A Study of Liquid Desiccant System Performance

CONFERENCE PAPER · JANUARY 2009

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Topic 4. New HVAC&R component development, High efficient heat pump and refrigeration system

A Study of Liquid Desiccant System Performance

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ABSTRACT Desiccant systems have been proposed as energy saving alternatives to vapor compression air conditioning for handling the latent load. Desiccants are classified as either liquid or solid. The main components for a liquid desiccant system are the dehumidification and regeneration towers. Use of liquid desiccant offers several design and performance advantages over solid desiccant, especially when solar energy is used for regeneration. For liquid-gas contact, packed towers with low pressure drop provide good heat and mass transfer characteristics for compact designs.

This paper presents the results from a study of the performance of a packed tower absorber for lithium chloride desiccant dehumidification system. A finite difference model was developed to determine the packing height of the dehumidification towers. The finite difference model was written in MATLAB language which is a suitable model to measure the optimum height of a tower.

The paper also examines the effects of different design parameters on the height of a packed tower using a mathematical model. The effects of air and liquid flow rates, air humidity, desiccant temperature and concentration were reported on the packing height and humidity effectiveness of the column. In conclusion the results of the present study are compared with previous experimental studies.

Keywords: Liquid desiccant, Packing, Dehumidification, Finite difference

INTRODUCTION:

Each year many fossil fuels are used for moisture removal in both industrial and agricultural processes. The control of humidity is essential to maintaining healthy, productive and comfortable conditions (ASHRAE, 2008).

Desiccant materials that have a high affinity for water vapor can reduce energy use for drying and dehumidification. Researchers have shown that desiccant cooling systems can reduce the

overall energy consumption, as well as shift the energy used away from electricity and toward renewable (for example solar energy), cheaper fuels and waste energy (Daou et al., 2006).
Desiccants are classified as either liquid or solid. Example of solid desiccants includes silica gel, activated alumina, lithium chlorides salt, and molecular sieves. Liquid desiccants include lithium chloride, lithium bromide, calcium chloride, and triethylene glycol solutions.

The desiccants absorb or adsorb water vapor due to the difference in water vapor pressure between the surrounding air and the desiccant surface, then dehumidifying the incoming air stream. The desiccant is regenerated after becoming saturated with moisture, so that it can be dried enough to absorb water vapor in the next cycle. This is done by heating the desiccant material. The temperature of regeneration is dependent upon the nature of the desiccant. Each of liquid or solid desiccant systems has its own advantage and disadvantage. Liquid desiccant systems have lower regeneration temperature, lower pressure drop on air side and flexibility in utilization. Solid desiccant systems are compact, less subject to corrosion and carryover (Daou et al.2006).

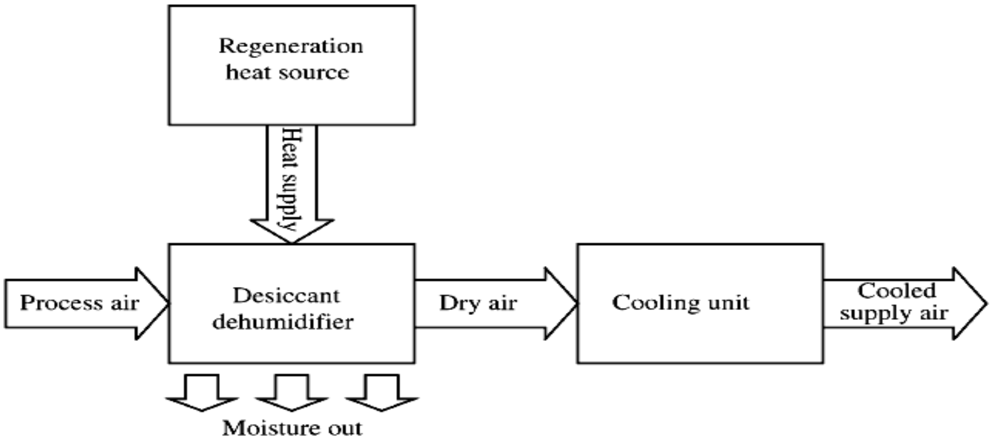

Figure 1: main component of a desiccant cooling system

The main components of a desiccant cooling system are absorber or dehumidifier, regenerator and cooling unit (Fig.1). In the Cooling unit in Figure 1, handling the sensible load can be done by the evaporator of traditional air conditioner, a cold coil or an evaporative cooler. Cooling loads in air conditioning systems are divided into two groups of sensible and latent load. Cooling process in compressed cooling system can be done by reaching air temperature to the saturation temperature. Such a saturated air is reheated until suitable temperature is achieved for comfort conditions. Energy can be saved through eliminating latent load if we can delete latent load economized energy from two standpoints:
a) Energy that reduces air temperature to below its dew point.
b) The energy to reheat air.
If ratio of sensible heat gain to total heat gain of the space (SHR) is low, these energies will reduce so much. A low value of SHR means that the total cooling load is predominately the latent load.
Liquid desiccant air conditioners are proposed as one of the technological options related to HVAC systems that have the potential to reduce energy consumption (Roth et al. 2005). In liquid desiccant systems the absorber and regenerator are in contact with the process air stream. Its

possible configuration includes finned-tube surface, coil-type absorber, spray tower, and packed tower. The packing of packed towers can be regular or random (Daou et al. 2006).

One of the examples for a liquid desiccant cooling system is represented in Fig. 2. Moist air enters the bottom of the dehumidification tower and travels up through a packing material. The cool strong liquid desiccant enters the top of the tower and travels down the packing materials counter-current to the air. Since, the cool strong desiccant vapor pressure is less than the moist air vapor pressure, water vapor will be transferred from the air to the liquid desiccant, and dehumidified air leaves the absorber tower .The performance of liquid desiccant cooling systems are dependent on thermodynamic variables, such as air and desiccant flow rate, air temperature and humidity, desiccant concentration and temperature.

The packing height prediction of the absorber of packed bed-type liquid desiccant system using a mathematical model is the aim of this paper.

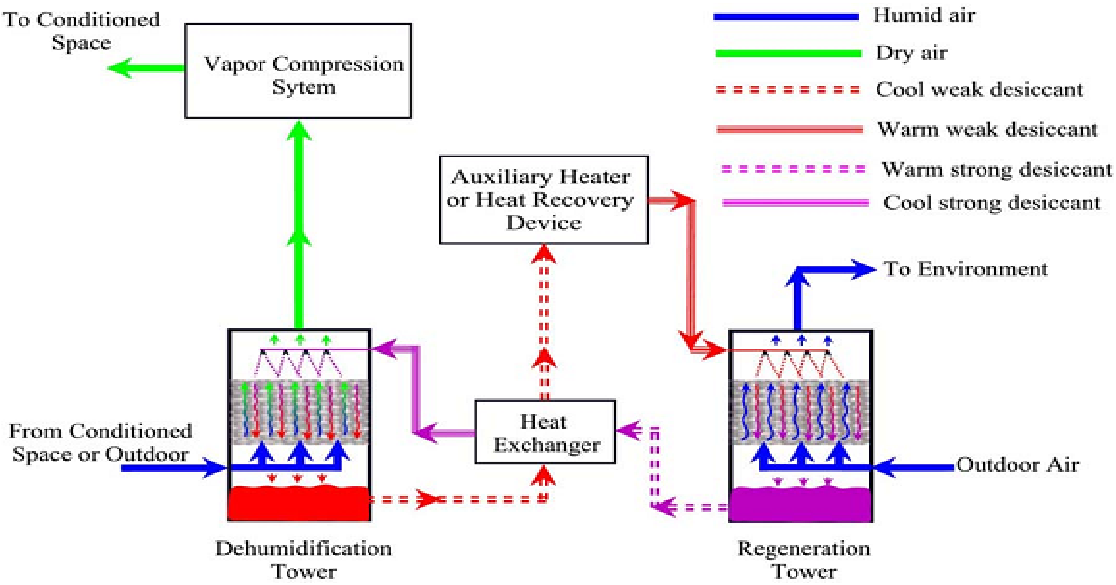

Figure 2: Main Component of Packed bed Liquid Desiccant cooling System

METHODOLOGIES

A finite difference model was developed to determine the packing height of the dehumidification tower. This model is based on the model for adiabatic gas absorption presented by Treybal (1981). Modelling the tower as adiabatic is a common assumption in other literature (Fumo and Goswami, 2002), (Oberg and Goswami, 1998) and (Mago and Goswami 2003).

Fig.3 (Treybal 1981) displays the control volume of a differential slice from the packed tower with significant material and heat effect entering and exiting the infinitesimal packing height. The direction of mass and heat transfer is taken as positive from the gas to the liquid. The assumptions are: a) The packed tower is adiabatic b) The heat of solution is neglected c) No resistance to heat transfer in the liquid phase d) The interfacial surface areas for heat and mass transfer are equal and e) No axial dispersion. Therefore, a one dimensional analysis is used. The inlet conditions of the desiccant are known, the outlet desiccant solution conditions are solved for the boundary conditions across the entire tower. To determine the height of the tower, starting with the first segment, the air and liquid states for a segment are determined, If the comparison between the calculated humidity ratio at the top of the segment and the known humidity ratio at the top of the tower shows that the humidity ratio at the top of the tower has not been reached, then another segment is added, until required exit humidity ratio is reached. By this method we can calculate the packing height for the tower.

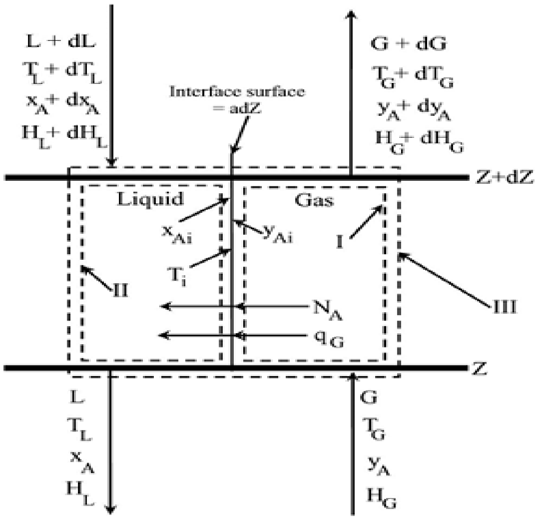

Figure 3: Differential segment from a Packed Tower

With those assumptions, the heat and mass transfer equations in the tower are listed below:

$$\frac{dY}{dZ} = - \frac{M_W . F_G . a_W}{G} \ln\left(\frac{1-y_i}{1-y}\right) \tag{1}$$

Where Y is the air humidity ratio, M_w is the molar mass for water, F_G is the gas-phase mass transfer coefficient, G is the superficial air flow rate, a_w is the wetted surface area of packing, y is the water mole fraction and y_i is the water mole fraction at interface, and given by Equation (2):

$$y_i = 1 - (1 - y).\left(\frac{x}{x_i}\right)^{F_L/F_G} \tag{2}$$

In this equation F_L is liquid phase mass transfer coefficient, x is desiccant mol fraction and x_i is interfacial mol fraction. The F-type mass transfer coefficients for air and desiccant (F_G and F_L) in Equation 1 and Equation 2 are computed from K-type coefficient correlation (Onda et al. 1968).
The change in air temperature across the differential segment can be expressed as:

$$\frac{dT_G}{dZ} = \frac{h' a_h (T_L - T_G)}{G.(c_{pa} + Y.C_{pw})} \tag{3}$$

Where T_G is the air temperature, Z is the packing height of the tower, T_L is the desiccant temperature, c_{pa} and $C_{p,w}$ are the specific heat of air and vapour respect, $h'a_v$ is the Ackermann correction for simulation heat and mass transfer (Treybal 1969).

The change in desiccant temperature, flow rate and concentration across the differential segment are given by the following Equations:

$$\frac{dT_L}{dZ} = \frac{G}{L.C_{pL}} \{(C_{p,w} + Y.c_{pa})\frac{dT_G}{dZ} + [C_{pv}(T_G - T_0) - C_{pL}(T_L - T_0) + \lambda_0]\frac{dY}{dZ}\} \qquad (4)$$

In this Equation T_0 is the reference temperature and λ_0 is latent heat of condensation.

$$\frac{dL}{dZ} = G.\frac{dY}{dZ} \qquad (5)$$

$$\frac{dX}{dZ} = \frac{G}{L}.X.\frac{dY}{dZ} \qquad (6)$$

Where L is superficial desiccant flow rate, X is the desiccant concentration.

The finite difference model was written using MATLAB computer language. These parameters required for the input data: air humidity ratio at the inlet and outlet of tower, air mass velocity, and liquid desiccant mass velocity, inlet temperature of air, inlet temperature of liquid desiccant and nominal size of packing.

RESULTS AND DISCUSSION

In this paper the size of a dehumidification tower is computed by finite difference method. The results are compared with experimental data reported by Fumo and Goswami (2002) and analytical method by Chen et al. (2006). The desiccant solution used in these works are LiCl, the packing used were 2.54cm (1 in) polypropylene Rauschert Hiflow® rings with specific surface area of 210 m^2/m^3. However, the method used for measuring the packing height was not discussed in Fumo and Goswami's work, and the height of packing remained at a constant value of 60 cm for all experiments. Therefore, the accuracy of the height measurement is unknown.

Table 1: Comparison of the Finite Difference Model with Experimental Data

Inputs	1	2	3	4	5
Humidity Ratio(kg_w/kg_a)	0.0180	0.0181	0.0215	0.0181	0.0181
Gas Mass Velocity [$kg/(s\text{-}m^2)$]	0.0890	1.513	1.187	1.180	1.176
Inlet Gas Temperature(°C)	30.1	30.2	29.9	30.1	30.0
Desiccant Concentration(kg_{licl}/kg_{sol})	0.346	0.343	0.339	0.347	0.348
Desiccant Mass Velocity[$kg/(s\text{-}m^2)$]	6.124	6.113	6.272	6.227	6.206
Moisture To Remove (%)	42.22	40.33	44.19	40.33	40.88
Inlet Desiccant Temperature(°C)	30.1	30.0	30.3	30.3	30.2
Packing Height from Finite Difference Model (cm)	59	61	58	57	57

In the present work, using their experimental data, the packing height is predicted by the finite difference method. Comparison between the simulated packing height and the actual packing height from Fumo and Goswami (2002) is presented in Table 1. In this table the packing height for every experimental data is constant and equals 60 cm. Table 1 illustrates that the finite difference model under predicts the packing height for the majority of the experimental runs. Evidently, values for height are very similar in these two works. Therefore, from an engineering point of view this model and computer programming results are within the acceptable range.

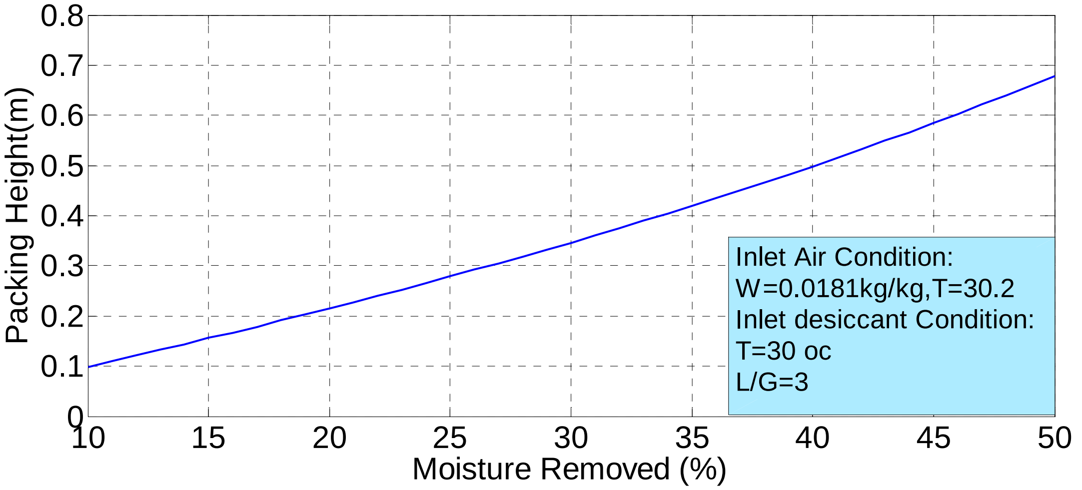

Figure 4: Packing height as a function of percent moisture removed.

Figure 4 shows that by increasing the desired amount of moisture removed the tower height will increase. The reason is that by increasing the required moisture-removal percentage, the mass transfer area increases. In other words, the height of the tower is related to the amount of moisture that is removed from the inlet air. In this Figure and other Figures the percent moisture removed is defined as:

$$\frac{\text{inlet air humidity ratio} - \text{outlet air humidityratio}}{\text{inlet air humidity ratio}} * 100$$

Since some of the references (Min Tu. et al. 2008 and Gommed and Grossman 2007) noted the optimum range for L/G as 0.15-3, we select a value of 3.0 for this parameter.

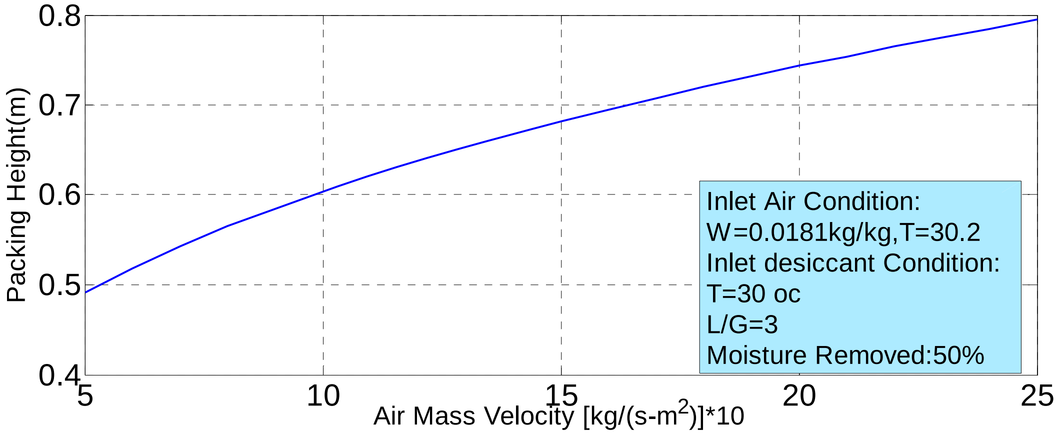

Figure 5: Packing height as a function of air mass velocity

Figure 5 also shows that increasing the air mass velocity results in an increase in packing height. However, the rates are not quite identical. This is because; the air exposure time with the desiccant is decreased as the flow rate increases.

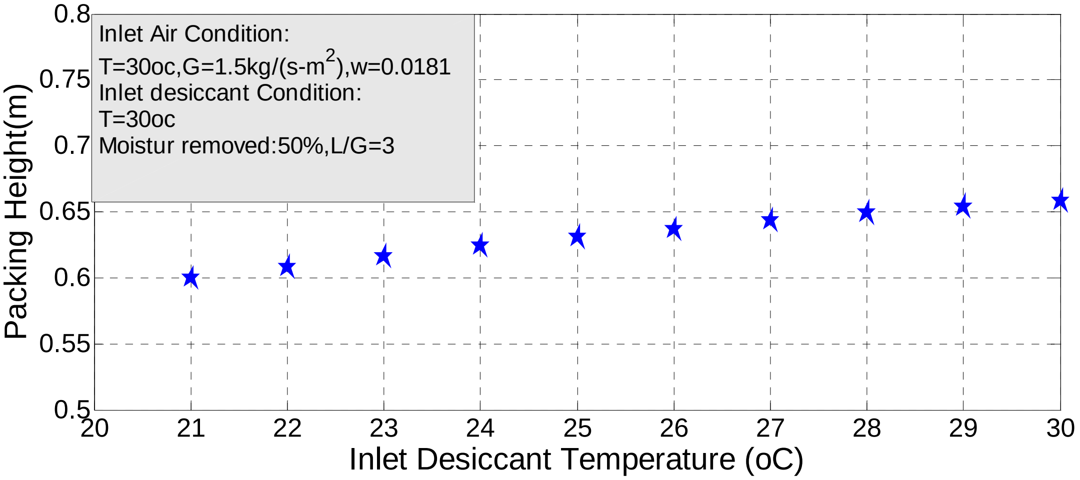

Figure 6: Packing height as a function of inlet desiccant temperature

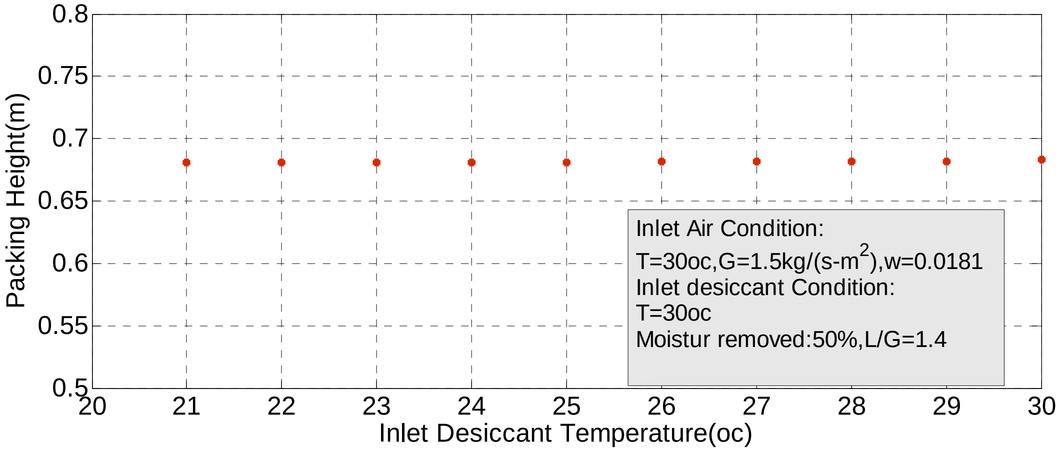

Figure 7: Packing height as a function of inlet desiccant temperature

Figure 6 demonstrates that increasing the temperature of inlet desiccant to air dehumidification, increases the packing height. But in Figure 7 packing height is approximately constant with increasing temperature. In this figure, the ratio between air mass flux and desiccant solution mass flux is 1.4, this ratio is used by Yin et al. (2007). This figure demonstrates that this value is in the optimum region and acceptable.

CONCLUSION

The packing height of absorber tower was predicted using the finite difference model. This model gives fairly accurate packing height based on fundamental equations, empirical correlations and some assumptions. This method shows that the design variables which have the greatest effects on the packing height, and also the factors affecting the performance of the dehumidifiers are: desiccant temperature, air temperature, air flow rate, desiccant mass flow rate and the amount of moisture removed.

The effect of these variables on the packing height is studied in this paper. The results illustrate that, as the amount of moisture removed increases so does the packing height in a steep slope shape. But, increasing the air mass velocity increases the height of packing by positive and diminishing slope. Increasing the inlet air temperature increases the packing height approximately linearly. The finite difference analysis model show that the result agreed well with the experimental data.

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