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The Primary Research on Liquid Desiccant Dehumidifier with Cooling Capacity Using Compressible Heat Pump System

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ABSTRACT

In this paper, a new kind of dehumidification system which consists of a dehumidifier, a generator, two heat exchangers and a mechanical vapor compressible heat pump was studied. When this system was operating, the desiccant solution was evenly distributed over the evaporator by many spray heads. The cool from evaporator was utilized to cool the absorption processes and simultaneously cool the air at desired condition to the space. The heat from condenser was utilized to heat diluted desiccant solution for regenerating. Both will enhance the capacity of dehumidification. According to the experimental results and a simplified model, the performance of dehumidifier was discussed under the effects of variables such as flow rate, temperature, concentration of desiccant solution, temperature and humidity of air, the effectiveness of heat exchanger and cooling capacity. The results show that good system performance and energy saving could be achieved if proper values of these variables are selected.

Keywords: liquid desiccant , dehumidification with cooling capacity, heat pump

1. INTRODUCTION

Air dehumidification is an important operation process not only in industry but also in comfort cooling. Although many methods are available for this operation, liquid desiccant system is more attractive due to its flexibility in operation along with an added benefit of absorbing inorganic and organic contaminants in the air and the ability of using a lower regeneration temperature(Oberg and Goswami,1998a). The absorber is the most important component to influence on the efficiency of liquid desiccant system. In order to maximize the heat and mass transfer and to minimize the pressure losses in the absorber, various designs of the absorber component have been investigated(Johannsen.1984,Chung *et al*.1998,Khan *et al*.1996).

Out of above these basic configurations, Howell(1987)investigated a cooled counter-flow absorber built of a falling film fin-tube exchanger,using TEG as desiccant.He found that the experimental data could be correlated with predictions of a simulation model only if a very small fraction of the exchanger surface was supposed to be wetted by the desiccant solution. Queiroz (1988)used an approach similar to a cooling tower design to experimentally and theoretically determine the heat and mass transfer parameters for known inlet and exit conditions of air and solution in an internally-cooled absorber. Beckmann and Albers(1996) developed a liquid desiccant cooling system using LiBr-H_2O solution as desiccant in an absorber which is periodically built up two different types of chambers which are separated by thin metal heat transfer walls.In one chamber the air is dehumidified whereas in the other chamber the heat of absorption is removed by the evaporative cooling of air flow.Khan(1998) in his paper presented a heat and mass transfer performance analysis of an internally-cooled liquid desiccant absorber.

Numerous models have been studied by different scholars to express the heat and mass transfer processes in the dehumidifier, which can be divided into simplified models and complicated models. In complicated models, a step-wise heat and mass balance across the dehumidifier is used to determine the performance of the dehumidification process. Since the outlet conditions of the desiccant are unknown, an iterative solution is necessary until the results converge to the known inlet conditions. In general, the amount of computation is huge and complex. Gandhidasan(2004) developed a relatively simple model for the preliminary design of an air dehumidification process occurring in a packed bed using liquid desiccant through dimensionless vapor pressure and temperature difference ratios. Empirical correlation of moisture effectiveness based on the experimental counter-flow dehumidifier has been given by Ullah(1988) et al. and Chung(1994), which is correlated by flow rate ratio of air to desiccant, inlet temperature ratio of air to desiccant, desiccant inlet concentration etc.

The purpose of the present study is to investigate experimentally a liquid desiccant dehumidifier with cooling capacity using compressible heat pump system, and develop a correlation of moisture effectiveness to predict the dehumidifier performance.

2. EXPERIMENTAL SETUP

A schematic diagram for the proposed liquid desiccant system is shown in Fig.1.The system uses lithium-chloride-water solution as desiccant. As the figure depicts, the system consists mainly of a evaporator as dehumidifier, a condenser as regenerator, a compressor, a expansion valve, a solution tank, two heat exchangers, fans etc. This system is referred to as heat pump type dehumidifier, The blower power is 37W, compressor rated power is 450W, COP of heat pump is 3.0. The desiccant at required temperature and flow rate is sprayed from the top by nozzles to effect a falling film at the surface of the finned-tube evaporator where the process air is crosswise cooled and dehumidified (referring to Fig.2).

The diluted solution that leaves the dehumidifier passes through a heat exchanger where it is first heated by the strong solution leaving the regenerator in a desiccant-to-desiccant heat exchanger. And then the diluted solution is pumped to regeneration sector(condenser) and is heated and concentrated again. The energy resources to regenerate the desiccant is from the heat produced by the condenser of heat pump. The heated, strong solution leaving the regenerator is cooled by dilute liquid desiccant from dehumidifier and cooling water cycling in the water-to-desiccant heat exchanger respectively and send into solution tank where it is stored for dehumidification. Finally, the dry and cool air can be obtained..

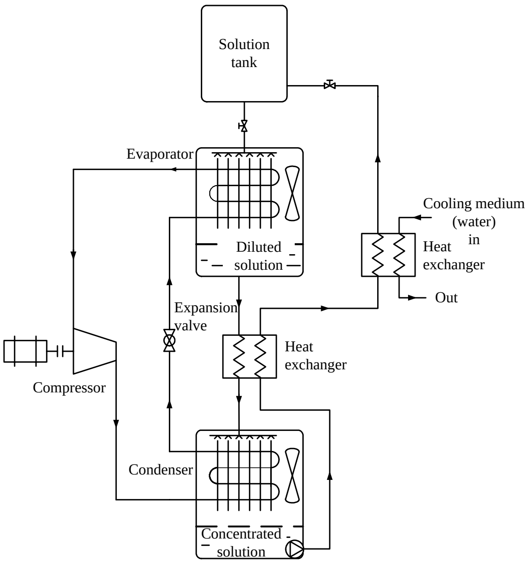

Fig.1 Diagram of experimental setup

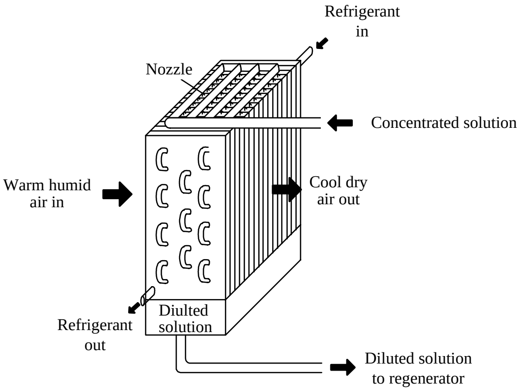

Fig.2 Diagram of the internally cooled liquid desiccant absorber

3. PERFORMANCE INDEXES

During an air dehumidification process, the water vapor from the humid air transfers to the desiccant solution. Many design variable affect the performance of the dehumidification process. The driving force for the mass transfer between the liquid desiccant solution and the air is the difference between the vapor pressure of the desiccant solution and the partial pressure of water vapor in the air. The desiccant solution vapor pressure is a function of its concentration and temperature whereas the partial pressure of water vapor in the air is a function of the air humidity ratio.In the present study enthalpy effectiveness and moisture effectiveness are adopted to predict the dehumidifier performance using liquid desiccant. Enthalpy and moisture effectiveness are defined as the ratio of the actual enthalpy or humidity ratio variance of the air passing through the dehumidifier to the variance under ideal conditions as shown below.

$$\eta_h = \frac{h_{a,in} - h_{a,out}}{h_{a,in} - h_{e,in}} \tag{1}$$

where $h_{a,in}$ and $h_{a,out}$ are the air inlet and outlet enthalpy, respectively. $h_{e,in}$ is the enthalpy of the air, which is at equilibrium with the desiccant solution at a particular concentration and temperature.

$$\eta_m = \frac{\omega_{a,in} - \omega_{a,out}}{\omega_{a,in} - \omega_{e,in}} \tag{2}$$

where $\omega_{a,in}$ and $\omega_{a,out}$ are the water contents of the inlet and outlet air streams, respectively. $\omega_{e,in}$ is the water content of the air ,which is at equilibrium with the desiccant solution at a particular concentration and temperature.

The overall energy balance for the dehumidifier can be written as

$$\dot{m}_a h_{a,in} + \dot{m}_{s,in} h_{s,in} - q = \dot{m}_a h_{a,out} + \dot{m}_{s,out} h_{s,out} \tag{3}$$

where $\dot{m}_a$ is the air flow rate, $\dot{m}_{s,in}$ and $\dot{m}_{s,out}$ are the desiccant inlet and outlet flow rate, respectively, q is the quantity of cooling from the evaporator.

Desiccant outlet flow rate can be written as

$$\dot{m}_{s,out} = \dot{m}_{s,in} + \dot{m}_a (\omega_{a,in} - \omega_{a,out}) \tag{4}$$

The effect of desiccant flow rate on the rate of condensation of water is given in terms of the desiccant concentration at the inlet and outlet of the dehumidifier as

$$\frac{1}{\xi_o} = \frac{1}{\xi_{in}}(1 + \frac{\dot{m}}{\dot{m}_s}) \tag{5}$$

where ξ_{in} and ξ_o are the desiccant inlet and outlet concentration, respectively. $\dot{m}$ is the mass flow rate of water condensed from the humid air.

The mass flow rate of water condensed from the humid air and absorbed by the strong desiccant solution is given by

$$\dot{m} = \dot{m}_a (\omega_{a,in} - \omega_{a,out}) = \dot{m}_a \eta_m (\omega_{a,in} - \omega_{e,in}) \tag{6}$$

Once the moisture effectiveness is determined, the mass flow rate of water condensed from the humid air to the desiccant solution can be obtained with known inlet parameters based on above Eqs. Since the complexity of combined heat and mass transfer processes in the dehumidifier, the effectiveness should be given based on experimental results. The following will give the empirical correlations of moisture effectiveness.

Moisture effectiveness can be rewritten in the form of Eq.(7), according to Eq.(2)

$$\eta_m = \frac{1 - \omega_{a,out} / \omega_{a,in}}{1 - \omega_{e,in} / \omega_{a,in}} \tag{7}$$

The denominator of Eq.7 can be obtained directly by the air and desiccant inlet parameters, hence only the ratio of air outlet humidity ratio to the inlet humidity ratio($\omega_{a,out}/\omega_{a,in}$) is required to predict moisture effectiveness. Ullah et al.(1988) have given the empirical correlation of moisture effectiveness, as shown in Eq.8 .

$$\eta_m = \frac{1-\{b_0\cdot(\frac{\dot{m}_a}{\dot{m}_{s,in}})^{b_1}\exp[b_2\cdot(\frac{t_{a,in}}{t_{s,in}})]/\xi_{in}^{b_3}\}}{1-\omega_{e,in}/\omega_{a,in}} \tag{8}$$

where $t_{s,in}$ is the desiccant inlet temperature.

The constants in the above equation are newly fitted by nonlinear regression of the present experimental data. The exponents for b_0, b_1, b_2 and $b3$ in Eq.(8) are 0.04993, 0.52678,-0.26238 and 2.56393, respectively.

4. RESULTS AND DISCUSSION

In order to investigate the performance of LiCl dehumidifier with cooling capacity, several parameters which affect the performance were studied. The parameters that were considered in this work included air inlet humidity ratio, desiccant concentration, desiccant flow rate, desiccant inlet temperature and air inlet temperature. The air flow rate is 0.0454kg/s, the air inlet humidity ratio was varied from 14.36 to 22.85g/kg. the desiccant flow rate was varied from15 to35g/s,the desiccant inlet concentration was varied from 36% to 44%, the air inlet temperature was varied from 26 to30℃ at an increment of 1℃, the desiccant inlet temperature was varied from 25 to 45℃ at an increment of 5℃.The inlet parameters for the experimental runs are shown in Table1.

Table 1: Inlet parameters for the experiment runs shown in Figs.3－7

	$\dot{m}_a$ (kg/s)	$t_{a,in}$ (℃)	$\omega_{a,in}$ (g/kg)	$\dot{m}_{s,in}$ (kg/s)	$t_{s,in}$ (℃)	ξ_{in} (%)	variable
Fig.3	0.0454	26-30	18.40	0.0353	25	42	$t_{a,in}$
Fig.4	0.0454	30	22.85	0.015-0.035	25	42	$\dot{m}_{s,in}$
Fig.5	0.0454	30	14.36-22.85	0.032	25	42	$\omega_{a,in}$
Fig.6	0.0454	30	22.85	0.0316	25-45	42	$t_{s,in}$
Fig.7	0.0454	30	22.85	0.030	25	36-42	ξ_{in}

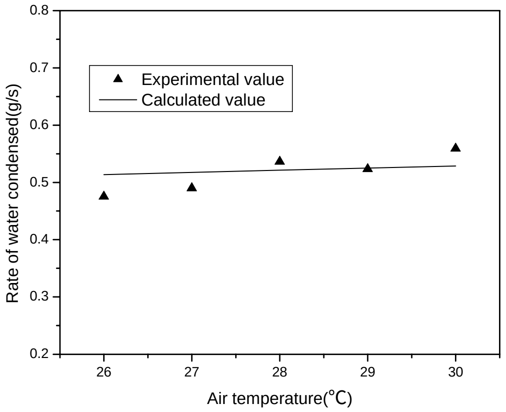

Fig.3 Influence of inlet air temperature on dehumidification

Figs.3－7 show that the experimental results and calculated values with Eq(6) and Eq(8). It is seen from the figures that the adapted present empirical correlation shows very good agreement with the experimental findings. The variables to have significant effect on the dehumidifier performance are: desiccant flow rate, inlet air humidity ratio and desiccant concentration. The water condensation rate almost unchanged with inlet air temperature and desiccant temperature, it can be explained because air and desiccant into the dehumidifier are cooled by the evaporator of heat pump(Fig.3 and Fig.6).

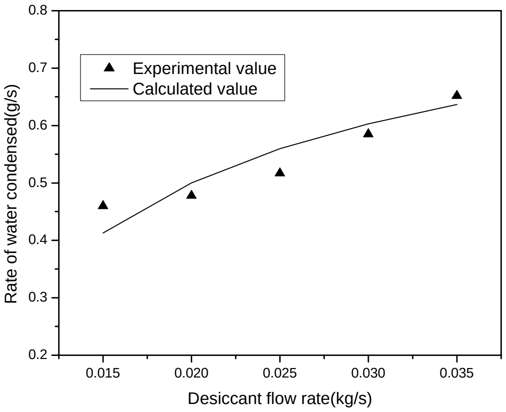

Fig.4 Influence of desiccant flow rate on dehumidification

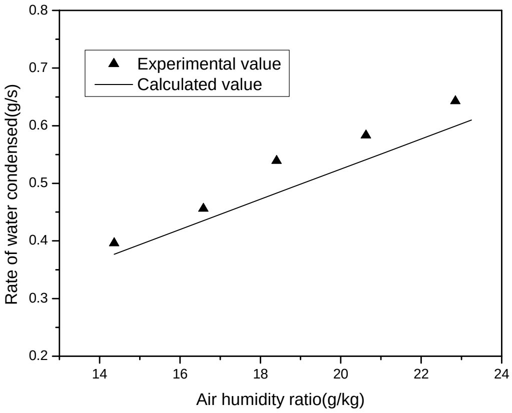

Fig.5 Influence of inlet air humidity ratio on dehumidification

The influence of desiccant flow rate on the air dehumidification process is given in Fig.4, the other five inlet parameters are shown in Table 1. It is obvious from the figure that The water condensation rate increases remarkably with increasing desiccant flow rate. Those effects may be attributed to that with the desiccant flow rate increasing, the variation of the desiccant concentration through the dehumidifier decreases. As the result, increasing the desiccant flow rate decreases the variation of the surface vapor pressure of the desiccant through the dehumidifier and, hence, increases the average water vapor pressure difference between the air and desiccant in the dehumidifier.

It is seen from Fig.5 that the water condensation rate increases with the inlet air humidity ratio increasing, the other five inlet parameters are shown in Table 1. It happens because a higher humidity ratio implies a higher air vapor pressure and consequently higher potential for mass transfer.

Fig.7 shows the effect of desiccant inlet concentration on the dehumidifier performance, the other five inlet parameters are shown in Table 1. As shown in Fig.7, the water condensation rate increaseds significantly with increasing desiccant inlet concentration. The reason is as follows. Increasing the desiccant inlet concentration decreases the desiccant surface vapor pressure and, so, increases the average water vapor pressure difference between the air and desiccant in the dehumidifier, leading to lower air outlet humidity ratio.

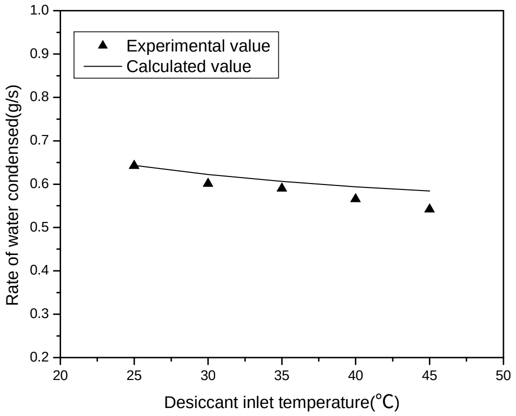

Fig.6 Influence of inlet desiccant temperature on dehumidification

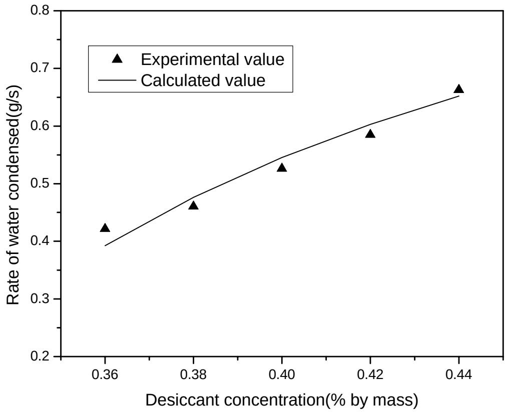

Fig.7 Influence of inlet desiccant concentration on dehumidification.

4. COMPARISON WITH OTHER DESICCANT SYSTEMS

In order to analyze the performance of liquid desiccant dehumidifier in the present study, comparison of the mass flow rate of water condensed from the humid air and the moisture effectiveness was made between the dehumidifiers with and without cooling capacity. Reliable sets of experimental data for dehumidification of air using lithium chloride as the liquid desiccant are presented by Fumo and Goswami(2002). A comparison of typical experimental results for fourteen cases as presented by Fumo and Goswami, with the results obtained from the current study, is given in Table 2. During the comparison, for the present dehumidifier with cooling capacity, the mass flow rate of water condensed from the humid air and the moisture effectiveness were calculated by Eq(6) and Eq(8) with known inlet parameters presented by Fumo and Goswami. The results shown that The mass flow rate of water condensed from the humid air and moisture effectiveness of the dehumidifier with cooling capacity in the present study are much higher than the experimental results of the packed bed absorption tower without cooling capacity in Fumo and Goswami research. This can be attributed to absorption process with cooling capacity that improves the dehumidifier performance significantly.

Table 2: Comparison of calculated results with experimental values in other literature

$\dot{m}_{a.}$ (kg/s)	$t_{a,in}$ (℃)	$\omega_{a,in}$ (g/kg)	$\dot{m}_{s,in}$ (kg/s)	$t_{s,in}$ (℃)	ξ_{in} (%)	Experimental data provided by Fumo and Goswami		Predicted values by Eq.(6) and (8) for the present study	
						$\dot{m}$ (g/s)	η_m (%)	$\dot{m}$ (g/s)	η_m (%)
0.0414	30.1	18.0	0.11	30.1	34.6	0.32	75.5	0.35	84
0.0548	30.1	18.1	0.138	30.3	34.7	0.40	72	0.48	87
0.0703	30.2	18.1	0.088	30.0	34.3	0.52	72.9	0.6	85.3
0.0553	35.5	18.8	0.138	30.3	34.5	0.42	71	0.52	88
0.055	40.1	18.0	0.123	30.5	34.4	0.36	66.8	0.49	92.5
0.0564	30.3	14.2	0.077	30.1	33.9	0.23	67.2	0.29	88.6
0.0552	29.9	21.5	0.089	30.3	33.9	0.53	73.1	0.62	86
0.0553	30.1	18.0	0.065	30.2	34.4	0.38	67.8	0.45	82
0.055	30.2	18.1	0.133	30.2	34.4	0.39	71.1	0.46	83
0.0557	29.9	17.7	0.086	25.0	34.7	0.50	74.1	0.55	82.9
0.0547	29.9	17.8	0.073	35.2	34.9	0.21	52.7	0.32	81.2
0.0549	29.9	17.9	0.118	30.1	33.1	0.36	72.5	0.45	90.7
0.0554	29.9	17.9	0.128	30.2	33.8	0.38	71.4	0.45	88.2
0.0547	30.0	18.1	0.143	30.2	34.8	0.41	72.2	0.52	92

5. CONCLUSION

This paper experimentally studied the dehumidification performance of liquid desiccant(LiCl) dehumidifier with cooling capacity using compression heat pump system. Reliable sets of data for air dehumidification were obtained. It was found that the water condensation rate increased with increasing desiccant flow rate, air inlet humidity ratio and desiccant inlet concentration, and changed very little with air inlet temperature and desiccant inlet temperature. The adapted correlations shows very good agreement with the experimental findings. It is found from the comparison with other literature that absorption process with cooling capacity can improve the dehumidifier performance significantly.

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