

Influence of Operating Parameters on the Performance of a Liquid Desiccant Ventilation Dehumidification System

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Abstract

Dehumidifying the ventilation air before being introduced into an air conditioned space is an important issue since it is the main source of latent load. If the ventilation air is dry enough, the size and then the energy consumption of the air conditioning system in the space will be reduced significantly. A liquid desiccant system is an interesting choice due to its many advantages. The key performance indices of the system are the moisture removal rate and the dehumidification effectiveness. This study reports the influence of the main operating parameters on the performance of the packed bed type liquid desiccant dehumidification system from the literature as well as a set of experiment carried out in Nakhon Pathom, Thailand. The actual experiment used 40% concentration calcium chloride solution as the desiccant. The results from the experiment were found to be corresponding to the past researches except the influence of the air flow rate which was still inconclusive. Nevertheless, it can be concluded that the performance of a liquid desiccant system will be high when the flow rate and the concentration of the desiccant solution are high and its temperature is low. Also, the performance will be high if the temperature of the dehumidified air is low. The air flow rate depends on the required ventilation rate while the input humidity level of the dehumidified air depends on the outside air condition.

Keywords: dehumidification system, liquid desiccant, calcium chloride, packed bed, ventilation air

Introduction

In a tropical climate like Thailand, it is inevitable to create thermal comfort for building occupants. Cooling load inside a building comprises sensible and latent load. The latter mostly comes from the ventilation air. Cooling load can be handled by a variety of air conditioning systems such as a vapor compression system or an absorption cooling system. Almost all of the systems are temperature-control using a thermostat. When the inside temperature reaches the setpoint, the system will stop regardless of any excessive humidity level in the space which could cause uncomfortable feeling. One way to resolve this problem is to apply the overcool and reheat scheme. The setpoint temperature will be reduced to increase the condensation thus the removed moisture until the desired humidity level is attained then an artificial heat source is employed to bring the temperature

List of Symbols

Symbols

G	= air flow rate, kg/s
h	= enthalpy of air, kJ/kgda
m	= moisture removal rate, kg/s
T	= temperature, °C
W	= humidity ratio of air, kgw/kgda
α	= dehumidification effectiveness
β	= temperature effectiveness
ε	= enthalpy effectiveness
γ_o	= critical surface tension of packing material, N/m
γ_σ	= surface tension of liquid desiccant, N/m
ξ	= concentration of liquid desiccant, % by mass

Subscripts

a	= air
ab	= absorption
in	= inlet
out	= outlet
s	= liquid desiccant

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back to the setpoint value. This method clearly consumes a lot of energy.¹⁻³

Another way to cope with this problem is the use of a liquid desiccant ventilation dehumidification system which has been studied for decades in America and Asia. Liquid desiccant is popular due to its flexibility and lower regeneration temperature (40-80°C compared with 80-120°C of the solid desiccant).⁴⁻⁵ Triethylene glycol (TEG), calcium chloride (CaCl₂), lithium chloride (LiCl), and lithium bromide (LiBr) solutions are commonly used as the liquid desiccant. Configuration of the dehumidifier could be spray chamber, spray coil, plate heat exchanger, or packed bed type. The shape may be cubical or cylindrical. When the ventilation air comes into contact with the desiccant, heat and mass transfer takes place and both the humidity level of the air and the concentration of the desiccant are reduced.

Key performance parameters of the dehumidification process are moisture removal rate and dehumidification effectiveness.⁶ Both values depend on 2 groups of input parameters comprising physical ones (e.g., size of packing and dehumidifier) and operating ones (e.g., flow rate, temperature, and humidity of the air and flow rate, temperature, and concentration of the desiccant).

This article discusses about the influence of the operating parameters on the performance of the dehumidification process gathered from the literature as well as from an actual experiment. The discussion is limited to the case of packed bed dehumidifiers using liquid desiccants.

Dehumidification Process

The dehumidification process mentioned in this article is the one that uses liquid desiccant to remove moisture from the ventilation air before being introduced into a conditioned space. The air may directly contact with the desiccant in a cross-flow, counter-flow, or parallel-flow manner. The process is a simultaneous heat and mass transfer process. The humidity level of the air and the concentration of the desiccant will be decreased after the process. The performance of the system is determined by the moisture removal rate and the dehumidification effectiveness.

Influence of Operating Parameters on Dehumidification Process Performance from the Literature

Moisture Removal Rate

This parameter can be viewed as a direct performance indicator of the system since it tells how much moisture can be absorbed by the desiccant. It can be calculated from the difference of the humidity ratios between the inlet and outlet air and the air flow rate as shown in Equation 1.

$$m_{w,ab} = G_a (W_{a,in} - W_{a,out}) \quad (1)$$

It can also be calculated from the difference of the concentration between the inlet and outlet desiccant and the desiccant flow rate as shown in Equation 2.

$$m_{w,ab} = \frac{G_s (\xi_{s,out} - \xi_{s,in})}{\xi_{s,out}} \quad (2)$$

Dehumidification Effectiveness

The dehumidification effectiveness is defined as the ratio of the actual dehumidifying capacity to the theoretical or maximum one which would occur when the humidity ratio of the outlet air is in equilibrium with the inlet desiccant as shown in Equation 3.

$$\alpha_{ab} = \frac{W_{a,in} - W_{a,out}}{W_{a,in} - W_{s,in}} \quad (3)$$

Since the dehumidification process is a simultaneous heat and mass transfer process, Equation 3 alone is not sufficient to identify the performance because it only refers to the mass transfer capability. In order to cover the heat transfer capability, either heat transfer or enthalpy effectiveness has to be evaluated according to Equations 4 and 5, respectively.

$$\beta_{ab} = \frac{T_{a,in} - T_{a,out}}{T_{a,in} - T_{s,in}} \quad (4)$$

$$\epsilon_{h,ab} = \frac{h_{a,in} - h_{a,out}}{h_{a,in} - h_{s,in}} \quad (5)$$

Chung (1994)⁶ carried out a study on a liquid desiccant dehumidification system using TEG and LiCl solutions. The system was of packed bed type. The effectiveness of the system has been modeled as a function of flow rates of the fluids, temperature of the fluids at the inlets, size of the packing, and properties of the desiccant as expressed in Equation 6. The model was an improved version of that proposed by Ullah et al. (1988).⁷

$$\alpha_{ab} = \left\{ 1 - \frac{0.205 \left(\frac{G_{s,in}}{G_{a,in}} \right)^{0.174} \exp \left[0.985 \left(\frac{T_{a,in}}{T_{s,in}} \right) \right]}{aZ^{0.184} X^{1.680}} \right\} \left\{ 1 - \frac{0.152 \exp \left[0.686 \left(\frac{T_{a,in}}{T_{s,in}} \right) \right]}{X^{3.388}} \right\} \quad (6)$$

Equation 7 shows the relationship between the dehumidification effectiveness and relevant input parameters developed by Martin and Goswami (2000).⁸

$$\alpha_{ab} = 1 - C_1 \left(\frac{G_{s,in}}{G_{a,in}} \right)^x \left(\frac{h_{a,in}}{h_{s,in}} \right)^y (aZ)^z \quad (7)$$

Where,

$$x = k_1 \frac{\gamma_s}{\gamma_0} + m_1 \quad (8)$$

$$z = k_2 \frac{\gamma_s}{\gamma_0} + m_2 \quad (9)$$

Table 1 Influence of Operating Parameters on Dehumidification Process Performance from the Literature

Researchers	Liquid Desiccant	Configuration	Experiment/Theory	L/G Ratio	Findings
Patnaik et al. (1988) ⁹	LiBr	Packed bed	Experiment	0.90-1.00	
Chen et al. (1989) ¹⁰	LiCl	Packed bed	Experiment	0.857-1.321	
Kavasogullari et al. (1991) ¹¹	LiCl, CaCl ₂	Packed bed	Experiment	0.2259	
Sadasivam and Balakrishnan (1991) ¹²	LiBr	Packed bed	Theory	0.5-1.2	
Chung et al. (1993) ¹³	LiCl	Packed bed	Experiment	0.754-8.10	Moisture removal rate ↑ when:
Radhwan et al. (1993) ¹⁴	CaCl ₂	Packed bed	Theory	-	- air flow rate ↑
Oberg and Goswami (1998) ¹⁵	TEG	Packed bed	Experiment	-	- air temperature ↓
Fumo and Goswami (2002) ¹⁶	LiCl	Packed bed	Experiment	4.90-5.63	- air humidity ratio ↑
Abdul-Wahab et al. (2004) ¹⁷	TEG	Packed bed	Experiment	2.613-11.54	- desiccant flow rate ↑
Chen et al. (2006) ¹⁸	LiCl	Packed bed	Theory	4.90-5.64	- desiccant temperature ↓
Chengqin et al. (2006) ¹⁹	LiBr	Packed bed	Theory	-	- desiccant concentration ↑
Liu et al. (2006) ²⁰	LiBr	Packed bed	Experiment	-	
Gommed (2007) ²¹	LiCl	Packed bed	Experiment	-	Dehumidification effectiveness ↑ when:
Katejanekam et al. (2008) ²²	LiCl	Packed bed	Experiment	3.5-15.4	- air flow rate ↓
Liu et al. (2008) ²³	LiCl, LiBr	Packed bed	Theory	1.25	- air temperature ↓
Babakhani and Soleymani (2009) ²⁴	LiCl	Packed bed	Theory	0.236-2.359	- air humidity ratio ↑
Giovanni (2009) ²⁵	LiBr	Packed bed	Experiment	0.36-1.39	- desiccant flow rate ↑
Hassan (2009) ²⁶	CaCl ₂	Packed bed	Experiment	1.9-2.0	- desiccant temperature ↑
Moon et al. (2009) ²⁷	CaCl ₂	Packed bed	Experiment	1.29-1.38	- desiccant concentration ↑
Tretiak and Abdallah (2009) ²⁸	Clay-CaCl ₂	Packed bed	Experiment	-	
Yin et al. (2009) ²⁹	LiCl	Packed bed	Experiment	0.122-0.8	
Kabeel (2010) ³⁰	CaCl ₂	Packed bed	Experiment	0.773-1.42	
Zhang et al. (2010) ³¹	LiCl	Packed bed	Experiment	0.122-0.8	
Ge et al. (2011) ³²	LiCl, CaCl ₂	Packed bed	Experiment	4.125-5.181	
Gao et al. (2012) ³³	LiCl	Packed bed	Experiment	1.25-1.875	

Considering Equations 6 and 7, the important parameters indicating the operating condition of the system are the ratio of the desiccant flow rate to the air flow rate (L/G ratio or Gs/Ga) and the ratio of the inlet air temperature to the inlet desiccant temperature (T_a/T_s or h_a/h_s instead in Equation 7). It can be observed from both equations that the effectiveness will be high when the humidity ratio of the air and the flow rate and concentration of the desiccant are high, whereas the temperature of the desiccant and the flow rate and temperature of the air should be low.

Table 1 summarizes the influence of the operating parameters on the performance of the liquid desiccant dehumidification process reviewed from the literature. It is found that the process would perform better (moisture removal rate is higher) when the air flow rate, desiccant flow rate, air humidity ratio, and desiccant concentration are higher, whereas the air and desiccant temperature should be lower. For the effectiveness, its value would be higher when the air humidity ratio, desiccant flow rate, desiccant temperature, and desiccant concentration are higher, while the air flow rate and temperature should be lower.

Influence of Operating Parameters on Dehumidification Process Performance from an Actual Experiment

This section discusses the influence of the operating parameters on the performance of an actual dehumidification process. The dehumidifier used in this experiment was a counter-flow packed bed type with a diameter of 0.68 m and a height of 1.90 m. Outside was insulated with 0.15-m fiberglass. Inside was filled with 25-mm Pall ring packings that formed a 0.50-m packed bed.

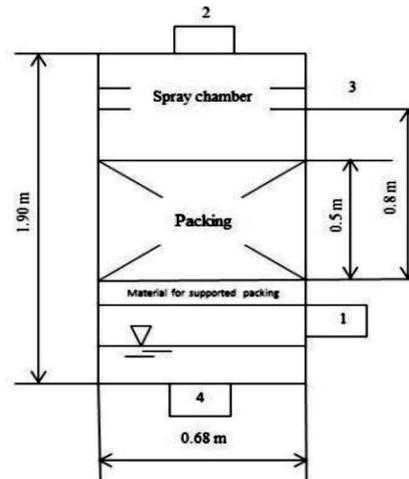


Figure 1 Dehumidifier Used in the Experiment³

The concentration of the $CaCl_2$ solution was controlled at approximately 40% by mass. The dehumidified air flow rate was varied at 0.04, 0.06, and 0.08 kg/s. The desiccant flow rate was varied at 0.02, 0.07, and 0.12 kg/s. The temperature and humidity of the air were at ambient condition. The temperature of the desiccant also depended on the ambient condition because it was cooled by cooling water supplied by a cooling tower. The experiment was carried out during February and March, 2011.⁵ The L/G ratio of the experiment was within the range of 0.277-2.77.

Influence on Moisture Removal Rate Influence of Air Flow Rate

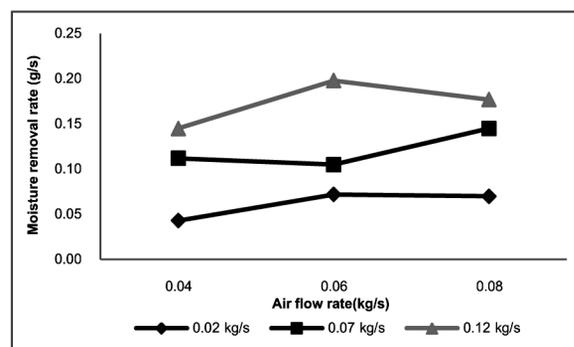


Figure 2 Relationship between Moisture Removal Rate and Air Flow Rate

Figure 2 illustrates the influence of the air flow rate on the moisture removal rate. It can be seen that at the desiccant flow rates of 0.02 and 0.12 kg/s, the moisture removal rate increased with the increase of the air flow rate until a certain point then it became nearly constant or gradually decreased. However, the trend did not apply to the case of the desiccant flow rate of 0.07 kg/s. Therefore, it should be said that the influence of the air flow rate on the moisture removal rate was still inconclusive.

Influence of Desiccant Flow Rate

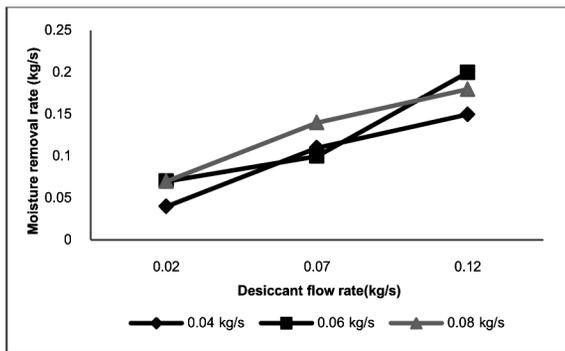


Figure 3 Relationship between Moisture Removal Rate and Desiccant Flow Rate

It can be seen from Figure 3 that the moisture removal rate increased with the increase of the desiccant flow rate. This is due to the fact that the amount of the desiccant in the system is greater thus the moisture transfer which is corresponding to the previous researches.

Influence of Air and Desiccant Temperature

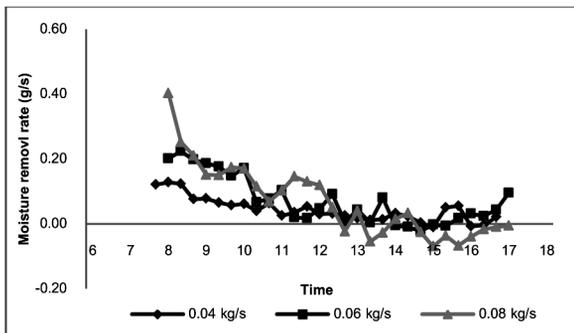


Figure 4 Daily Moisture Removal Rate at a Fixed Desiccant Flow Rate and Varied Air Flow Rate

From Figure 4, as the system operated along the day the temperature of the air and the desiccant increased from 8 a.m. until 4 p.m. as opposed to the decreasing moisture removal rate. This suggests that the moisture removal rate increases with the decrease of the temperature of the fluids which is corresponding to the literature.

**Influence on Dehumidification Effectiveness
Influence of Air Flow Rate**

Figure 5 shows the influence of the air flow rate on the dehumidification effectiveness. It can be seen that at the desiccant flow rates of 0.02 and 0.12 kg/s, the effectiveness increased with the increase of the air flow rate until a certain point then it became nearly constant or gradually decreased because of the less contact time between the air and the desiccant. Nonetheless, the trend was different for the case of the desiccant flow rate of 0.07 kg/s. Therefore, it should be said that the influence of the air flow rate on the effectiveness was still inconclusive.

Influence of Desiccant Flow Rate

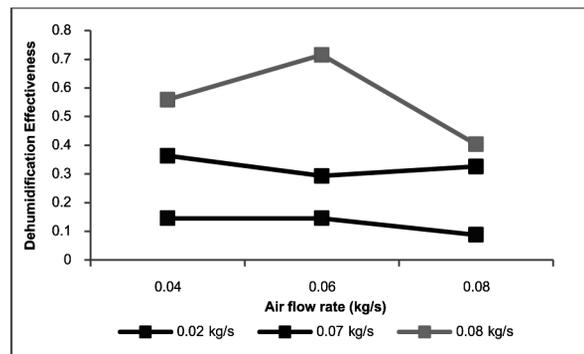


Figure 5 Relationship between Dehumidification Effectiveness and Air Flow Rate

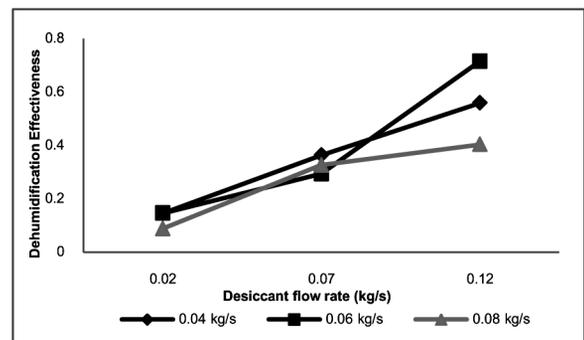


Figure 6 Relationship between Dehumidification Effectiveness and Desiccant Flow Rate

It can be seen from Figure 6 that the dehumidification effectiveness increased with the increase of the desiccant flow rate since the amount of the desiccant in the system is greater which corresponds to the past researches.

Influence of Air and Desiccant Temperature

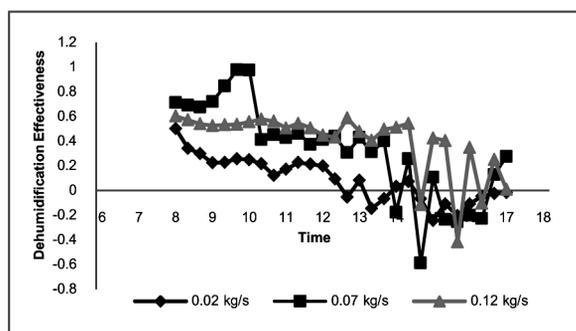


Figure 7 Daily Dehumidification Effectiveness at a Fixed Desiccant Flow Rate and Varied Air Flow Rate

From Figure 7, as the system ran along the day the temperature of the air and the desiccant increased from 8 a.m. until 4 p.m. as opposed to the decreasing dehumidification effectiveness. This implies that the effectiveness increases with the decrease of the temperature of the fluids which is corresponding to the literature.

Conclusion and Suggestions

This article reports the influence of the main operating parameters on the performance of the liquid desiccant dehumidification process reviewed from the literature and from an actual experiment. From the literature, the moisture removal rate increases with the increase of the air flow rate, desiccant flow rate, air humidity ratio, and desiccant concentration, but with the decrease of the air and desiccant temperature. The dehumidification effectiveness increases with the air humidity ratio, desiccant flow rate, desiccant temperature, and desiccant concentration, but with the decrease of the air flow rate and temperature.

From the actual experiment, the influence of the air flow rate on the performance was not conclusive. One assumption is that the L/G ratio may have an effect which needs further studies. Nevertheless, the increase of

the desiccant flow rate causes better performance which agrees well with the literature.

Finally, it can be concluded that a liquid desiccant dehumidification process would work best at high desiccant flow rate and concentration and low desiccant temperature, while the inlet temperature of the air and the desiccant should be low. The air flow rate would be depending on the required ventilation rate whereas the inlet air humidity would be up to the ambient condition.

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