the smaller the pressure difference between the LiCl solution and the air, the slower the evaporation of water. Secondly, the higher the pressure is, the higher the boiling point of LiCl solution is, and the lower the latent heat of vaporization of water is, the higher the boiling point is, the lower the latent heat of vaporization of water will be, which will promote the evaporation of water. At the temperature difference of 10 □ and 16 □, the evaporation of LiCl solution decreases with the increase of pressure. It is because the first reason in the process of increasing the pressure from 6kPa to 10 kPa is the main reason; at the temperature difference of 12 □, the evaporation of LiCl solution decreases slowly first and then rapidly with the increase of pressure. Because the first reason is more important in the process of increasing pressure from 8kPa to 10kPa, the evaporation of LiCl solution increases first and then decreases with the increase of pressure at 14 □. It's because the second reason for the pressure going up from 6kPa to 8kPa is the main reason, and the first reason for the pressure going up from 8kPa to 10kPa is that the main reason is that the four curves tend to bend downward. It is because the first reason is becoming more and more important. This shows that pressure has two sides in the vacuum evaporation process of LiCl solution. In figure 6, in the vacuum evaporation experiment of pure water, the evaporation rate changes with the pressure. The overall monotonicity is the same, and the reason is the same as in figure 5, but the four curves in figure 5 have a downward trend, and the four curves in figure 6 have a tendency to bend upward, only because in figure 6, The vacuum evaporation experiment of pure water, without the effect of the concentration of LiCl solution, the interaction between the two causes is different. So the concentration of LiCl solution has the dual effect of pressure on vacuum evaporation of LiCl solution. In figure 7, all four curves decrease with the increase of pressure, and the reason is the same as that in figure 5. However, in figure 7, there is no phenomenon that the evaporation of LiCl solution in figure 5 increases first and then decreases with the increase of pressure at 14 □ temperature difference, only because the interaction between the two causes is different. This indicates that the structure size of the evaporator will influence the pressure on the vacuum evaporation of LiCl solution.

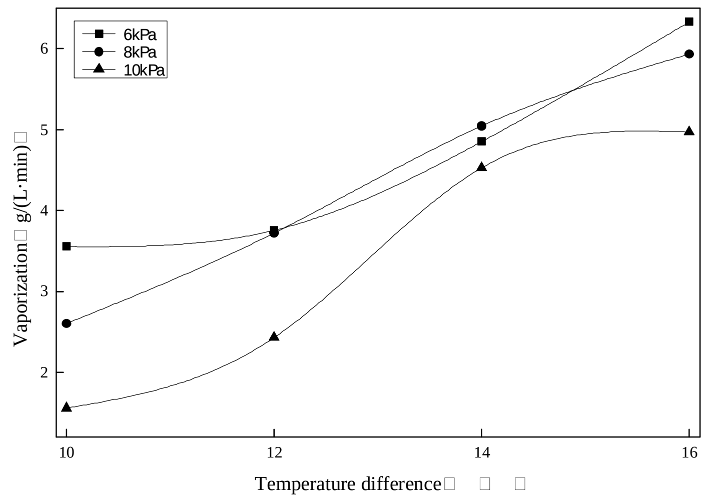


Fig. 2 effect of temperature difference on evaporation under different pressures (spherical evaporation bottle)

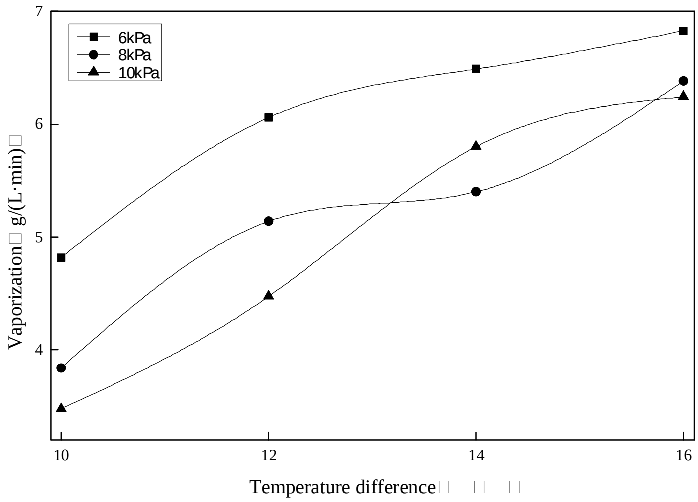


Fig. 3 effect of temperature difference on evaporation of pure water under different pressures (spherical evaporation bottle)

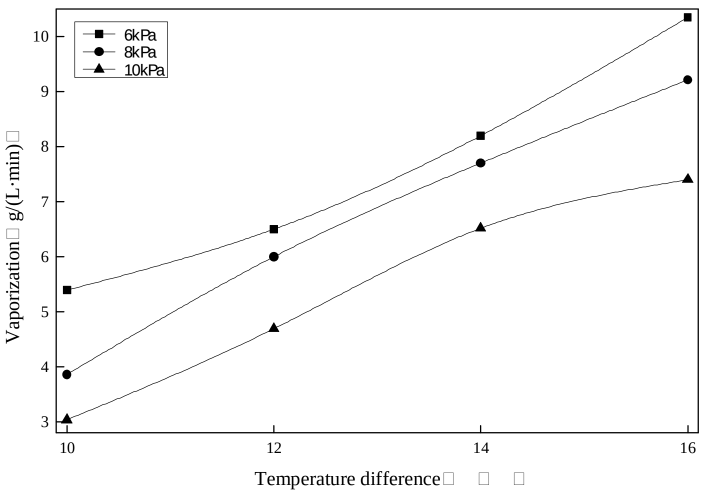


Fig. 4 effect of temperature difference on evaporation under different pressures (conical evaporation bottle)

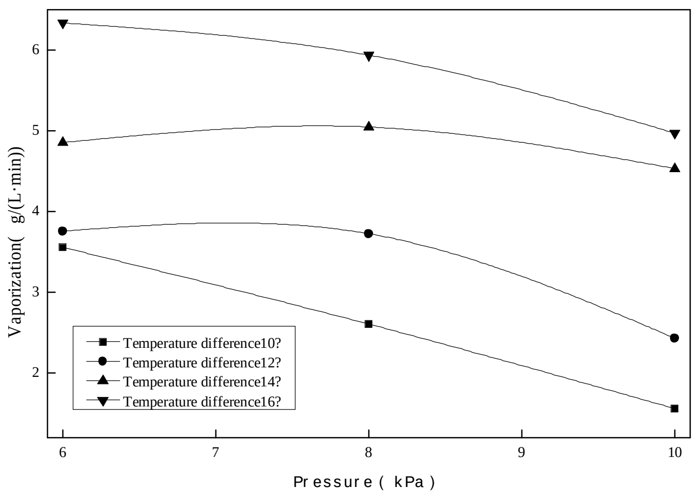


Fig. 5 effect of pressure on evaporation under different temperature difference (spherical evaporation bottle)

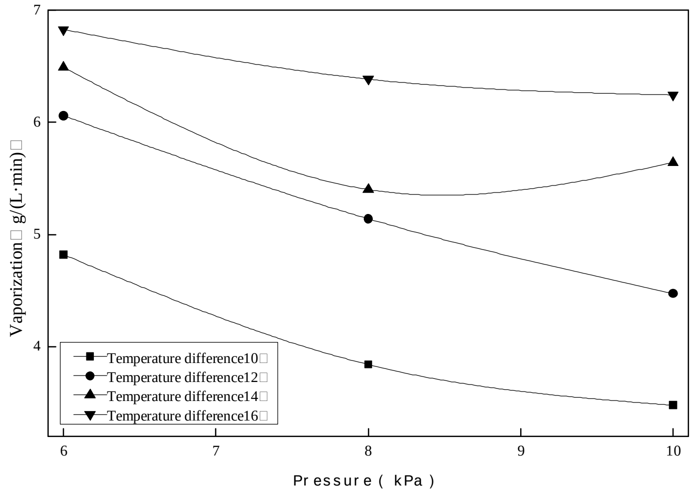


Fig. 6 effect of pressure on evaporation of pure water under different temperature differences

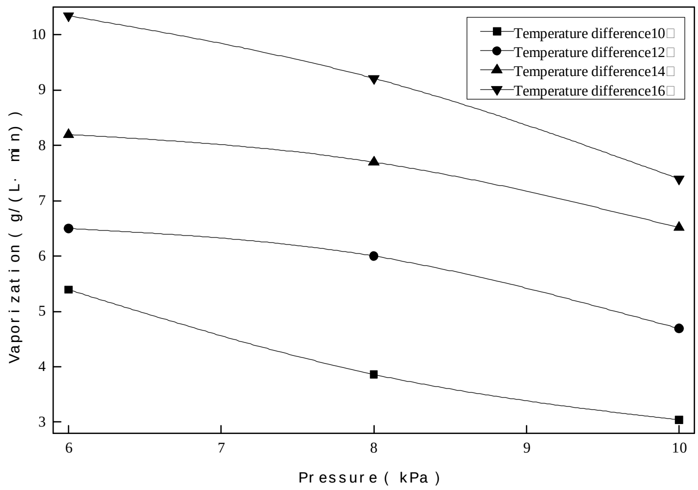


Fig. 7 effect of pressure on evaporation under different temperature difference (conical evaporation bottle)

## Conclusions

In this experiment, the regeneration process of LiCl solution at vacuum was studied. The effects of solution pressure (6kPa-10kPa) and temperature difference (10℃ -16℃) on the evaporation of LiCl solution were studied. The effects of different shape size evaporation bottles (spherical and conical) on solution evaporation were also compared.

The temperature difference has two sides in the vacuum evaporation process of LiCl solution. On the one hand, the increase of temperature difference will generally increase the heat transfer between the heat source and the solution, and there is a tendency to accelerate the evaporation and regeneration, on the other hand, The increase of temperature difference will produce a large number of bubbles on the wall of the evaporative vessel under certain conditions, which will increase the thermal resistance and hinder the evaporation and regeneration. The structural size of the evaporator will affect the gap between the two aspects in the vacuum evaporation process of LiCl solution.

## Acknowledgements

This work was financially supported by the Key projects of Tianjin Applied Foundation and

Frontier Technology Research Program(16JCZDJC31500).

## References


[1] LIU X L,LI J Z,LI Y A,et al. Application of liquid Desiccant Air-conditioning System in Archival Repository [J]. BUILDING SCIENCE,(2010),26(2):67-71.

[2] ZHANG G R,LI M X,HAO C S. Studying on Independent temperature and Humidity Control Applied in Hospital Building [J]. Building Energy & Environment,(2008),27(4):37-39.

[3] ZOU Z Y,YANG X X ,DING J. A double-effect liquid desiccant dehumidifier driven by hybrid solar-trough/gas-boiler [J]. CHEMICAL INDUSTRY AND ENGINEERING PROGRESS,(2009),28(9):1559-1567.

[4] LIU X H,JIANG Y. Temperature and humidity independent control air conditioning system [M]. Beijing: China Building Industry Press,(2006).

[5] GAO W Z,LIU J H,WU Z M,et al. Difference analysis of theoretical and experimental results of the liquid desiccant regenerative performance [J]. HVAC,(2009),7(39):85-89.

[6] MEHTA J R,RANE M V. Liquid desiccant based solar air conditioning system with novel evacuated tube collector as regenerator [J]. Procedia Engineering. (2013),51: 688-693.

[7] WEN X T,LIANG C H,LIU C X,et al. Energy-saving analysis of solution regeneration in heat-source tower based on recovery of air energy [J]. CIESC Journal,(2011),62(11):3242-3246.

[8] PENG D G,CAO R Q,ZHANG X S,et al. Heat and mass transfer coefficients of liquid desiccant dehumidification/regeneration processes with non-thermal equilibrium (□) Experiments and calculation result [J]. CIESC Journal,(2011),62(9):2441-2446.

[9] LAZZARIN R M,CASTELLOTTI F. A new heat pump desiccant dehumidifier for supermarket application [J]. Energy and Buildings,(2007),39(1):59-65.

[10] QIAN J F,YIN Y G,ZHANG X S,et al. Performance of solar liquid desiccant regeneration [J]. CIESC Journal,(2014),65(S2):272-279.

[11] GAO W Z,SHI Y R,CAO D. Concentrating $CaCl_2$ Droplets by Fast Evaporation of Water in Vacuum [J]. CHINESE JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY,(2014),34(9):900-904.

[12] LIU L,MI M L. Thermal Dynamic Study of Vacuum Evaporation of Brine Droplet [J]. CHINESE JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY,(2014),34(6):565-570.

[13] ZOU G W,ZOU T H,HAN Y S,et al. Simulation and experimental study on regeneration of desiccant solution on different conditions [J]. CHEMICAL INDUSTRY AND ENGINEERING PROGRESS,(2016),35(7):1963-1968.

[14] DENG S F,ZOU T H,ZHANG T,et al. Numerical Simulation and Experimental Evaluation of Desiccant-Solution Recycling in Vacuum [J]. CHINESE JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY,(2015),35(5):544-549.