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CFD Analysis of Dehumidification Characteristics of Cross Flow Dehumidifier with Calcium Chloride as Liquid Desiccant

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Abstract

Dehumidifier is a key component in the liquid desiccant air conditioning system (LDACS) for reducing the humidity. The main objective of this paper is to investigate the effect of the concentration and the mass flow rate of the liquid desiccant as well as the mass flow rate of air on the flow characteristics during the dehumidification process using CFD (Computational Fluid Dynamics) approach. The liquid desiccant used is lithium chloride with a concentration of 32% to 50%. Three-dimensional modelling is proposed in this study to obtain more realistic results. The simulation results show that in order to generate the high decrease in the humidity ratio, the dehumidifier with high concentration of liquid desiccant, low mass flow rate of air, and high mass flow rate of liquid desiccant should be applied. The other interesting result is that the dehumidifier with concentration of liquid desiccant of 50%, and the mass flow rate of desiccant liquid of 0.26 kg/s will produce the highest decrease in the ratio of the humidity. These results can be a guideline to design the dehumidifier in more effective way.

Keyword: Computational Fluid dynamic (CFD), dehumidifier, humidity, liquid desiccant

INTRODUCTION

There are several methods to reduce the humidity and one of them is the method of sorbent dehumidification. This method uses sorbent or desiccant to reduce the moisture in the air. This method is divided into two parts, namely an adsorbent and absorbent. The examples for the adsorbent are synthetic polymers, activated carbon, activated alumina, synthetic zeolites and silica gel which have a large internal surface area. In addition, in the adsorbent the water molecules condense without changing the properties of solids. The second part, i.e. absorbent is hygroscopic liquid such as lithium bromide, triethylene glycol, lithium chloride, and calcium chloride solutions which is denatured during binding of moist air [1]. The advantage of the use of a liquid desiccant is easier to regenerate and the air pressure drops to less than using solid desiccant. Regeneration process has a function to return of desiccant properties to their initial state. However, in application the liquid desiccant is more expensive than the solid desiccant. At the other side, the solid desiccant has a positive behaviour, that is, not too expensive and has a higher drying capability compared to solid desiccant. As a consequence, the liquid desiccant needs some higher energy to take the regeneration process.

In relating to the improvement of the dehumidifier performance, some researchers have published their significant results. Feyka and Vafai [2] proposed the typical cooling to improve the efficiency of a liquid desiccant refrigeration cycle significantly. They concluded that the cooling is approximately 17°C below the ambient temperature, and the relative humidity of the inlet air can be reduced up to 22 percent. In addition, the proposed cycle produces 18–23 percent higher coefficient of performance as compared to a chiller cycle operating between the same temperatures. Experimentally, Zhang et al. [3] studied the mass-transfer characteristics of a structured packing dehumidifier/regenerator with a lithium chloride solution as the desiccant. The authors concluded that higher solution temperature resulted in lower overall mass-transfer coefficients.

Later, Gao et al. [4] established the cross-flow dehumidifier in which LiCl solution was used. In order to describe the heat and mass transfer performance of the dehumidifier, the enthalpy efficiency and moisture efficiency were adopted. Their significant outcome is that the performance of Dehumidifier can be improved by increasing the thickness, width or height simultaneously without increasing the pressure loss. Other interesting study was shown by Li et al. [5]. Theoretically, they proposed a new method for selecting a cost-effective mixed desiccant group. Some helpful tips for dehumidifier design were described, for example better effect with rougher surface and adsorption absorption complex plan must be applied.

The main aim of this study is to investigate the effect of the concentration and the mass flow rate of the liquid desiccant as well as the mass flow rate of air on the flow characteristics of the dehumidifier computational fluid dynamic (CFD). The main focus is how to improve the dehumidifier performance by reducing the moisture in the dehumidifier. Several parameters are compared to find the best parameter for dehumidifier based on operating conditions.

ANALYSIS

In this section, the general formulations for heat and mass transfer between air and desiccant film and its boundary conditions are presented. The heat and mass transfer between air and desiccant film in a counter flow channel is presented in Fig. 1. The desiccant film falls vertically in the channel and the air is flowing in the upward direction. Thus, the governing equations which are used to analyse the cases studied are shown in Equations (1) to (5). Mass balance of a fluid element states that the rate of mass across a fluid element is equal to the net mass flow rate into the fluid element. The mass conservation equations can be formulated as follows [6]:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \tag{1}$$

Newton's second law states that the change rate of momentum of fluid particle is equal to the number of forces acting on the particle. The rate of increase in the momentum of the *x*, *y*, *z* direction per unit volume of fluid particles are known as Navier-Stokes equation and are expressed as follows [6]:

$$\rho\frac{Du_i}{Dt}=-\frac{\partial p}{\partial x_i}+\rho G_i+\frac{\partial}{\partial x_j}\left[2\eta e_{ij}-\frac{2}{3}\eta\left(\nabla . u_i\right)\delta ij\right] \tag{2}$$

The energy equation is derived from the first law of thermodynamics. It express that the rate of energy change of fluid particles is equal to the summation of the rate of increase of heat of fluid particles and the total work. It reads [6]:

$$\frac{\partial(\rho E)}{\partial t}+\frac{\partial(u_i[\rho E+p])}{\partial x_i}=\frac{\partial}{\partial x_i}\left(k_{eff}\frac{\partial T}{\partial x_i}-\sum_j h_j J_j+u_j\left(\tau_{ij}\right)_{eff}\right)+S_h \tag{3}$$

During the dehumidification process, in order to predict the local fraction of each element, the species transport equation is used. It reads:

$$\frac{\partial}{\partial t}\left(\rho Y_i\right)+\nabla .\left(\rho\vec{u}Y_i\right)=-\nabla .\vec{J_i}+R_i+S_i \tag{4}$$

The method of calculating vapor diffusion flux toward the wall in a turbulent flow according to Fick's law are as follows:

$$\vec{J_i}=-\left(\rho D_{i,m}+\frac{\mu_t}{Sc_t}\right)\nabla Y_i-D_{T,i}\frac{\nabla T}{T} \tag{5}$$

Figure 1 shows the computational domain of the simulation with the symmetrical boundary condition for simplicity. The dimension of the cross flow dehumidifier is 500 mm in length, 300 mm in width and 500 mm in height.

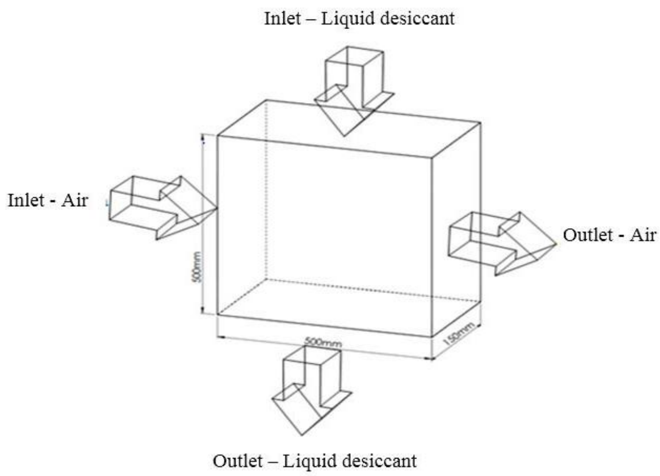

Figure 1: Computational domain and its boundary condition

In this study, the calcium chloride is used as the desiccant film and its properties are taken from calcium chloride properties handbook [7]. The model is based on the cross flow of liquid desiccant dehumidifier. In the simulation, it assumes that chemical reaction is not considered. Fluid entering the dehumidifier is humid air and liquid desiccant. Air mass flow rate is varied from 0.08 kg/s to 0.14 kg/s, the mass flow rate of liquid desiccant is varied from 0.1 kg/s to 0.26 kg/s, the concentration of liquid desiccant is varied from 32% to 40% of lithium chloride, while for calcium chloride, they are varied from 30% to 50%. In this work, the temperature of air is set to 33 °C, the temperature of the liquid desiccant is 25 ºC, whilst the humidity ratio of the air is 8 g/kg. For analysis, some assumptions are applied as follows:

1. The three dimensional flow is in a steady state condition.
2. Turbulent flow and the fluid is considered as incompressible (M_a <0.3).
3. The walls are considered as no slip situation.

RESULTS AND DISCUSSIONS

In this study, the validation will be conducted based on the published work from experimental results of the Gao et al. [4]. Then, the extension work will be performed varying concentrations of liquid desiccant, air mass flow rate, and mass flow rate of liquid desiccant.

A. Validation

Figure 2 shows the relation of the efficiency of moisture with the concentration of liquid desiccant. It can be seen from Figure 1 that the trend of the simulation result is relatively in a good agreement with the experimental work by Gao et al. [4]. The trends of "increase-then-decrease" behaviour predicted for the efficiency of moisture are shown by two approaches (experimental and simulation) with increasing the concentration of liquid desiccant. With respect to the air mass flow rate effect on the efficiency of moisture, the CFD method developed here is also able to obtain the results which is slightly similar to the published work [4], as shown in Figure 3. It can be seen that increasing the air mass flow rate will decrease the efficiency of moisture.

From Figures 2 and 3, the difference between the result of the present study and the experimental work is around 20 %. The most possible explanation is that the CFD based simulation assumed that the temperature is constant along the computational domain both for the liquid and the air. However, in general, the CFD method developed here matches well with the published work and thus it can be used to analyse other cases with respect to the exploration of other parameters influence in the cross flow dehumidifier.

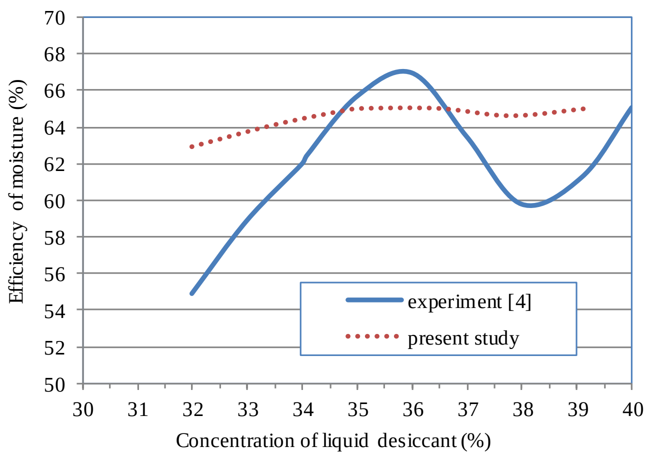

Figure 2: Effect of the concentration of liquid desiccant on the efficiency of moisture: Present study versus experimental wok [4]

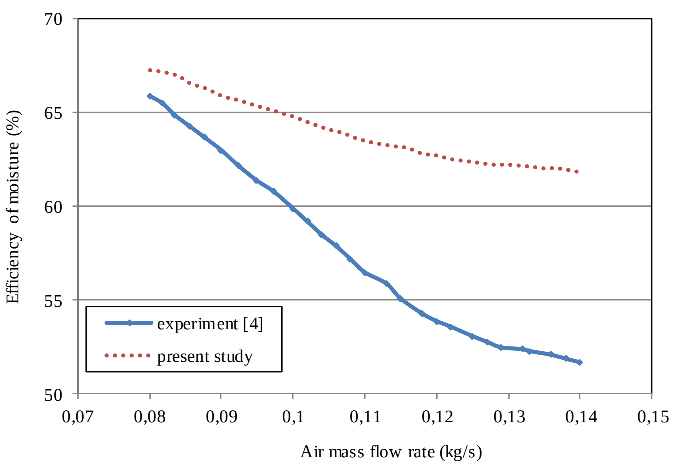

Figure 3: Effect of the air mass flow rate on the efficiency of moisture: Present study versus experimental wok [4]

B. *Humidity ratio characteristics*

Figure 4 depicts the effect of the concentration of liquid desiccant on the decrease in the humidity ratio. It is found that the larger the concentration of liquid desiccant, the larger the decrease in the humidity ratio. This is because the liquid desiccant with high concentration has higher hygroscopic (i.e. the ability to absorb air humidity) compared to liquid desiccant with low concentration. Based on Figure 4, it is also clear that the maximum decrease in the humidity ratio occurs at the concentration of liquid desiccant of 50 %. The decrease in the humidity ratio is about 8.75 g/kg.

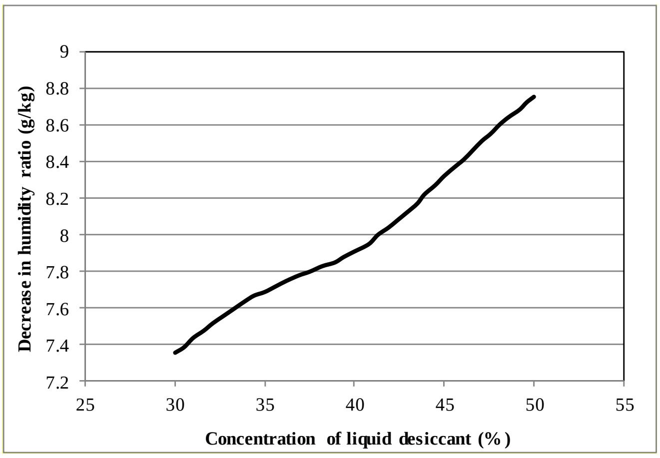

Figure 4: Effect of the concentration of liquid desiccant on the humidity ratio

Figure 5 reflects the effect of the air mass flow rate on the decrease in the humidity ratio. It can be seen that the air mass flow rate has significant role in affecting the humidity ratio. Increasing the air mass flow rate will decrease the decrease in the humidity ratio. On the other words, the larger the air mass flow rate, the smaller the decrease in the humidity ratio. Based on Figure 5, it can be seen that the biggest decrease in the humidity ratio is 9.2 g/kg at air mass flow rate of 0.08 kg/s. From the physical point of view, this is because the low air mass flow rate makes the moist air which enters into the dehumidifier relatively smaller compared than the liquid desiccant. This leads to the contact between the moist air and liquid desiccant be longer. Therefore, the liquid desiccant will absorb more water vapour contained in the humid air.

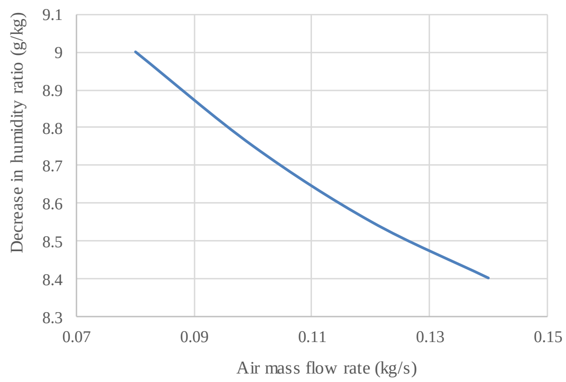

Figure 5: Effect of the air mass flow rate on the decrease in the humidity ratio

Figure 6 shows the effect of the mass flow rate of the liquid desiccant on the decrease in the humidity ratio. It can be observed that increasing the mass flow rate of the liquid desiccant will increase the decrease in the humidity ratio. In this simulation, the biggest decrease in the humidity ratio is 8.83 g/kg when mass flow rate of desiccant liquid is 0.26 kg/s. It is also shown that the smallest decrease in the humidity ratio (i.e. 8.53 g/kg) is achieved when the mass flow rate of liquid desiccant is 0.10 kg/s. On the other words, in order to achieve the best performance of the dehumidifier, a high mass flow rate of the liquid desiccant is used. This is because the contact which occurs between the moisture air and liquid desiccant can be longer due to the high liquid desiccant flow rate. Therefore, the dehumidification process becomes better.

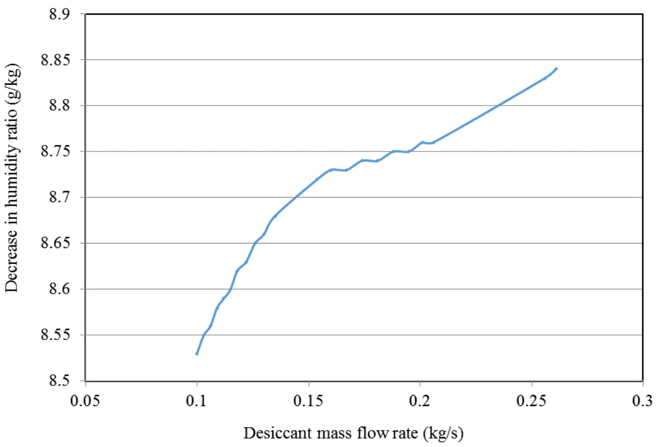

Figure 6: Effect of the mass flow rate of the liquid desiccant on the decrease in the humidity ratio

CONCLUSION

In the present paper, the investigation of the effect of the concentration and the mass flow rate of the liquid desiccant as well as the mass flow rate of air on the flow characteristics during the dehumidification process was carried out. The CFD (Computational Fluid Dynamics) approach is used to solve the engineering problems. The following conclusions can be drawn as follows:

1. The validation of the CFD method developed here has been successfully performed.
2. It is found that the larger the air mass flow rate, the smaller the decrease in the humidity ratio.
3. A decrease in the concentration of desiccant film enhances the dehumidification process of the air.

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