EXPERIMENTAL STUDY CONCERNING MASS TRANSFER INSIDE THE PACKED COLUMN OF SOLAR COOLING LIQUID DESICCANT SYSTEM USING COUNTER FLOW CONFIGURATION

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ABSTRAK

Sistem desiccant telah diusulkan sebagai alternatif untuk menghemat energy dibandingkan pendingin udara kompresi uap untuk menangani beban laten. Penggunaan desiccant cair menawarkan beberapa keuntungan desain dan performa dibandingkan desiccant padat, terutama ketika energi matahari digunakan untuk proses regenerasi. Desiccant cair mengalami kontak dengan gas di dalam packed column dan perpindahan panas dan perpindahan massa akan terjadi. Paper ini untuk mempelajari perpindahan massa dan perpindahan panas di dalam packed column pada dehumidifier dan sistem regenerator. Dan nantinya, laju dehumidifikasi dan regenerasi yang dipengaruhi oleh laju aliran desiccant, temperatur dan kelembaban udara, dan temperatur desiccant dan semua variasi tersebut akan mempengaruhi performa dari sistem tersebut.

ABSTRACT

Desiccant systems have been proposed as energy saving alternatives to vapor compression air conditioning for handling the latent 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 column and the heat transfer and mass transfer will occur. This proposal is trying to study the mass transfer and heat transfer inside the packed column of dehumidifier and regenerator systems. And later on, the rates of dehumidification and regeneration that were affected by desiccant flow rates, air temperature and humidity, and desiccant temperature and all that variation will influence the performance of the systems.

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

1. Introduction

Dehumidification is the process of removing water vapor from damp air and the latent cooling load in a building HVAC system. The purpose is to reduce or lower the relative humidity in the area or a container during transportation. Low relative humidity ensures dry packaging, prevents rotting and reduces incident of fungal development and is essential for cargo such as cigarette, electronic components, photographic films, onions, ginger and garlic etc. Just as a lack of moisture in the air can make a workplace uncomfortable, too much moisture can have the same effect. A relative humidity level of somewhere between 40% and 60% has been proven to be ideal for comfort and efficient equipment operation. When the environment is too humid, people may be uncomfortable and equipment may not function as intended. In fact, high humidity almost guarantees that mildew and mould will get into the environment, potentially causing health problems for people working in the area.

There are three methods to remove or to reduce the water vapor from the damp air. First using a sorbent dehumidification, the damp air are passing to the rotating desiccant drum, water vapor will be condense in the surface of the desiccant. Second using refrigerant dehumidification, passing the damp air in the surface of heat exchanger that already lowered the temperature below the dew point temperature. Third using air cycle dehumidification, when the water is being pressurized and then the temperature will be increased as a result of increasing pressure [1]. The sorption dehumidification of air by the desiccant is an interesting alternative to the traditional dehumidification process of cooling air below the dew point. The air may be dehumidified by a liquid desiccant, such as hygroscopic salt or glycol solutions in a spray tower or packed column, or by solid desiccant, such as silica gel, zeolites, or activated alumina in dehumidification wheel [2]. Desiccant can be applied to many air conditioning application if meet this term; latent load is bigger than the sensible load, energy consumption for desiccant regeneration is lower than the energy for air dehumidification by cooling under dew point temperature and reheating, if the refrigeration compression is use for air dehumidification the level of moisture control for an area requires cooling below freezing point, temperature level control for an area or a process that needed a lot of air supply at temperature below freezing point. In many situations cost for refrigeration vapor compression system can be very high. A process using desiccant offer a lot of benefit in energy consideration, the initials cost of equipment and maintenance [3]. The desiccant can bind and hold moisture and then remove the contaminant in the air flow to improve indoor air quality. Desiccants also use to remove organic vapor, in special case to control microbiology contaminant (Battele 1971; Buffalo Testing Laboratory 1974). Hine *et.al*. (1991) also stated that

desiccants can remove unnecessary substance that can reduce indoor air quality. Desiccants material can absorb hydrocarbon vapor because attached with the water vapor in the air. Cosorbtion phenomena show increase in air quality on space area system in the HVAC system building.
And the liquid desiccants have been proposed as alternatives to the conventional vapor compression cooling systems to control air humidity, especially in the hot and the humid areas. Research has shown that a desiccant cooling system can reduce the overall energy consumption, as well as shift the energy use away from electricity and towards renewable and cheaper fuels [4]. Burns et.al. (1985) found that utilizing desiccant cooling in a supermarket reduced the energy cost of air conditioning by 60% as compared to conventional cooling [5]. And the reference [4] modeled a hybrid solar cooling system obtaining an electrical energy savings of 80%. Chengchao and Ketao (1997) showed by computer simulation that solar liquid desiccant air conditioning system has advantages over vapor compression air conditioning system and its suitability for hot and humid areas and high air flow rates [6].

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 50-70 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 16-18 ^{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 360^{O} 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.

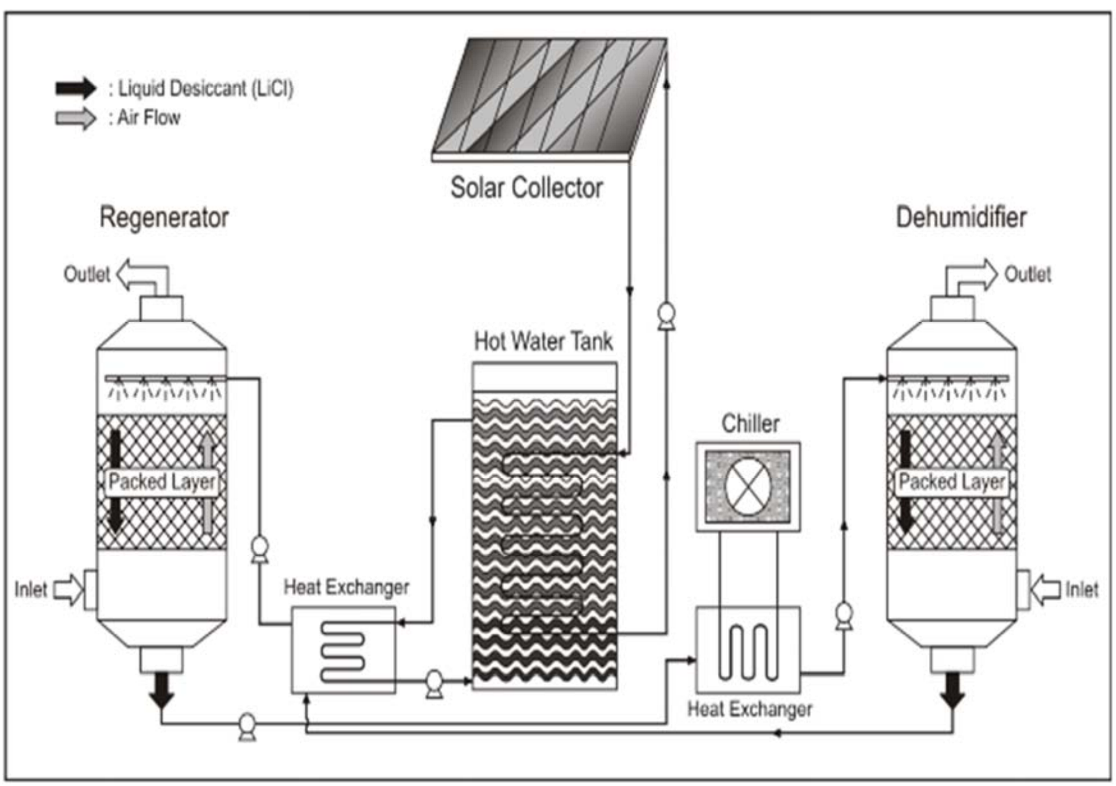

Figure 1. The Regenerator and Dehumidification System

3. Theoretical Analysis

The dehumidifier is filled with packing materials. Liquid desiccant sprayed from the top wetting the packing materials, while the air induced from the bottom in a counter flow configuration shown in figure 2. Heat transfer occurs because of a temperature difference, while mass transfer occurs because partial pressure difference between liquid desiccant and water in the air.

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]. 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.

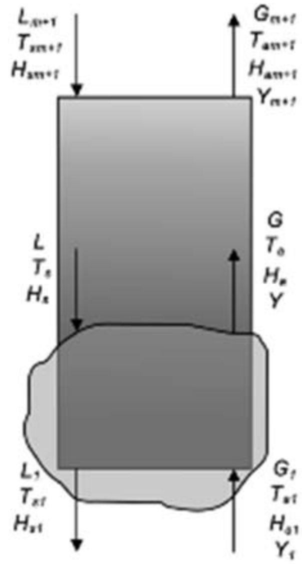

Figure 2. Continuous counter flow adiabatic packed column

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.

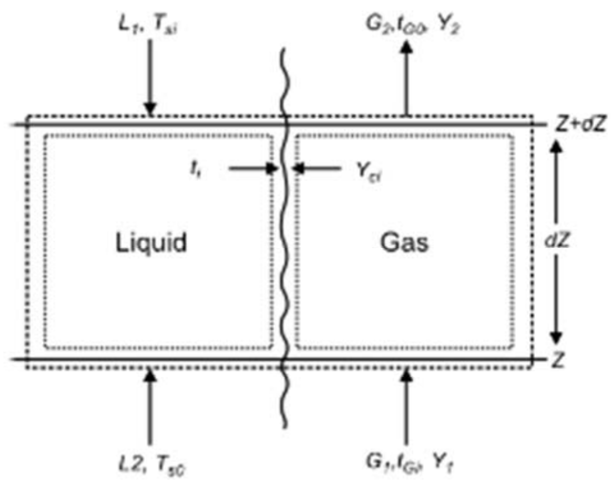

Figure 3. Differential section of a packed column

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

$$L - L_1 = G(Y - Y_1)$$
$$dL = G(dY) \quad (1)$$

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/m^{3}s) is defined by the rate of water transferred from the air to liquid desiccant.

$$M_{de}\,adZ = G(Y_{in} - Y_{out}) \quad (2)$$

Using the same method, the regeneration mass rate M_{reg} (kg/m^{3}s) is defined by the amount of water mass rate evaporating from the liquid desiccant to air.

$$M_{reg}\,adZ = G(Y_{out} - Y_{in}) \quad (3)$$

Sensible heat at gas side, as energy rate per tower cross sectional area,

$$q\,adZ = \frac{N_V M_V C_V}{1 - e^{-N_V M_V C_V / h_G}}(t_G - t_i)adZ \qquad h_G{}'a(t_G - t_i)dZ \quad (4)$$

Enthalpy balanced based on Figure 3. Rate in – rate out = Heat transfer rate

$$GH - \{G(H + dH) - GdY[C_V(t_G - t_0) + \lambda_0]\} = q_G adZ \quad (5)$$

The mass transfer coefficient between the air and the liquid desiccant is defined dehumidification or regeneration mass rate per unit area. It is assumed that the interfacial area is the same for heat and mass transfer.

The mass transfer coefficient air side is,

$$k_G a = \frac{G}{Z}\ln\left(\frac{Y_1 - Y_i}{Y_2 - Y_i}\right) \quad (6)$$

The heat transfer coefficient gas side is,

$$h_G = \frac{1.195G'c_p\left[\frac{d_s G'}{\mu_G(1-\varepsilon_{Lo})}\right]^{-0.36}}{Pr_G^{\,0.667}} \quad (7)$$

The variation mass transfer coefficient air side is given by Treybal,

$$\frac{F_G Sc_G{}^{2/3}}{G} = \frac{k_G p_{B,M} Sc_G{}^{2/3}}{G} = 1.195\left[\frac{d_s G'}{\mu_G(1-\varepsilon_{Lo})}\right]^{-0.36} \quad (8)$$

4. EXPERIMENTAL ANALYSIS

From experimental data we can analyze mass transfer inside the packed layer but only from air side and already determined by using theoretical analysis equation that already mentioned previously. From fig. 4 we can see the tendencies of humidity in outlet decreasing because the mass transfer were working well to remove the moisture out from moist air.

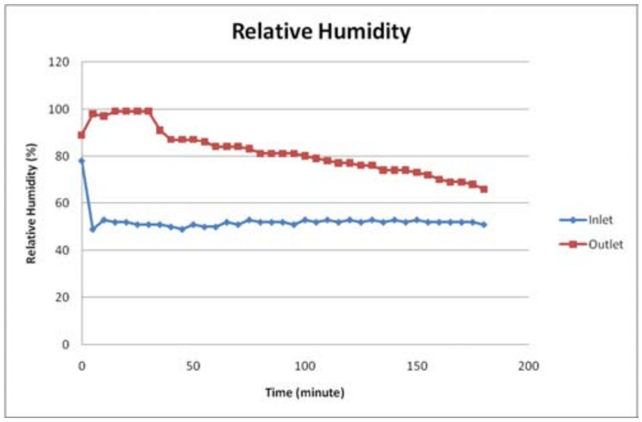

Figure 4. Relative Humidity Inlet and Outlet

But from fig. 5 the temperature on outlet is not showing the significant difference to decrease the room temperature down. Temperature difference between inlet and outlet is not huge only 3 ^oC to 4 ^oC.

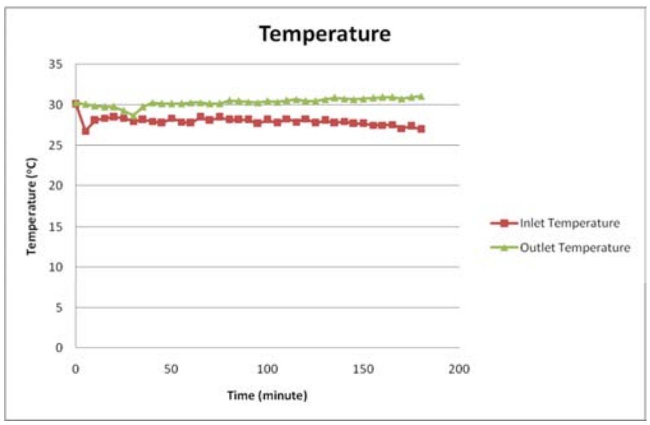

Figure 5. Temperature Inlet and Outlet

The enthalpy between inlet and outlet is shown in fig. 6.

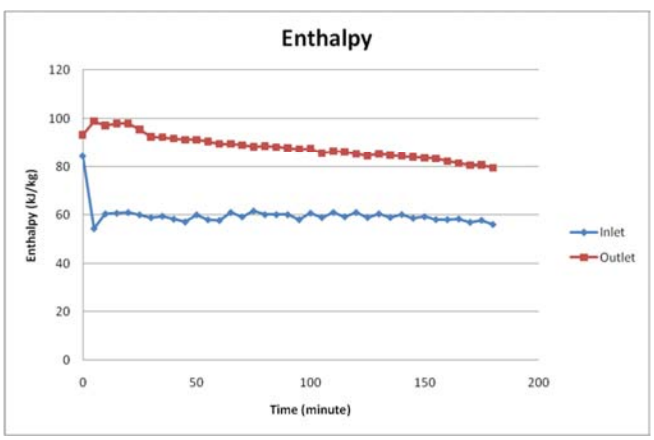

Figure 6. Enthalpy Inlet and Outlet

The mass transfer rate is shown in fig.7 that there is a tendency to increase as it shown by the trend line of fig.7. This caused by lithium chloride as liquid desiccant still have ability to absorb the moisture. However, as we already experience this tendency will be decrease because the lithium chloride will become dilute. This is because our experiment is not long enough to see that phenomenon.

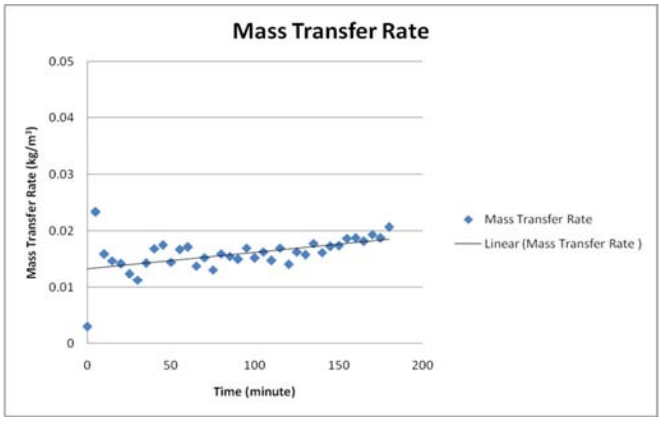

Figure 7. Mass Transfer Rate

5. Conclusion

1) Lithium chloride has a good ability to absorb moisture from the moist air we can see the mass transfer rate ranging from 0.01 to 0.002 kg/m^3 shown by fig.7.
2) Relative humidity in outlet has a tendency to decreased this is caused by dehumidification effects, relative humidity in outlet from 89% decrease to 66% after 180 minutes.
3) Decrease in temperature between inlet and outlet is around 3 to 4 ^{o}C this caused by lithium chloride temperature is set only 20 ^{o}C.

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