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Study on the Performances of Air Flow Fate Effect on a Structured Packed Tower at Adiabatic Condition in a Liquid Lithium Chloride Cooling System

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Abstract

The liquid desiccant air-conditioning system has been proposed as an alternative to the conventional vapor compression cooling systems to control air humidity. The complete system of liquid desiccant air-conditioning system is consisted two main components those are humidifier (regeneration) and dehumidifier. Humidifier part is connected to the load when summer season which is the air condition is hot and humid have to be turned into comfort condition on human. This paper purpose is performances study of air flow rate effect on a structured packed tower on cooling and dehumidifier system using liquid lithium chloride as the desiccant.

Experimental apparatus used in this present study is consisted of three components those are load chamber, packed tower and chiller. Load chamber's volume is $40m^3$, and packed tower dimension is cubic with length 0.4m occupied with packed column. Totally, 15 experimental has done using 5 times repeat on each variable of air velocity that varying on 2m/s, 3m/s and 4m/s with other conditions are controlled. Air inlet initial temperature and relative humidity are set respectively on $30^{o}C$ and 52%, desiccant flow rate is 0.63 kg/s, desiccant temperature is $10^{o}C$ and desiccant concentration is 0.4.

The result of this study shows that averagely, the moisture removal rate and the heat transfer rate are influenced by the air velocity. Higher air velocity will increase the heat transfer and decreasing the moisture removal rate. At adiabatic condition the air velocity of 2 m/s respectively is having the higher moisture removal rate acceleration then the air velocity of 3m/s and 4 m/s until the steady state condition

Key words: Air flow rate, heat and mass transfer, liquid desiccant, lithium chloride, dehumidifier

1. Introduction

The liquid desiccant air-conditioning system has been proposed as an alternative to the conventional vapor compression cooling systems to control air humidity. The largest energy requirement associated with the liquid desiccant system is the heat used for desiccant regeneration, so that the effectiveness of the desiccant regeneration process greatly influences the overall system performance. The regeneration of liquid desiccant can be driven by solar energy, waste heat or other low-grade heat source hence makes this system is suitable to be applied nowadays on global energy crisis.

The complete system of liquid desiccant air-conditioning system is consisted two main components those are humidifier (regeneration) and dehumidifier. Humidifier part is connected to the load when summer season which is the air condition is hot and humid have to be turned into comfort condition on human. Many researches have done on improving the performance of this system.

Liu [3] explains that regenerator effectiveness of the liquid desiccant system increases with desiccant flow rate and inlet concentration, decreases with air flow rate and desiccant inlet temperature, and is affected little by air inlet temperature and humidity ratio. Esam [4] also explains that the packings in the dehumidifier have made of wood or aluminum found that the moisture removal rate increased with increasing inlet triethylene glycol concentration, triethylene glycol flow rate and air flow rate. Both of experiments has done by varying the air flow rates but have different result. This present study purposes is to verify the air velocity effect and also study of performances of air flow rate effect on a structured packed tower on cooling and dehumidifier system using liquid lithium chloride as the desiccant.

2. Experimental setup

2.1 Experimental Apparatus

Experimental apparatus in this experiment is consisted of three components those are load chamber, packed tower and chiller as shown as figure 1. Load chamber's volume is $40m^3$, and packed columns dimension is cubic with length 0.4m. All component including packed column box, load chamber, chiller and pipes are isolated in order minimizing heat losses.

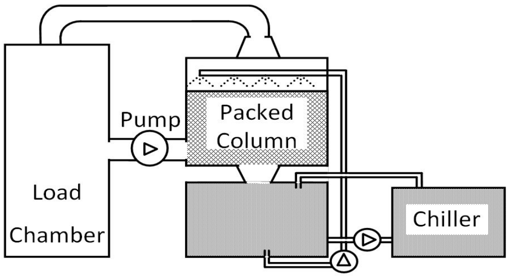

Fig. 1 Experiment apparatus

The packing used on this experiment is shown on figure 2. The diameter of this packing is 3cm and constructed column occupied the packed column box.

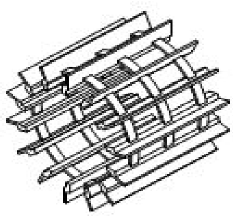

Fig. 2 Packing used in the experiment

Desiccant used in this experiment is liquid Lithium Chloride. Desiccant is flow passing the packed column using pump and also flow passing the chiller.

Air cycle is a flow of humid air from load chamber pumps to the packed column using counter flow orientation against the cooled desiccant flow and after passing the packed column, the output air is flowing back to the chamber.

The desiccant have two cycles, these are the cooling desiccant cycle and feed desiccant cycle. The cooling cycle is a flow of liquid lithium chloride pumps from the desiccant collector to the chiller in order to cooling down the temperature and looped back to the collector. The feed cycle is a flow of desiccant from collector pumps to the top of packed column and flow down to the packed column to meet with air flow due to getting the mass and heat transfer.

2.2 Measuring System

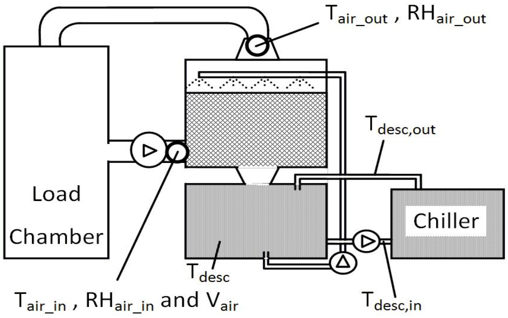

Fig. 3 Measurement System

In order to get the inlet and outlet air properties, relative humidity transducers are placed on those locations. Temperature data got from transducer are used to get the water vapor saturation pressure which is required to determine a number of moist air properties, principally the saturation humidity ratio. Values of the saturation pressure over liquid water for the temperature range of 0 to 200°C are calculated from the following formulas [1]).

$$\ln p_{wa} = \frac{C_1}{T} + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 \ln T \qquad (1)$$

Where $C_1 = -5.8002206\text{x}10^{-3}$; $C_2 = 1.3914993$; $C_3 = -4.8640239\text{x}10^{-2}$; $C_4 = 4.1764768\text{x}10^{-5}$; $C_5 = -1.4452093\text{x}10^{-8}$ and $C_6 = 6.5459673$

The vapor pressure p_s of water in saturated moist air differ negligibly from the saturation vapor pressure p_{ws} of pure water at the same temperature. Consequently, p_s can be used in equations in place of p_{ws} with very little error [2]:

$$p_s = x_{ws}\ p \qquad (2)$$

x_{ws} is the mole fraction of water vapor in saturated moist air at temperature T and pressure p, and p is the total barometric pressure of moist air.

The humidity ratio of moist air w is the ratio of the mass of water vapor m_w to the mass of dry air m_a contained in the mixture of the moist air, in (kg/kg). The humidity ratio (w) can be calculated as

$$w = \frac{m_w}{m_a} \qquad (3)$$

Since dry air and water vapor can occupy the same volume at the same temperature, the ideal gas equation and Dalton's law for dry air and water vapor can be applied and can be rewritten as

$$w = \frac{m_w}{m_a} = \frac{p_w V R_a T_R}{p_a V R_W T_R} = \frac{R_a}{R_W}\frac{p_w}{p_{at} - p_w}$$

$$w = \frac{53.352}{85.778}\frac{p_w}{p_{at} - p_w}$$

$$w = 0.6219\frac{p_w}{p_{at} - p_w} \qquad (4)$$

R_a and R_w are gas constant for dry air and water vapor respectively. For moist air at saturation, becomes

$$w_s = 0.62198\frac{p_{ws}}{p_{at} - p_{ws}} \qquad (5)$$

p_{ws} is pressure of water vapor of moist air at saturation

The difference in specific enthalpy Δh for an ideal gas at a constant pressure can be defined as

$$\Delta h = c_p(T_2 - T_1) \qquad (6)$$

c_p is specific heat at constant pressure, T_1 and T_2 are temperature of ideal gas at point 1 and point 2. As moist air is approximately a binary mixture of dry air and water vapor, the enthalpy of the moist air can be evaluated as

$$h = h_a + h_W \qquad (7)$$

where h_a and h_w respectively are enthalpy of dry air and total enthalpy of water vapor

The moist volume of moist air v is defined as the volume of the mixture of the dry air and water vapor when the mass of the dry air is exactly equal to 1 unit mass (kg), that is

$$v = \frac{V}{m_a} \qquad (8)$$

v is total volume of mixture and ma is mass of dry air. In a moist air sample, the dry air, water vapor, and moist air occupy the same volume. By applying the ideal gas equation, then

$$v = \frac{V}{m_a} = \frac{R_a T_R}{p_{at} - p_w} \qquad (9)$$

From Eq. (4), $p_w = p_{at}\ w/(w+0.62198)$. Substituting this expression into Eq. (9) gives

$$v = \frac{R_a T_R (1 + 1.6078w)}{p_{at}} \quad (10)$$

3. Experimental conditions and procedure

3.1 Experiment condition

Totally, 15 experimental has done using 5 times repeat on each variable of air velocity that varying on 2m/s, 3m/s and 4m/s with other conditions are controlled. Air inlet initial temperature and relative humidity are set respectively on 30^{o}C and 52%, and to get the adiabatic condition, no heat and moisture source are placed on the load chamber, desiccant flow rate is set to 0.63 kg/s, desiccant temperature is 10^{o}C and desiccant concentration is 0.4.

3.2 Experiment Procedures

Every conditions are set first, including load chamber are given an initial air condition on 30^{o}C and 52% RH, lithium chlorides controlled at 10^{o}C and velocity of air is controlled at 2m/s and then all apparatus component runs and data logger are logging the transducer data every second until 1 hour running time.

The procedure of next variables those are air velocity at 3m/s and 4 m/s are done using same procedure as the first variable's procedure and all variable are repeat 5 times experiment and all properties of air are calculated using equation 1 until 10.

4. Result and discussion

4.1 Result

Experiment results of the effect of air flow velocity varying on 2m/s, 3m/s and 4m/s are shown and figure 4-8. Figure 4 shows the moisture removal of air. Moisture removal rate is changed by changing the air velocity, increasing the air velocity will decreasing the moisture removal rate acceleration until 30 minutes running time.

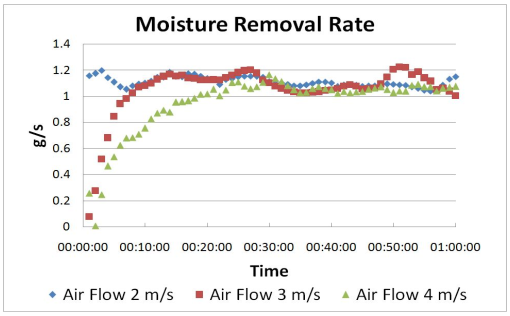

Fig. 4 Moisture removal rates along time

Figure 5 shows the rates of heat transfer. By increasing the air velocity, the heat transfer rate is increased at any time.

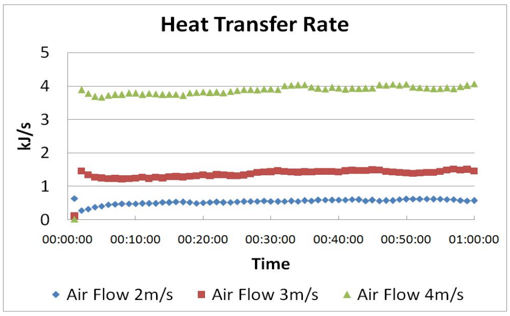

Fig. 5 Heat transfer rates along time

Data on each variation are averaged along the running time and showing on figure 6 until 7. Average moisture removal rates are decreased by increasing the air velocity as shown on figure 6 oppositely, increasing of velocity will increasing the heat transfer between desiccant and air as shown on figure 7.

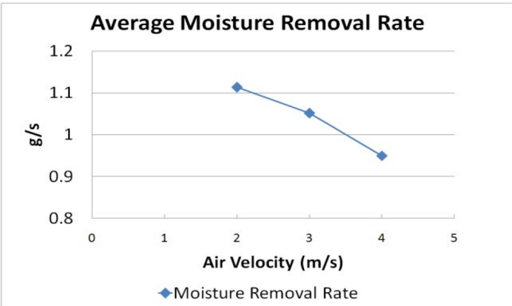

Fig. 6 Moisture removal rates on air velocity variable

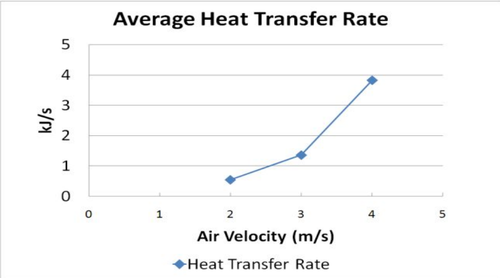

Fig. 7 Heat transfer rates on air velocity variable

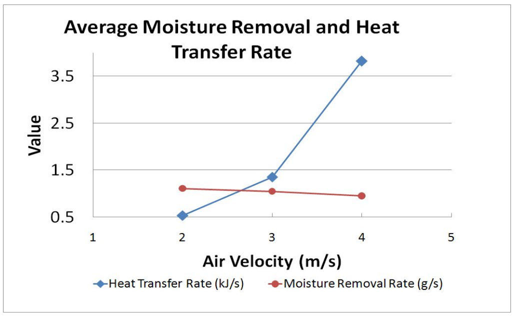

Fig. 8 Moisture removal and heat transfer rates on air velocity variable

4.2 Discussion

The moisture removal rate is influenced highly by diffusion than convection method hence as shown on figure 4 known that final rate of moisture removal are having relatively same values among air velocity variant with value for about 1 g/s. Before that point, lower air velocity is having the highest moisture removal rate acceleration. This phenomenon is caused by the diffusion mass transport is highly influenced by the contact surface area, temperature different between air and lithium chloride and also the concentration. Diffusion speed are high when concentration of desiccant is high but oppositely get low when the velocity is high hence the moisture removal rates at velocity of 2 m/s is come as the highest than 3m/s and 4m/s. On adiabatic condition, the moisture removal rate will tend to constant point that shown when all air velocity variant has the same moisture removal rate as shown on figure 4.

The heat transfer rate is highly influenced by the air velocity. Higher air velocity makes the viscous boundary layer and thermal boundary layer thickness are decreased hence the heat transfer are occurred higher on higher air velocity as shown at figure 5.

5. Conclusion

Averagely, the moisture removal rate and the heat transfer rate are influenced by the air velocity. At adiabatic condition higher air velocity will increase the heat transfer and decreasing the moisture removal rate. This experimental result shows that the air velocity of 2 m/s respectively is having the higher moisture removal rate acceleration then the air velocity of 3m/s and 4 m/s at unsteady state moisture removal region.

6. References

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