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Study Characteristics in Packed Tower of Liquid Desiccant Solar Cooling System Using Counter Flow Configuration

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ABSTRACT

High water vapour content in air can cause a number of problems as for human or surrounding materials. For human a high water vapour can create physiological stress, discomfort, and also can encourage ill health. While, the cause for the environment is can accelerate the corrosion of metals, accelerate the growth of spores and mould, can reduce the electrical resistance of insulators and etc.

Desiccant systems have been proposed as energy saving alternatives to vapor compression air conditioning for handling especially the latent load and also sensible load. Use of liquid desiccants offers several design and performance advantages over solid desiccants, especially when solar energy is used for regeneration. The liquid desiccants contact the gas inside the packed tower of liquid desiccant solar cooling system and the heat transfer and mass transfer will occur. This thesis is trying to study the characteristics inside the packed tower of dehumidifier systems. This characteristics consist of mass transfer rate, heat transfers rate, human comfort and energy that consume by the system. Those characteristics were affected by air flow rates, air temperature and humidity, and desiccant temperature and all that variation will influence the performance of the systems. The results of this thesis later on can be used to determine the best performance of the systems.

Key words: solar cooling, dehumidification, regeneration, lithium chloride

Nomenclature

x	=	*humidity ratio (kg/kg)*
p_w	=	*partial pressure of water vapor in moist air (Pa)*
p_w	=	*atmospheric pressure of moist air (Pa)*
h	=	*enthalpy (kJ/kg)*
T	=	*temperature (^oC)*
ρ	=	*density of moist air (kg/m^3)*
v	=	*specific volume of moist air per mass unit of dry air and water vapor (m^3/kg)*
p	=	*pressure in the humid air (Pa)*
R_a	=	*286.9 - the individual gas constant air (J/kg^{o}C)*
R_w	=	*461.5 - the individual gas constant water vapor (J/k ^{o}C)*
$M_{de}adZ$	=	*mass transfer rate in dehumidifier at Z direction (kg/s)*
G	=	*mass flow rate (kg/s)*
Y_{inlet}	=	*humidity ratio at inlet (kg/kg)*
Y_{outlet}	=	*humidity ratio at outlet (kg/kg)*

1. INTRODUCTION

High water vapour content in air can

cause a number of problems as for human or surrounding materials. For human a high water vapour can create physiological stress, discomfort, and also can encourage ill health. While, the cause for the environment is can accelerate the corrosion of metals, accelerate the growth of spores and mould, can reduce the electrical resistance of insulators and etc [1].

In the industrial world the air humidity control have a huge role to produce a desireable high quality materials. As example is moisture control in printing industry, for several printing process the paper were passed through to a several different printing machine so certain air condition is necessity to maintain quality of the printing. Other problems caused by high humidity are the emergence of static electrical field, waving or paper scrolling or ink that not dry fast [2].

Other applications on humidity control are foods or drinks processing and canning industry, various kinds of breads and cookies making process need humidity between 40-80%, electrical products between 15-70%, pharmacy between 15-50%, tobacco industry 55-88% and etc [3]. So it needs a device or a system to lower the humidity of air or often called with dehumidifier.

To lower the relative humidity can be done by using the absorbent dehumidifier by contacting the lithium chloride solution with air. The lithium chloride solution will absorb the water vapor that contained in the air until the amount of water vapor in the air decreased [1].

Because in under humid outdoor conditions, conventional electric vapour compression cooling systems are not capable of removing the moisture without first cooling the air down below the dew point temperature and then reheating. This method would result in excessive energy requirements and higher utility demand charges. Using desiccant systems to treat the air and remove the moisture from the conventional cooling systems would enable conventional vapour compression systems to meet the new operating requirements without incurring severe energy wastages.

Desiccant systems are growing in popularity because of their ability to independently control humidity levels (latent loads) in buildings, thereby allowing conventional air-conditioning systems to primarily control temperature (sensible loads). In hospital operating rooms as an extreme example of a critical building heating, cooling and ventilation application, humidity and temperature can be controlled separately, allowing the surgeon and operating staff to work comfortably under intense lighting while wearing several layers of protective clothing. There is no need to compromise conditions in, one operating suite because of the demands of a procedure being performed in another served by the same system.

In recent years, applied researchers have become increasingly interested in solar powered cooling systems. The closed cycle adsorption cooling system clearly offers an alternative to conventional cooling technologies. It has a very important advantage in that it needs only low grade thermal energy instead of high grade electricity. Air conditioning is usually carried out using vapour compression systems. However, increased global warming and the environmental impact of chlorofluorocarbon (CFC) and other similar refrigerants on the ozone layer has stimulated interest in developing "environmentally-friendly" air conditioning systems. Liquid desiccants employ packed beds, packed towers, spray chambers or sprayed coil units. These systems have several advantages including lower pressure drop of air across the desiccant material, suitability for dust removal by filtration, lower regeneration temperature and ease of manipulation.

2. EXPERIMENTAL APPARATUS AND TEST PROCEDURE

An experimental apparatus was developed to carry out studies on a liquid desiccant dehumidification. A schematic of the experimental apparatus is shown in Fig. 1. The dehumidifier tower was constructed 40cm length × 40cm width it made from acrylic to allow for flow visualization. The height of the tower is constant and equal to 95cm. In this experiment used plastic packing because better suited and more efficient, light in weight. The plastic packing was stuffed using an orderly position, has 3 cm height and 3 cm diameter. And place inside tower using the name of packed layer. The packed layer is 35cm height, 35cm width and 35cm height. The packed column systems consist of a fan, heat exchanger, chiller and pump. Fan driven by variable speed direct current motor provides the air supplies. A large chamber at the bottom of the tower provides a good air distribution entering the column, whereas an acrylic with holes at the top removes desiccant droplets carried out by the air at the highest velocity. Lithium chloride was stored in an acrylic tank about 50 liters, and after the lithium chloride regenerated by regenerator then the liquid lithium chloride will be cooled by chiller. The liquid lithium chloride is cooled between 10-20 ^{O}C and became concentrated liquid. The basic operation of dehumidifier is after the liquid desiccant leave the regenerator and enters the heat exchanger tank and then will be cooled using chiller. Lithium chloride distributed over the packed column using spray heads evenly spaced in square configuration. An air dehumidification system is shown in Fig. 1. The system consists of two loops: the air dehumidification loop and the liquid desiccant regeneration loop. Both of them using a counter flow packed column configuration.

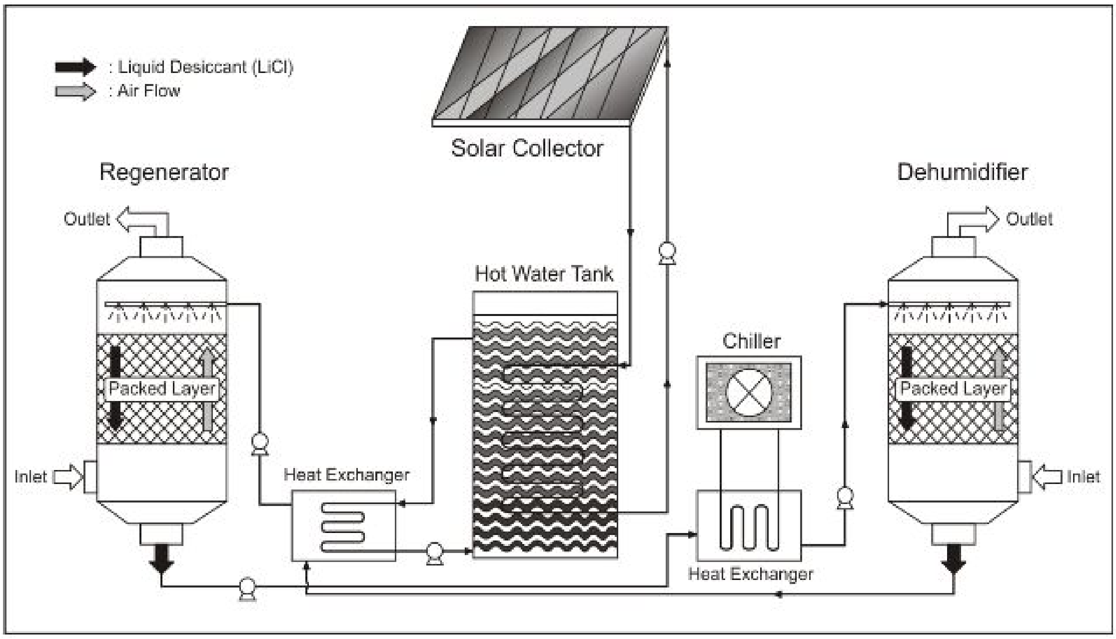

Figure 1. The Regenerator and Dehumidification System

3. THEORETICAL ANALYSIS

The data that observed are consist of relative humidity before and after passing through dehumidifier tower (RH_{in} and RH_{out}), temperature before and after passing through dehumidifier tower (T_{in} and T_{out}), and also the wattage data of every devices like pumps, blower and chiller. The experiment time is 60 minute for every variation. The variations consist of two air flow velocity from 3 m/s and 4 m/s and also liquid desiccant temperature from 10°C, 15°C and 20°C.

Totally there are 6 experiments to cover all variations.

In this experiment all analysis is from the air side, because it is easier to gain all information from air properties. From the data temperature and relative humidity we can gain so much information:

1. Humidity Ratio

$$x = \frac{0.62198 \times p_w}{(p_a - p_w)}$$

2. Enthalpy of Moist Air

$$h = \left(1.006\frac{kJ}{kg^{o}C}\right)T + x\,[(1.84\,kJ/kg^{o}C)\,t + (2501\,kJ/kg)]$$

3. Moist Air Density

$$\rho = \frac{1}{v}$$

and v is a specific volume of moist air per mass unit of dry air and water vapor,

$$v = (R_a\,T/p)\,[(1 + x R_w / R_a)/(1 + x)]$$

The data analysis is separated into four different analysis. That each analysis will represents different analysis area. Final purpose is to give us a better understanding about the liquid desiccant solar cooling system.

3. 1. Mass Transfer Rate Analysis

The theoretical analysis of the heat transfer and mass transfer was derived from Treybal's work [4] on adiabatic gas absorption in accordance with [5,6].

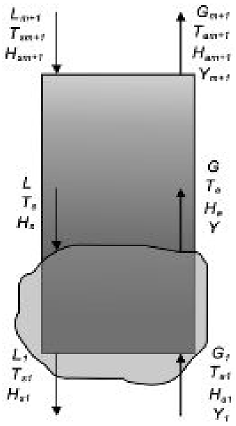

Figure 2. Continuous Counter Flow Adiabatic Packed Column

The model is based on the following assumptions:

- The system is adiabatic,
- The thermal resistance in liquid phase is negligible compare to the gas phase,
- Temperature gradients in the flow direction (Z-direction, referring to fig. 2) only,
- Only water is transferred between the air and the desiccant,
- The interfacial surface area is same for heat and mass transfer, and it is equal to specific surface area of the packing,
- The heat of mixing is negligible as compared to the latent heat of condensation of the water,
- The resistance to heat transfer in the liquid phase is negligible.

Fig. 3 shows a differential section of the packed column 1 m^2 in cross section area and dZ in height: the heat and mass transfer takes place at the interface between solution and air in a counter flow configuration.

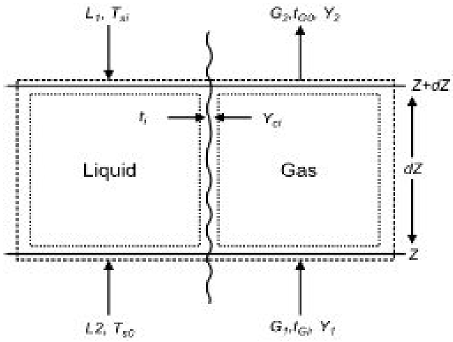

Figure 3. Differential section of a packed column

A mass balance for liquid and gas over the lower part of tower is,

$$L - L_1 = G\,(Y - Y_1)$$

$$dL = G\,(dY)$$

The rate relationship are fairly complex and will be developed in the manner of Olander refer to Fig. 3, which represents a section of tower of differential dZ. The interfacial surface of the section is ds, the specific interfacial surface per packed volume is a, the volume of packing per unit cross section is dZ and $ds = a\,dZ$.

The parameter dehumidification mass rate M_{de} (kg/s) is defined by the rate of water transferred from the air to liquid desiccant.

$$M_{de}\,a\,dZ = G\,(Y_{inlet} - Y_{outlet})$$

3. 2. Heat Transfer Rate Analysis

Enthalpy balanced based on Figure 3,

$$Heat\ Transfer\ Rate = Rate\ in - Rate\ out$$

3. 3. Human Comfort Analysis

The human body is a warm-blooded mammal, which constantly generates excess heat. It gets its energy from the metabolic process of food digestion. Some of this energy allows the body to perform work; the balance represents heat exchanged with its surroundings. Heat is a thermal energy transfer due to a difference in temperature and is expressed in joules (J).

By using ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy as a reference to the analysis that specifies conditions or comfort zones in winter and summer where 80% of sedentary or slight active persons find environment thermally acceptable.

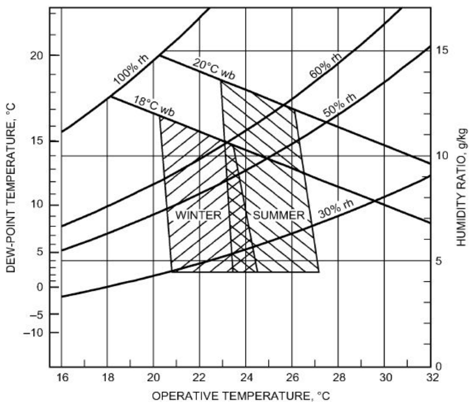

Figure 4. ASHRAE Summer and Winter Comfort Zones [7]

3. 4. Energy Analysis

By using the energy analysis we can figure the energy that consume by each variations and determine the optimum energy were consumed.

4. EXPERIMENTAL ANALYSIS

From experimental data we can analyze mass transfer rate inside the packed layer but only from air side, heat transfer rate, human comfort area and the energy consumption of each variations.

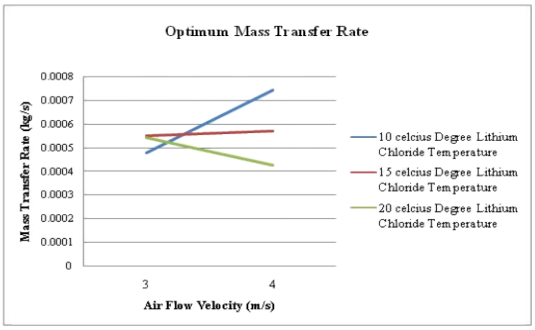

Figure 5. Optimum Mass Transfer Rate

Figure 5 shows the optimum mass transfer rate of mass transfer analysis by taking the average mass transfer rate at each variation. The figure shows the variation of 10^{o}C lithium chloride temperature and 4 m/s air flow velocity have the highest mass transfer rate. At 15^{o}C lithium chloride temperatures have a slight increase on mass transfer rate when the different air flow velocity change from 3 m/s to 4 m/s. The worst variation is at 20^{o}C lithium chloride temperature by the change of air flow velocity from 3 m/s to 4 m/s the mass transfer rate became decreased.

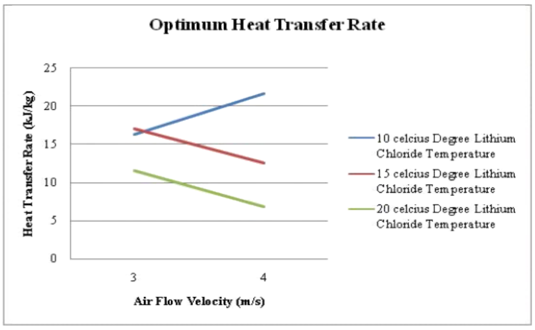

Figure 6. Optimum Heat Transfer Rate

Figure 6 shows the optimum heat transfer rate of heat transfer analysis by taking the average heat transfer rate at each variation. The figure shows the variation of 10^{o}C lithium chloride temperature and 4 m/s air flow velocity have the highest heat transfer rate. The worst variation is at 15^{o}C and 20^{o}C lithium chloride temperature by the change of air flow velocity from 3 m/s to 4 m/s the heat transfer rate became decreased.

Figure 7 is the inset from ASHRAE summer comfort zone. The blue point is the variation temperature of lithium chloride at 10°C and air flow at 3 m/s. There is a starting or initial point and end or final point. The initial temperature inside the is 30.6°C and 87% relative humidity after through experiment for one hour the final temperature inside the room is 24.6°C and 43% relative humidity. This result according to the ASHRAE standard is already in the summer comfort zone.

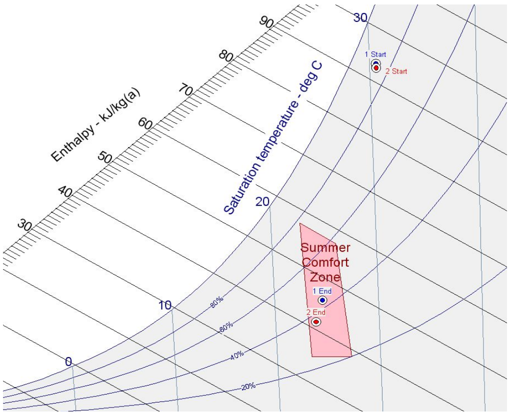

Figure 7. Initial and Final Point of Temperature and RH inside the Room

The red point is the variation of the same temperature of lithium chloride but different air flow which is at 4 m/s. The initial temperature is at the same condition 30.6°C and relative humidity is 86%. At the end of one hour experiment time the final red point is at 23.9°C and 37% relative humidity. This result also according to the ASHRAE standard is already in the summer comfort zone.

The result from another variation also concludes that all the variations according to ASHRAE standard were in the summer comfort zone.

Figure 8 shows the optimum energy consumption of energy analysis by taking the average energy consumption at each variation. The figure shows the variation of 10°C lithium chloride temperature and 4 m/s air flow velocity have the highest energy consumption. The best variation is at 20°C lithium chloride temperature at air flow velocity from 3 m/s the energy consumption smallest among other variations.

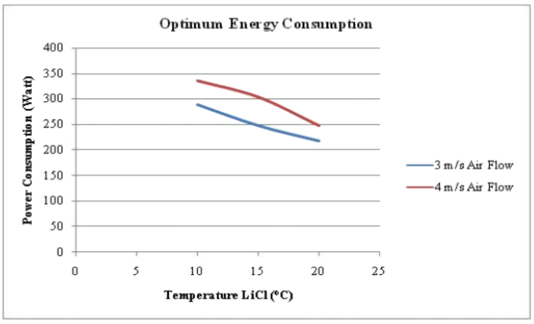

Figure 8 Optimum Energy Consumption

5. CONCLUSION

In this research were conducts an experiment to study the characteristics of lithium chloride solar cooling system by using counter flow configuration. These experiments have several variations to see connection between each variable. There are six variations totally it consists of two different air flow and three different liquid desiccant temperatures. After data were collect and then we are conducting four different analysis to find the best setting throughout different angles and perspectives.

1. Mass Transfer Analysis

The highest mass transfer rate among the variations is at 10°C lithium chloride temperature and 4 m/s air flow velocity. It has average mass transfer rate 0.00075 kg/s. The worst variation is at 20°C lithium chloride temperature and 4 m/s air flow velocity, the average mass transfer rate only 0.0004 kg/s.

2. Heat Transfer Analysis

The highest heat transfer rate among the variations is at 10°C lithium chloride temperature and 4 m/s air flow velocity. It has average heat transfer rate 22 kJ/kg. Again the worst variation is at 20°C lithium chloride temperature and 4 m/s air flow velocity, the average heat transfer rate only 7 kJ/kg.

3. Human Comfort Analysis

By using the ASHRAE standard 55, Thermal Environmental Conditions for Human Occupancy as a reference to the analysis that specifies conditions or comfort zones in winter and summer we can see that all variations are inside the comfort zone. In conclusions, all variations passed the ASHRAE standard summer comfort zone.

4. Energy Analysis

To see the optimum energy consumed by each variation is by taking the average energy consumption at each variation. The energy analysis shows that the variation of 10°C lithium chloride temperature and 4 m/s air flow velocity have the highest energy consumption. The best variation is at 20°C lithium chloride temperature at air flow velocity from 3 m/s the energy consumption smallest among other variations.

After considering all aspect we can decide that the variation at 20°C lithium chloride and 3 m/s air flow velocity is the best setting among other variations. Although this variation does not have the highest mass transfer rate and highest heat transfer rate but this variation is already in the ASHRAE standard summer comfort zone and the most important is this variation also consumes the lowest energy among other variations.

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