

Study on the Equilibrium Point of Heat and Mass Transfer between Liquid Desiccant and Humid Air with in the Solar Air Conditioning System

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ABSTRACT

The liquid solar air conditioning system is introduced as an alternative solution to control air condition and to save electrical energy consumption. The heat and mass transfer performances of dehumidifier/regenerator in liquid solar air conditioning system are influenced by air and desiccant condition. The application of this system, the thermal energy from the sun and inlet air are unable to control, but operation parameter of other components such as pump, fan and sensible cooling unit are able to control.

The equilibrium point of heat and mass transfer are the liquid desiccant and inlet air conditions, where, the heat and mass are not transferred between the liquid desiccant and vapor air. By knowing equilibrium point of heat and mass transfer, the suitable optimal desiccant conditions for certain air condition are funded. This present experiment study is investigated the equilibrium point heat and mass transfer in various air and desiccant temperature. The benefit of equilibrium point heat and mass transfer will be helpful in choose and design proper component to optimize electrical energy consumption.

Key words: Dehumidifier, Lithium Chloride, Packed Tower.

Nomenclature

T_s = saturated temperature of moist air, ($^{\circ}\text{C}$)

ϕ = relative humidity (%)

w_s = Humidity ratio of saturated moist air

x_w = mole fraction of water vapor

x_{ws} = water vapor in a saturated moist air sample

h_a = specific enthalpy of dry air

h_w = specific enthalpy of water vapor

consumption for air conditioning has been increased every year. It is more used to operate conventional air conditioning system, and then reach human comfort of air condition. In addition, most of conventional air conditioning system is controlled only air temperature; therefore humidity is out of control up to now. The humid air condition is so high that peoples feel hot even though the temperature is not too high. Because of the limitation of conventional air conditioning system, people turn the temperature down. It is consumed electrical energy over and again.

The cooling load of a building related with the air handling system can be divided into two types; the sensible cooling load, and the latent cooling load. The sensible cooling load

1. INTRODUCTION

In the summer, electrical energy consumes very high rate. The rate of electrical energy

that is energy required to change dry air temperature, but not in the moisture content. The latent cooling load is used to reduce the humidity level of the space.

The non-conventional air conditioning system is needed to handle both of sensible cooling load and latent cooling load to get human comfort condition and also electrical energy consumption should be saved by using renewable energy.

Many researchers tested experimentally on the performance of packed bed dehumidifier and regenerator [2-6]. Liquid desiccant air conditioning systems [1-3] have been proposed as alternatives to the conventional vapor compression of cooling systems to control air humidity, especially in hot and humid areas. The dehumidifier is the most significant heat and mass transfer component in the dehumidifier, 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 [3,5-6] is a result of the interaction of the heat and mass transfer processes.

The solar desiccant air conditioning system is the best solution to solve them. But until now, people have difficulties in designing economic system, and deciding proper desiccant condition to get human comfort air. How many cooling/heating loads, that the liquid desiccants are needed at certain humid air condition in the summer.

Equilibrium point is the condition where heat and mass are not transferred between LiCl desiccant and the vapor air. This point can gave us description about process in the solar desiccant air conditioning system. This point is also helpful in heating/cooling energy estimation of LiCl desiccant for certain air condition.

The important benefit of the equilibrium point heat and mass transfer in dehumidification/regeneration solar desiccant air conditioning system research are to choose proper sensible handling unit and to decide optimal time to change from regeneration to dehumidification process.

The targets of the present study are to find the effect of LiCl desiccant temperature and air inlet temperature.

2 Experiment Method

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

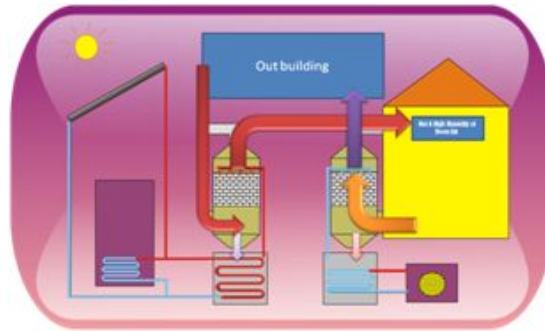


Figure 1 Schematic air flow in the experiment of solar cooling system

Table 1. The Parameter of experiment

Controlled variables	LiCl temp	Air Inlet
Inlet air temperature	32 ⁰ C	32-22 ⁰ C
Inlet air humidity	80%	80%
air flow rate	4 m/s	4 m/s
Desiccant temperature	50 – 25 ⁰ C	20 ⁰ C
Desiccant specific weight	1150	1150
Desiccant circulation flow rate	6 lt/mnt	6 lt/mnt
Total desiccant volume	200lt	200lt
Time /Experiment data	30 second	

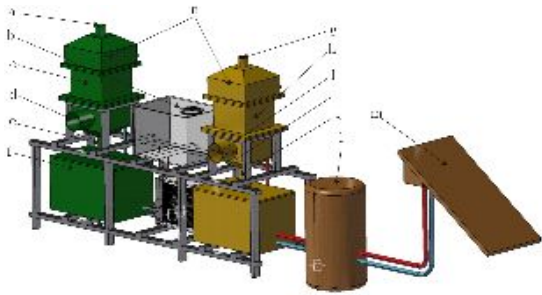


Figure.2 Three dimensional view solar air conditioning system.

Where:

- a. Outlet air Counter flow type in dehumidifier system.
 - b. Transfer storage tank.
 - c. Packed tower in dehumidifier system.
 - d. Inlet air Counter flow type in dehumidifier system.
 - e. Solution outlet
 - f. Solution storage in dehumidifier system
 - g. Outlet air Counter flow type in regenerator system.
 - h. Packed tower in regenerator system.
 - i. Inlet air Counter flow type in regenerator system.
 - j. Chiller
 - k. Solution outlet
 - l. Heat-storage tank
 - m. Solar panel
 - n. Solution diffuser tank
- The Packed layer dimensions are $400 \times 400 \times 400 \text{ mm}^3$. It is made of acrylic plastic and the packed structure is uniform. Top of the packed layer is LiCl diffuser, it is supported by small pump circulate LiCl from storage tank to the diffuser. By using gravity forces, it drops trough packed layer then back to the storage tank.
 - To circulate vapor air, blower is used in the outlet duct of plastic pipe. The air flow rate holds in 4 m/s circulating inside room.

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. The carryover of desiccant with the air has been reduced by putting eliminator at the packed tower air outlet

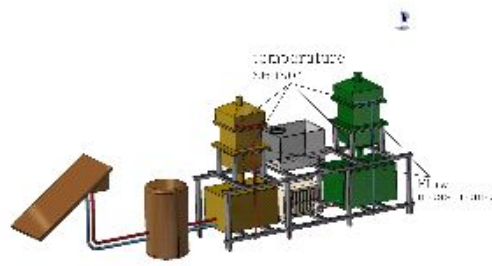


Figure.3 Instrumentation in the dehumidifier solar cooling experiment

3. Instrumentation system

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

Liquid desiccant flow rate is measured by *Denwier* placed before diffuser, after pumped on the packed tower. Air flow rate is measured by *Tesco*, a digital vane type anemometer is gave 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°C and $0.1\% \text{ RH}$. At inlet and outlet packed bed layer, the thermocouple are 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, see figure 3.

4 Calculation mass transfers from air side

Therefore, ideal gas equations will be used in this text for the formulation and calculation of the thermodynamic properties of moist air gradually.

The water vapor saturation pressure is required to determine a number of moist air properties, particularly the saturation humidity ratio. The saturation pressure over liquid water at the temperature range of 0 to 200°C is explained as:

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

Note:

$$C_1 = -5.800 \ 220 \ 6 \ E+03$$

$$C_2 = 1.391 \ 499 \ 3 \ E+00$$

$$C_3 = -4.864 \ 023 \ 9 \ E-02$$

$$C_4 = 4.176 \ 476 \ 8 \ E-05$$

$$C_5 = -1.445 \ 209 \ 3 \ E-08$$

$$C_6 = 6.545 \ 967 \ 3 \ E+00$$

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

$$\phi = \frac{p_w}{p_{ws}} \Big|_{t,p} \quad (2)$$

Humidity Ratio W . 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 lb / lb (kg/kg). The humidity ratio can be calculated as

$$W = 0.62198 \frac{p_w}{p - p_{ws}} \quad (3)$$

Specific volume v . The moist volume of moist air v , ft³ / lb (m³ / kg), 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 lb (1 kg), with the relation $p = p_{da} + p_w$

$$V = \frac{0.2871(t + 273.15)(1 + 1.6078 W)}{p} \quad (4)$$

For the system in Figure 4, the steady-flow material balance equations are,

$$\dot{m}_{da} W_1 = \dot{m}_{da} W_2 + \dot{m}_w \quad (6)$$

Thus,

$$\dot{m}_w = \dot{m}_{da} (W_1 - W_2) \quad (7)$$

3 Calculation heat transfer from air side

Enthalpy h . The enthalpy of a mixture of perfect gases equals to the sum of the individual partial enthalpy of the components. Meanwhile t is the dry-bulb temperature in °C. The moist air specific enthalpy in kJ/kgw the specific enthalpy of moist air can be written as follows:

$$h = 1.006t + W(2501 + 1.86t) \quad (8)$$

the steady-flow energy balance equations are,

$$\dot{m}_{da} h_1 = \dot{m}_{da} h_2 + \dot{q}_2 + \dot{m}_w h_{w2} \quad (9)$$

Thus,

$$\dot{q}_2 = \dot{m}_{da} [(h_1 - h_2) + (W_1 - W_2) h_{w2}] \quad (10)$$

5. Experiment result and discussion

Sensible cooling unit is needed to get human comfort condition. Cooling unit is also raised up moisture absorbing performance of LiCl liquid desiccant. By knowing equilibrium point, will be helpful to chose proper cooling unit and to optimization energy consumption.

Equilibrium point is the condition where heat and mass is not transferred between LiCl desiccant and the vapor air. This point can gave us description about process in the solar desiccant air conditioning system.

LiCl desiccant temperature variable

Figure 4 is the graph of temperature data, the LiCl liquid desiccant gradually down from 52°C to 27°C.

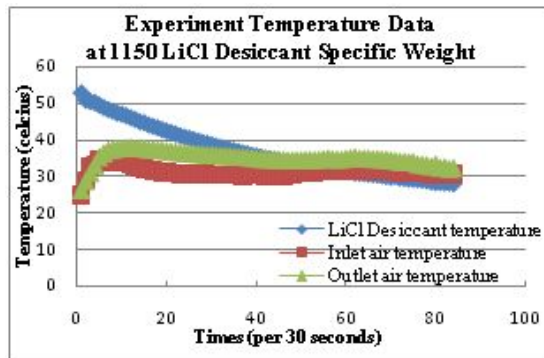


Figure.4 The experiment temperature data at 1150 LiCl desiccant specific weight graph

In the first experiment, the graph is unstable until 8 minutes, the inlet and outlet temperature are 25°C , and become stable at 30°C .It is shown environment condition temperature before solar air conditioning system is work. The trend lines of inlet and outlet temperature are stable. Inlet air temperature is controlled variable at 30°C and 80% relative humidity. Outlet temperature is higher than outlet temperature, it is happened because, at normal condition the same vapor pressure automatically temperature is increased to the higher than 30°C and relative humidity decreased than 80%. After contacting with hot temperature of LiCl desiccant, the outlet air temperature is increase more at 36-37 °C and 45% relative humidity.

The experiment is stopped at 27 °C temperature of LiCl desiccant. In this point outlet temperature is cooler than at the first experiment, but the similar phenomenon appear. Even the vapor pressure decrease, the outlet air temperature is still higher than inlet air temperature, but the relative humidity decrease and stable at 40%.

See figure 5. The equilibrium point of mass transfer is reached at 42°C LiCl desiccant temperature, 15 minutes experiment. In this point the mass is not transfer between LiCl desiccant and vapor air.

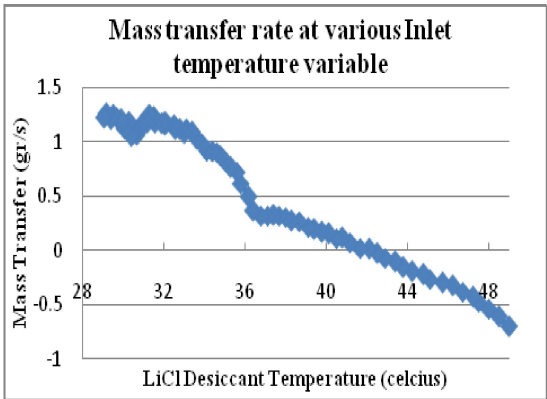


Figure 5 Mass transfer rate at 1150 LiCl desiccant specific weight

In first experiment the LiCl temperature is 50°C and gradually decrease to 42°C, in

this condition the mass is transferred from LiCl to the vapor air (regeneration process), the graph is shown heat transfer rate in minus value. After 15 minutes, LiCl desiccant temperature is decrease from 42°C to 27°C. The mass transfer graph line is raised up become positive value, it means at this condition the mass is transferred from air to the lithium chloride (dehumidification process).

The equilibrium point is shown that at air condition 30°C and relative humidity 80%, to regenerate 1150 LiCl desiccant specific weight, heat sources is needed upper than 42°C.

The equilibrium point of heat transfer rate is reached after 20 minutes experiment in other word, 38°C of LiCl desiccant temperature. In this point, the heat is not transferred between LiCl liquid desiccant and vapor air. The similar trend line appears in mass transfer rate graph, after 10 minutes experiment or LiCl desiccant temperature is lower than 38°C, the mass is transferred from the air to lithium chloride desiccant, and outlet air temperature become cold (as cooler).

The opposite phenomenon appear before 20 minutes experiment in other word, the temperature of LiCl desiccant is upper than 38°C, that the mass is transferred from desiccant to the vapor air, and then the air become warm (as heater). See figure 6.

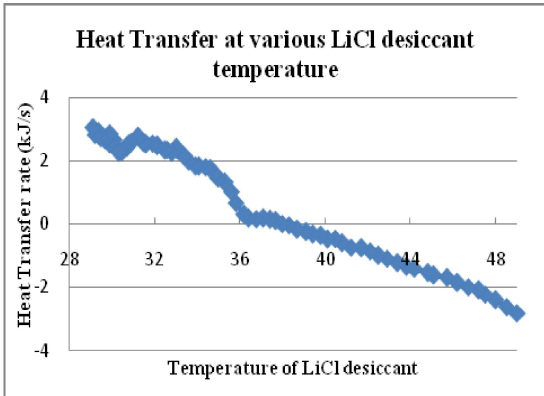


Figure 6 Heat transfer rate at 1150 LiCl specific heat

Variable inlet Air Temperature

The graph shows the air inlet temperature gradually down from 32 to 22°C degree.

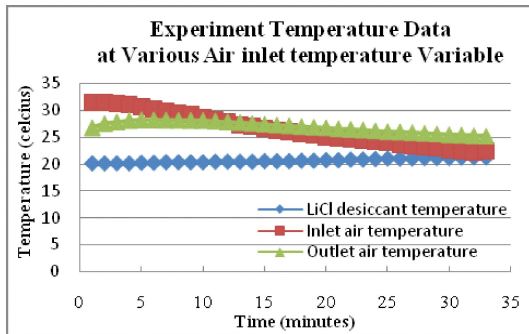


Figure 7. Experiment temperature data at various air inlet temperatures

When the inlet air is contacted with 20°C LiCl desiccant, the outlet air trend line is relative stable at 25–26°C degree. After 13 minutes outlet air is warmer than inlet air, because the heat is added from LiCl desiccant, even LiCl desiccant temperature is lower than air temperature, see heat transfer graph.

The vapor pressure is the expression of the air temperature and humidity properties condition. The inlet vapor pressure air is linier increased with the temperature increase. See figure 7.

It is described that, in the first experiment at 31°C, the inlet temperature and relative humidity is higher than outlet air, it is shown by the inlet vapor pressure on upper side of outlet vapor pressure

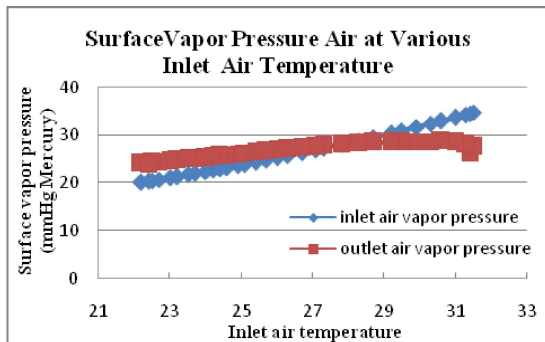


Figure.8 The graph of vapor pressure comparison between inlet and outlet air at various inlet temperature

The difference of vapor pressure is decreased with the decrease of inlet temperature. After the inlet temperature is lower than 28°C, the opposite situation happens. The inlet vapor pressure is lower than outlet vapor pressure. It is described that, in this condition the outlet temperature and relative humidity is higher than inlet temperature and relative humidity because the heat and mass are transferred from LiCl desiccant to the outlet air. See figure 8.

Figure 9 is shown, the trend line of the heat transfer rate is increased with the air inlet temperature increase. The equilibrium point of heat transfer rate is at 26.5°C inlet temperature. If the 20°C LiCl desiccant temperature is operated at upper than 26.5°C inlet air temperature, the heat is transferred from inlet air to LiCl desiccant. However, if the 20°C LiCl desiccant temperature is lower than 26.5°C, the heat is transferred from LiCl desiccant to the air.

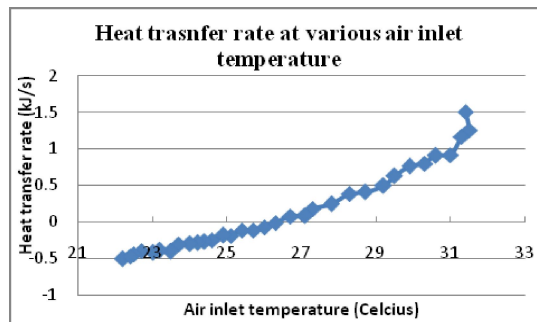


Figure 9The graph of Heat transfer rate at various air inlet temperatures variable

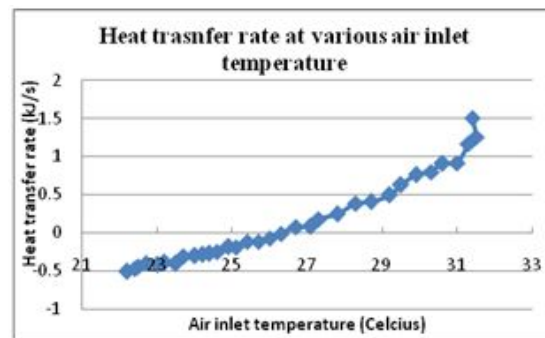


Figure 10 The graph of mass transfer rate at various air inlet temperatures variable

The graph shows that the equilibrium point of mass transfer is happened at 24⁰C inlet air temperature. Upper than 24⁰C of inlet air temperature, the mass transfer position is at the positive point. It is described that the mass is transfer from inlet air to the LiCl desiccant (dehumidification process). In another side, lower than 24⁰C of outlet air temperature, the mass is transferred from LiCl desiccant to the air (regeneration process). See figure 10.

7. CONCLUSIONS

The study case is in the summer with 30⁰C air temperature, 80% relative humidity, 1150 LiCl desiccant specific weight, and 200 Lt Volume desiccants:

- The heat transfer rate is reached equilibrium point at 38⁰C of LiCl desiccant temperature. It means, if the LiCl desiccant temperature below 38⁰C, the heat is transferred from air to the lithium chloride. If the LiCl desiccant temperature below 38⁰C, the heat is transferred from lithium chloride to the air.
- The Mass transfer rate is reached equilibrium point at 42⁰C temperature of LiCl desiccant. The dehumidification process is happened at temperature LiCl desiccant below 42⁰C, and the regeneration process at temperature upper 42⁰C LiCl desiccant temperature. The study case is in the summer with 30⁰C air temperature, 80% relative humidity, 1150 LiCl desiccant specific weight, and 200 Lt Volume desiccants:
- The equilibrium point of heat transfer rate is at 26.5⁰C inlet temperature. If the 20⁰C LiCl desiccant temperature is operated at upper than 26.5⁰C inlet air temperature, the heat is transferred from inlet air to LiCl desiccant. If it is lower than 26.5⁰C, the heat is transferred from LiCl desiccant to the air.
- The equilibrium point of mass transfer is happened at 24⁰C inlet air temperature. It is described that, if inlet air below 24⁰C, the mass is transferred from inlet air to the LiCl desiccant. If inlet air upper 24⁰C,

mass is transferred from LiCl desiccant to the inlet air.

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