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Experimental Study on Heat and Mass transfer Coefficient Comparison Between Counterflow Types and Parallel in Packed Tower of Dehumidification System

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Abstract

In summer electrical energy is consumed in very high rate. It is used to operate conventional air conditioning system. Hot and humid air can germinate mould spores, encourage ill health, and create physiological stress (discomfort). Dehumidifier solar cooling effect is the one alternative solution saving electrical energy. We use surplus heat energy in the summer, to get cooling effect and then to get human reach to comfort condition. These devices have two system, dehumidifier and regeneration system. This paper will be focus in dehumidifier system. Dehumidifier system use for absorbing moisture in the air and decreasing air temperature. When the liquid desiccant as strong solution contact with the vapor air in the packed tower, it works. The heat and mass transfer performances of flow pattern in the packed tower of dehumidifier are analyzed and compared in detail. In this experiment was introduced, the flow patterns are parallel flow and counter flow. The performance of these flow patterns will calculate from air side. Which is the best flow pattern that gave huge mass transfer rate? The proposed dehumidifier flow pattern will be helpful in the design and optimization of the dehumidifier solar cooling system

Keywords : Dehumidifier, Heat and Mass Transfer, Lithium Chloride, Packed Tower

1. INTRODUCTION

The energy crisis is the biggest issue over the world. Fossil fuel as source energy is decrease, on the other side energy consume, pollution and global warming are increase, day by day. The renewable energy is the one of solution to solve energy crisis that covers the every country, especially electrical energy. In the summer electrical energy is consumed in very high rate. It is used to operate conventional air conditioning system. Hot temperature and high humidity causes disadvantage and uncomfortable condition. Heat energy from the sun is the one of renewable energy. It is surplus energy in the summer and we can use it to get cooling effect.

In recent years, extensive research has been performed on the liquid desiccant as solution system. It has advantages in dealing with the latent load of buildings. It can reduce electricity energy [1-4]. Furthermore, an added benefit of the liquid desiccant as solution system is the potential to remove a number of pollutants and bacterial from the air stream [4, 5]. The dehumidifier is the one of the key component in a dehumidifier solar cooling effect. Many researchers have performed experimental test on the heat and mass transfer performance of the dehumidifier of packed bed dehumidifiers and regenerators [2-5]. During experiments, the inlet and outlet parameter of air and desiccant through the dehumidifier can be easily measured, while the temperature and concentration distributions within the dehumidifier are difficult to measure directly.

The packed tower is the most significant heat and mass transfer component in the dehumidifier system. Moisture is transferred from the conditioned air to the desiccant..

The air outlet temperature or humidity ratio may exceed the range of the air and desiccant inlet parameters [3, 5] is a result of the interaction of the heat and mass transfer processes. Knowledge of the air outlet reachable handling region will greatly contribute to the design and optimization of liquid desiccant systems.

Previous experiments have been focused on counter flow [2–5] . In the sensible heat exchanger, the counter flow configuration performs best, and the parallel flow configuration performs poorest at the same conditions. Description of counter flow and cross flow dehumidifier are summarize in figure 1.

The experiment in this paper, we chose several significant effects of the experiment variables. They are air inlet temperature, air humidity, liquid desiccant temperature, liquid desiccant density, air flow rate and liquid desiccant flow rate.

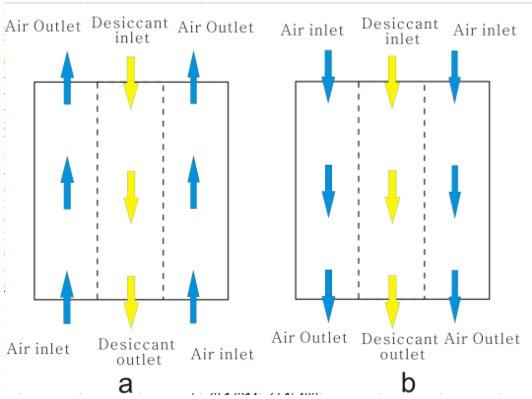

Fig.1 Flow in the packed Tower (a) Counter flow type and (b) Parallel flow type

This paper will present which is the best combination temperature to get optimal mass transfer rate. Then, we can decide which optimal temperature of liquid desiccant to get huge heat and mass transfer effect with low electrical energy consumption, also greatly contribute to the design packed tower and optimization of liquid desiccant cooling system

2. EXPERIMENT SETUP

The Liquid desiccant of air-conditioning has been proposed as an alternative to the conventional vapor compression of cooling system to control air humidity. In this experiment, we use Lithium Chloride as desiccant.

The work principle of dehumidifier system in Counter flow and Parallel flow types as follow;

- Lithium Chloride desiccant as strong solution in storage tank is cooled by chiller. To save electrical energy, temperature of LiCl holed at 18^{0}C. A small pump is supported to circulate 4 lt/mnt LiCl between chiller and storage tank. 15 Lt LiCl in the storage tank is chosen. This volume is relative small because we want to know the LiCl performance in short time.

- The Packed layer dimensions are 400 x 400 x 400 mm^3. It is made of acrylic plastic, the packed structure is uniform. Above of packed layer is LiCl diffuser. It is supported by small pump of LICI circulation from storage tank to the diffuser. Using gravity forces, it drops through packed layer then back to the storage tank.

- To circulate vapor air, we use blower in the outlet duct plastic pipe. The air flow rate holds in 10 m/s circulating inside room.

- In the parallel flow pattern, air inlet is in the above of packed layer and in under packed layer at counter flow pattern. Heat and mass transfer process between air and LiCl desiccant are risen up inside of packed layer.

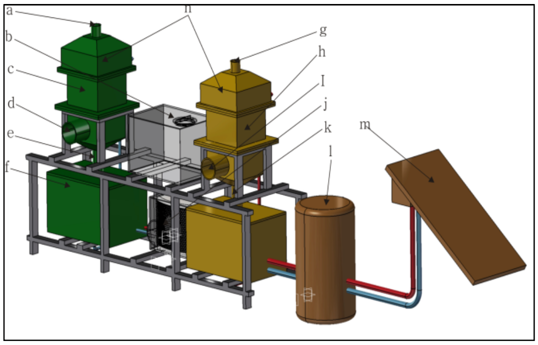

Figure.2 Three dimensional views of dehumidifier solar cooling effect

Where:

a. Inlet air of Parallel flow type or outlet air of Counter flow type in dehumidifier system.
b. Transfer storage tank.
c. Packed tower in dehumidifier system.
d. Outlet air of Parallel flow type or inlet air of Counter flow type in dehumidifier system.
e. Solution outlet
f. Solution storage in dehumidifier system
g. Inlet air of Parallel flow type or outlet air of Counter flow type in regenerator system.
h. Packed tower in regenerator system.
i. Outlet air of Parallel flow type or inlet air of Counter flow type in regenerator system.
j. Chiller
k. Solution outlet
l. Heat-storage tank
m. Solar panel
n. Solution diffuser tank

The property of LiCl liquid desiccant is acid fluid. The problem of corrosion from desiccant has been minimized by changing all part with plastic material and using titanium alloy in the heat exchanger in chiller. The carryover of desiccant with the air has been reduced by putting eliminator at the packed tower of air outlet.

3. MEASUREMENT

The instrument set up as described above was provided with appropriate instrument for making the various measurements.

Liquid desiccant flow rate is measured by *Dewier* placed before diffuser, after pumping on the packed tower. Air flow rate is measured by a *Tesco*, a digital vane type anemometer giving the velocity directly in meter per second.

Air temperature and humidity are recorded by *TandD* digital thermo recorders which have least count of 0.1^{0}C and 0.1 % RH. At inlet and outlet packed bed layer, the thermocouple is recorded by *Fluke Net Data Acquisition System (DAQ)* with at least count of 0.0001°C.

LiCl liquid desiccant temperatures are also measured by Fluke Net DAQ System. Specific gravity is measured by hydrometer. The reading has been taken at various points indicated in the setup diagram (Fig.3)

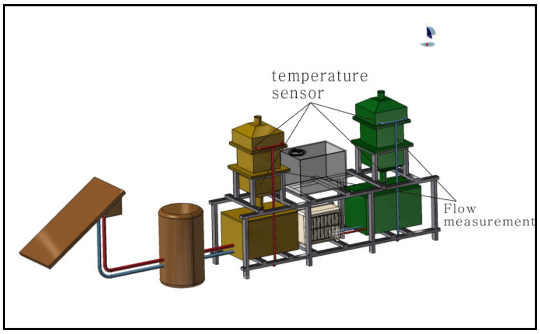

Figure.3 Instrument in the dehumidifier solar cooling experiment

4. Heat and Mass Transfer Calculation

Calculating heat and mass transfer in the packed tower from air side will give complete imagination about all procession compared than from liquid desiccant.

The humidity ratio, enthalpy, and moist volume are as follow:

Humidity ratio of saturated moist air W_s between 0 and 100^{0}F in the psichometric chart can also be calculated by the following simpler polynomial. The humidity ratio of the saturated air at the dry-bulb temperature is:

$$W_s = a_1 + a_2T_s + a_3T_s^{\ 2} + a_4T_s^{\ 3} + a_5T_s^{\ 4} \quad (1)$$

Where T_s = saturated temperature of moist air, ^{0}F(^{0}C)

a_1 = 0.00080264

a_2 = 0.014299

a_3 = 2.542e-06

a_4 = -2.5855e-08

a_5 = 4.038e-10

The saturated water vapor pressure of the air is

$$p_{ws} = \frac{w_s p_{at}}{w_s + 0.62198} \quad (2)$$

The relative humidity ϕ of moist air, or RH, is defined as the ratio of the mole fraction of water vapor x_w in a moist air sample to the mole fraction of the water vapor in a saturated moist air sample x_{ws} at the same temperature and pressure. The water vapor pressure air is

$$P_w = \phi\, p_{ws} \quad (3)$$

Then the humidity ratio of air is

$$w_r = 0.62198 \frac{p_w}{p_{at} - p_w} \tag{4}$$

The following assumptions are made for the enthalpy calculation of moist air:

1. The ideal gas equation and Gibbs-Dalton law are valid
2. The enthalpy of dry air is equal to zero at 0 ^{0}F(-17.8^{0}C)
3. All water vapor contained in the moist air is vaporized at 0 ^{0}F(-17.8^{0}C)
4. The enthalpy of saturated water vapor at 0 ^{0}F(-17.8^{0}C) is 1061 Btu/lb (2468 kJ/kg)
5. For convenience in calculation, the enthalpy of moist air is taken to be equal to the enthalpy of mixture of dry air and water vapor in which the amount of dry air is exactly equal to 1 lb (0.454 kg)

Based on the preceding assumption, the enthalpy h of moist air can be calculated as

$$h = h_a + wh_w \tag{5}$$

Then specific enthalpy of dry air h_a is given by

$$H_a = C_{pd}T = 0{,}240T \tag{6}$$

The specific enthalpy of water vapor h_w at constant pressure can be approximated as

$$h_w = h_{go} + C_{ps}T \tag{7}$$

Then the enthalpy of moist air can be evaluated as

$$h_r = c_{pd}T + w\,(hr_g + c_{ps}T) \tag{8}$$

$$h_r = 0.24T + w(h_{rg} + 0.444T) \tag{9}$$

In moist air, the dry air, water vapor and moist air occupy the same volume. If we apply the ideal gas equation, then moist volume of the air is

$$V_r = \frac{v}{m_a} = \frac{R_a T_R}{p_{at} - p_w} \tag{10}$$

Then, density of the moist air is

$$\rho_r = \frac{m_a}{V} = \frac{1}{v_r} \tag{11}$$

Mass transfer between moist air and liquid desiccant is given by

$$\dot{m} = \omega_{r(in)} - \omega_{r(out)} = \rho_{r(in)} - \rho_{r(out)} \tag{12}$$

5. EXPERIMENT RESULT AND DISCUSSION

The effect of contact air-liquid desiccant flow pattern; counter-flow and parallel flow on the solar cooling system performance will be analyzed in this section.

5.1 Counter flow type

The Lithium chloride desiccant in the dehumidifier device work very well. The room temperature and humidity is hold at 30^{0}C and 95%Rh from the first time until the end (see figure 4).

The trend line of air inlet relative humidity is decrease and become stable in 60%. After 160 minutes temperature inlet and outlet air is unstable. It is caused by work of chiller that it is turn on if temperature LiCl solution above 18^{0}C and turn off if temperature LiCl solution under 18^{0}C.

Using Psychometric chart, we can see

the change of temperature and humidity. In the first time 30C air temperature and 90% relative humidity air come in to the dehumidifier device and then at the outlet air temperature become 26 C and 50% relative humidity.

In, although we hold the air circulating room experiment temperature and humidity, the performance of LiCl solution is show with air inlet temperature and humidity decrease.

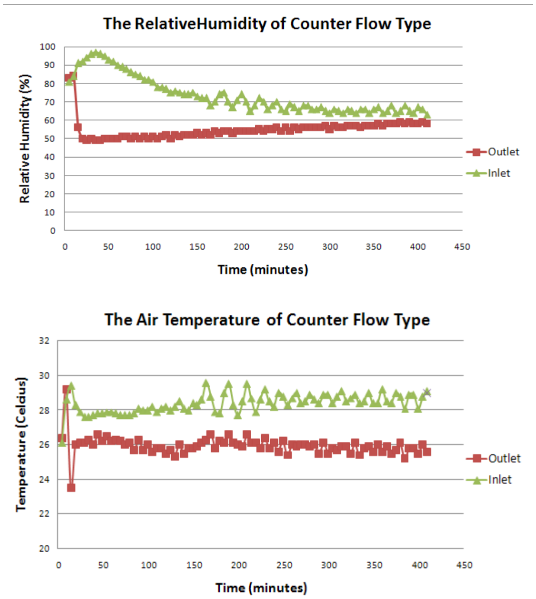

Figure.4 Temperature and humidity circulating air in the room

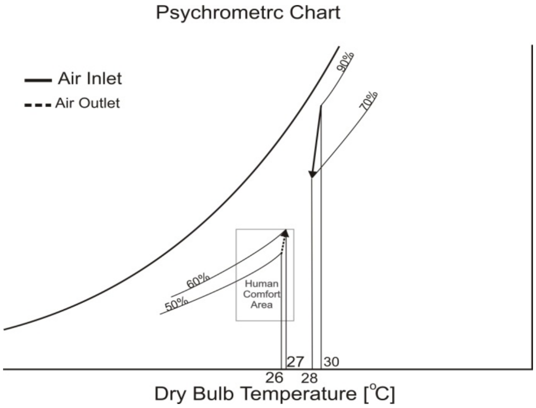

Figure. 5 The Inlet outlet temperature and humidity change in the psychometric chart

After 400 minute LiCl solution become dilute and performance to absorb moist air is decrease. The decrease of LiCl performance is raised by the change of air outlet temperature, from 26C to 27 C and the change of outlet relative humidity from 50% to 60%. At this point the change of temperature and relative humidity is crossed by Human comfort boundary. Although 15Lt LiCl solution sill can absorb moist air, the air is not comfort anymore. We need to regenerate 15 Lt LiCl solution.(See figure 5.)

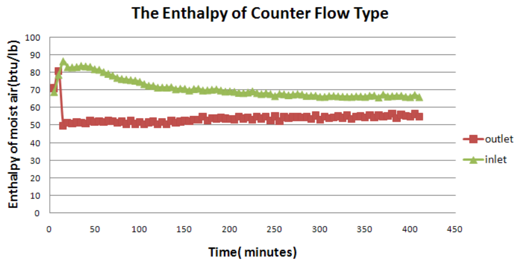

Figure.6 Enthalpy in dehumidifier system

The maximum enthalpy of inlet air is 83 btu/lb, after 230 minutes the it is become stable at 66 btu/lb. And it happened is inlet air that stable after 230 minutes with 54 btu/lb enthalpy. (See figure 6)

5.2 Parallel flow type

In parallel flow type, we only change the pump suction direction. The trend lines of temperatures from first time of experiment until the end of experiment are unstable because the effect of chiller works that turn on when temperature of LiCl above 18^0C and it is turn off when temperature of LiCl below 18^0C.

The minimum air outlet relative humidity is 43%. The trend line outlet air of humidity graph is increasing and if we add time experiment, it will reach human comfort boundary. The trend line of inlet relative humidity is decrease and become stable after 40 minutes at 59 %.(see figure 7)

By psychometric chart we can describe the change of moist air property trough dehumidifier. At the first experiment, we hold room air temperature and humidity at 30^0C and 90%. In the closed circulation room air, the performance of LiCl solution is showed by the change of inlet air temperature and relative humidity to 28^0C and 70 %.(see figure 8)

After 40 minutes experiment, 15 Lt LiCl solutions become dilute. It is showed by the change the air temperature and relative humidity, from 26^0C and 45% to 27^0C and 50%.

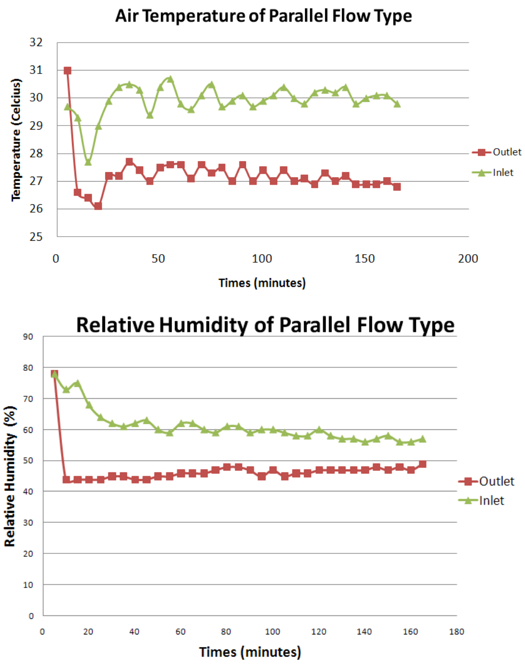

Figure.7 Temperature and humidity in parallel flow

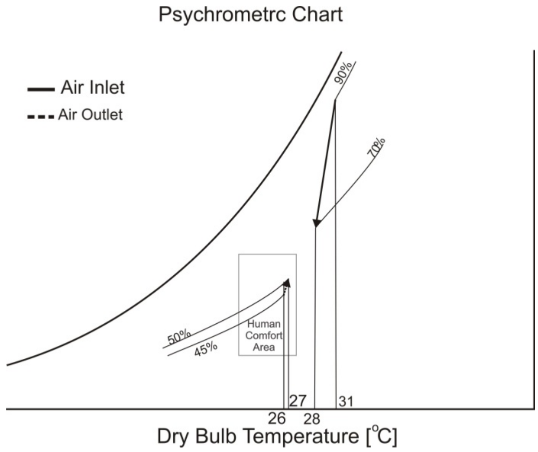

Figure 8 Inlet outlet temperature and humidity change in the psychometric chart

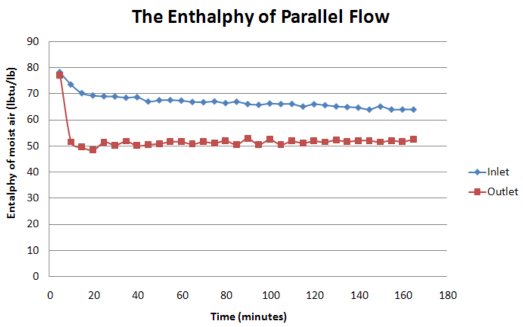

Figure.9 Enthalpy in parallel flow type

Before dehumidifier device work at the first time experiment enthalpy between inlet and outlet air is almost similar, 78 btu/lb. After dehumidifier work, air outlet enthalpy is lower than air inlet enthalpy. The minimum air outlet enthalpy is 49 btu/lb. The trend line become stable after 30 minute in 51 btu/lb. In the other side, the trend line of air inlet enthalpy is decrease.(see figure 9)

5.3 The Comparison between Counter flow and Parallel flow

The mass transfer comparison mass transfer between counter flow and parallel flow is investigated. The mass transfer rate trends lines both of flow are decrease and become stable with add time experiment.

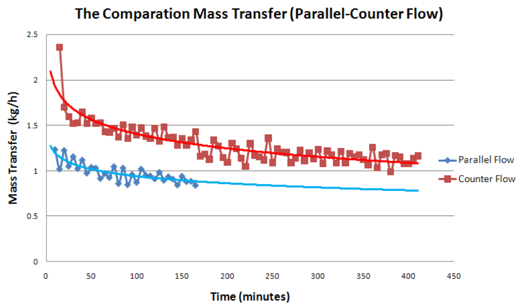

Figure 10 Comparison mass transfers between parallel counter flows

Counter flow mass transfer rate is higher than parallel flow. In the first time experiment, the trend line of counter flow mass transfer rate is 2,2 kg/h.

After 400 minute mass transfer rate is decrease until 1,3 kg/h. In the other side, the trend line mass transfer rate of parallel flow is 1,3 kg/h. After 173 minute mass transfer rate become 0.8 kg/h.(see figure 10).

The time of experiment between counter flow and parallel flow is different. It is happen because we decide stop experiment if the humidity and temperature trend line become stable. The change of mass transfer rate is small.

7. CONCLUSIONS

Performa of Lithium Chloride to in absorbing Vapor air is good. Considering with mass transfer rate, counter flow type is better than parallel flow.

Table 7.1 comparison mass transfer rate

Flow type	15 mnt	75 mnt	155 mnt
Counter flow(kg/h)	2.355	1.466	1.283
Parallel flow(kg/h)	1.021	1.048	0.883

The relative humidity of Counter flow is 60% and 27^{0}C temperature, after 227 minutes experiment. It is reach human comfort boundary and then we need regenerate this solution.

We suggest to other researcher that: The LiCl solution performance will know faster using open circulate room compare with closed circulate room air in constant temperature and relative humidity inlet flow air

REFERENCES

1. Waugman DG,Kini A Kettleborough CF.A review of desiccant cooling system. J Eneg Resour Technol 1993:115(1):1-8

2. Chung TW.Ghosh TK,Hines AL. Comparison between random and structure packing for dehumidification.IND Chem Res 1996:35(1)

3. Patnik S.Lenz TG. Lof GOG Performers studies for an experiment solar open-liquid desiccant air dehumidification system.Sol Eng 1990;44(3):123-135

4. Li WY, Dong Y, Fang CC. The experimental research of liquid dehumidifying system. Acta Energ Solaris Sinica 2000;21(4):391-5[in Chinese]

5. Fumo N, Goswani DY, Study of an aqueous lithium chloride desiccant system: aie dehumidification and desiccant regeneration. Sol Energ 2002;72(4):351-61.