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Entropy Generation in Liquid Desiccant Dehumidification System

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Abstract

In this paper, performance of the liquid desiccant dehumidification system in evaporation coolers was investigated by the Second Law of Thermodynamics analysis. This system was designed and manufactured for this purpose. Lithium chloride (LiCl), as liquid desiccant, and a packed bed column were used for dehumidification. The described system includes a part for processed air simulation in various temperatures and humidities. Entropy generation of the liquid desiccant dehumidifier was analyzed based on the second thermodynamic law. The effect of inlet parameters of the dehumidification column on the entropy generation was also investigated. The results showed that the entropy generation was highly dependent to operational conditions and inlet parameters of the desiccant dehumidification column.

Keywords: Liquid desiccant; dehumidification; entropy generation; lithium chloride;

1. Introduction

The adverse environmental effects of chlorofluorocarbons, used in traditional cooling systems and air conditioning industries, have been widely demonstrated. One of these new technologies, going to be the center of attention worldwide, is the desiccant cooling system, in which heat sources are used rather than electricity for cooling purposes. On the other hand, the efficiency of desiccant cooling systems is higher in comparison to traditional vapor compression air conditioning systems, and this reduces the energy consumption. Application of desiccant in the cooling system leads to elimination of humidity in the inlet air; so, cooling system operates with higher efficiency. The desiccants are encountered both in liquid and solid states. Both liquid and solid desiccant systems have their own advantages and shortcomings. In addition to lower regeneration temperature and favorable flexibility in utilization, the liquid desiccant has lower pressure drop on the air side. Solid desiccants are compact and less prone to corrosion or carry-over. Commonly used desiccant materials include lithium chloride, triethylene glycol, silica gels, aluminum silicates, lithium bromide solution and lithium chloride solution, etc [1]. More details about desiccant types, properties and the regeneration processes are presented in reference [2]. Although numerous studies

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about desiccant dehumidification systems have been recently undertaken by researches e.g. [3-9], only few papers have been yet appeared on the Second Law of Thermodynamics analysis of the liquid dehumidification cooling system. In this paper, experimental setup of the dehumidification column of the desiccant cooling system was designed and manufactured. The main purpose of this study is to evaluate entropy generation of dehumidification of the liquid desicant cooling system. The effect of operatinal inlet parameters to the desiccant dehumidification column (flow rate, tempreture and humidity ratio of the inlet air and flow rate, temperture and concentration of the desiccant solution) on the entropy generation was investigated experimentaly.

Nomenclature

Cp	Specific heat (kJ/(kg ^oC))
G	Mass flow rate (kg/s)
h	Enthalpy (kJ/kg)
h_{fg}	Latent heat of vaporization (kJ/kg)
Q	Rate of heat transfer (kJ/s)
s	Entropy (kJ/(kg.K))
S_{gen}	entoropy generation (kJ/(s.K))
T	Temperature (^oC)
Ua	Velocity of the air (m/s)
X	Mass concentration of desiccant solution (weight fraction)
ω	Humidity ratio of the air (kg/kg)
Subscripts	
a	Air
i	Inlet
o	outlet
s	Desiccant solution

2. Modeling

Here, in this section, a new model has been introduced for the Second Law of Thermodynamics analysis of the dehumidification process. The schematic presentation of the system with input and output terms is shown in Figure 1. In this process, the liquid desiccant solution is brought into packing tower and contacts directly with the processed air. The thick solution absorbs the water vapor from the air because the vapor partial pressure of the air is higher than that on the solution surface. Temperature of the solution increases due to release of the water latent heat. Therefore, the surface vapor partial pressure of the desiccant solution increases, depressing the solution absorption. Hence, coupled heat and mass transfer occurs during the dehumidification process. As clearly seen in the Figure 1, we have four major components to take into consideration as follows: Point 1. Referring to the input of moist air to the dehumidifier chamber to remove its humidity. Point 2. Referring to the input of liquid desiccant solution to dry the moist air. Point 3. Referring to the output of dry air after removing of its moisture by the liquid desiccant solution. Point 4. Referring to the output of dilute liquid desiccant solution, accompanied with moisture acquired from the air. Here, the mass, energy, and entropy balance equations were written for the above system, as a control volume system, shown in Figure 1 since writing the balance equations correctly is an essential way of solution to such systems.

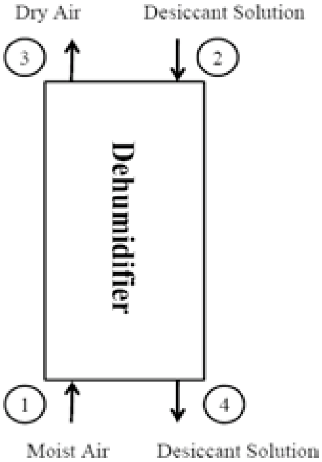

Figure 1. Schematic view of the dehumidification process with input and output terms.

In order to write the mass balance equations for the dehumidifier shown in Figure 1, two components i.e. liquid desiccant solution and process air are considered. Therefore, the mass balance equations for these elements are written as follows. For liquid desiccant solution:

$$(G_s\,X)_2 = (G_s\,X)_4 \qquad (1)$$

In this and other equations, a and s indexes are indicative of liquid and air flow respectively and numbers shown in each equation, are corresponding to the numbers shown in the figure. For the air, the equation should be:

$$(G_a)_1 = (G_a)_3 = G_a \qquad (2)$$

If ω is the humidity ratio of the air , it should be according to the mass balance equation, as follows:

$$(G_s)_4 = (G_s)_1 - G_a\,((\omega_a)_3 - (\omega_a)_1 \qquad (3)$$

The energy balance equation can be written for the entire system in the following manner, by taking input energy terms equal to output energy terms:

$$G_a\,(h_a)_1 + (G_s)_2\,(h_s)_2 = G_a\,(h_a)_3 + (G_s)_4\,(h_s)_4 + Q \qquad (4)$$

The enthalpy of moist air is defined as:

$$h_a = Cp_a\,T_a + \omega_a\,h_{fg} \qquad (5)$$

Note that here the values of $(h_a)_1$ and $(h_a)_3$ can directly be obtained from psychrometric chart. In this section, the entropy balance equation was written for the entire system in the way it was applied for energy balance equation for the input and output terms. Therefore, it can be written as follows:

$$G_a\,(s_a)_1 + (G_s)_2\,(s_s)_2 = Ga\,(s_a)_3 + (Gs)_4\,(s_s)_4 + Q/T + S_{gen} \qquad (6)$$

3. Experimental Setup

A liquid desiccant cooling system has been set up for this research as shown in Figure2. This system includes a section for processed air simulation with various temperatures and humidities. The air passes through a heater composed of many elements and the number of “on” elements is adjusted according to the temperatures needed for the test. Having passed the heater, air goes through a humidifying system. Water is pumped from a tank above the humidifier. A valve controls the water flow. After passing through the humidifier, water exits from the system’s lower part and returns back to the tank. After this stage, air gains the predicted temperature and humidity. The processed air passes through a packed bed column that includes a packing with specific area of 250 m^2/m^3. In this column, the lithium chloride solution with a previously defined concentration is used as the desiccant material. This solution is poured in tank 2 with a specific concentration. After coming in contact with the solution, the air loses its humidity and the solution becomes partially dilute and warm due to the release of latent heat. Then the liquid solution enters in the tank 1 and after its filling, the intervening pump starts and transfers the solution to the tank 2. In the second tank, the temperature lowers by cooling coils; so, it would be suitable for the drying process. A valve controls the flow rate of the input lithium chloride solution. After passing through the column, the humidity of processed air decreases and then it enters an evaporating cooling system so that its temperature is adjusted according to the room air. The water needed for this system is supplied from the system water tank and returns back into it again. Temperature of the air was measured before and after the humidifying column and also next to the evaporating cooling system. The mass concentration of the aqueous lithium chloride was tested by measuring the density and temperature of the solution. According to density and temperature of the solution, its mass concentration could be worked out. All the experiments were carried out under the steady state of the air and liquid desiccant. The flow rate of processed air was adjusted by a rate modifying inverter.

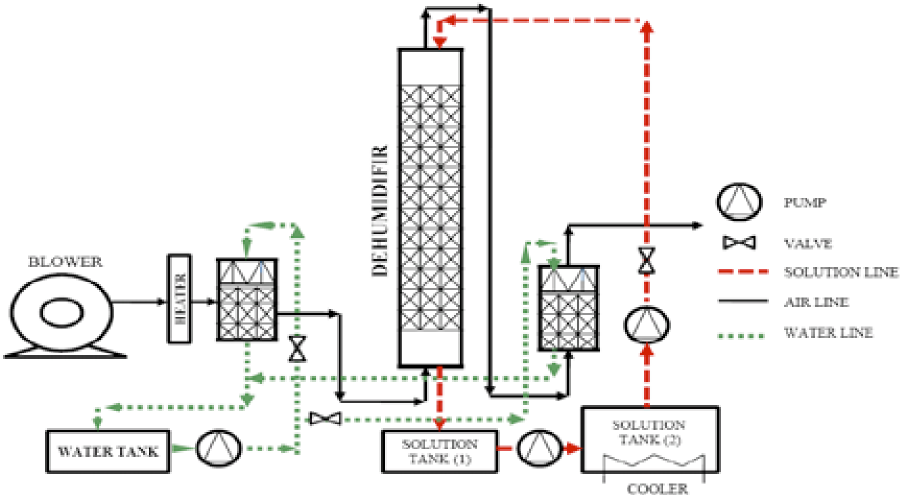

Figure2. Schematic diagram of the liquid desiccant cooling system setup

4. Results and Analysis

It is necessary to calculate entropy of lithium chloride solution for the Second Law of Thermodynamics analysis of the dehumidification system. Entropy of the lithium chloride solution can be calculated according to following equations described in reference [10]. According to presented equations and experimental data derived from the desiccant dehumidification system, the entropy generation of the system can be calculated and the effect of operational situations on this parameter can be evaluated. For study of the effect of inlet air temperature and humidity ratio on the entropy generation, some experimental trials were carried out according to situations mentioned in Table1.

Table1. Experimental inlet conditions

Air			Desiccant solution		
Ua(m^2/s)	$T_{a,i}$ (ºC)	$\omega_{a,i}$ (kg/kg)	$G_{s,i}$ (kg/s)	$T_{s,i}$ (ºC)	$X_{s,i}$ (kg/kg)
2.10-3.98 m^2/s	30.0-50.0	0.0150-0.0730	0.1240	21.0	0.3700

Figures 3(a) and 3(b) show the effect of temperature and humidity ratio of the air going with various rates into the dehumidifying packed bed column, on entropy generation in experimental condition. As shown, with the increase in temperature and humidity ratio, the entropy generation from the air increases. Also as demonstrated, the entropy generation increases in order to increase the processed air flow rate.

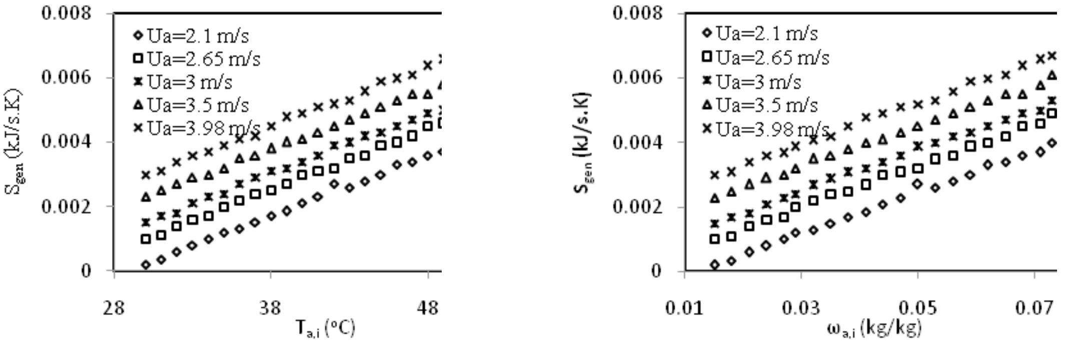

Figure3. (a) Effect of inlet air temperature on entropy generation (b). Effect of inlet air humidity ratio on entropy generation

Table 2 demonstrates the experimental settings applied for study of the effect of temperature of desiccant solution entering packed bed column, on entropy generation. The results of these tests are presented in figure 4. As shown, with the increase in solution temperature entropy generation decreases.

Table2. Experimental inlet conditions

	Air			Desiccant solution	
Ua (m^2/s)	$T_{a,i}$ (ºC)	$\omega_{a,i}$(kg/kg)	$G_{s,i}$ (kg/s)	$T_{s,i}$ (ºC)	$X_{s,i}$ (kg/kg)
2.10-3.98	39.0	0.040	0.1240	17.0-27.0	0.3850

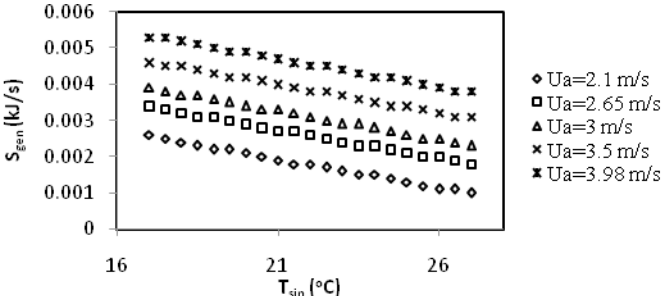

Figure4. Effect of inlet desiccant solution temperature on entropy generation

Figure 5 shows the effect of concentration of solution entering the dehumidifying column, on entropy generation. These experimental trials were performed in the settings presented in Table3. As demonstrated, changes in solution concentration have no significant effects on entropy generation in applied experimental settings.

Table3. Experimental inlet conditions

	Air			Desiccant solution	
Ua (m^2/s)	$T_{a,i}$ (ºC)	$\omega_{a,i}$(kg/kg)	$G_{s,i}$ (kg/s)	$T_{s,i}$ (ºC)	$X_{s,i}$ (kg/kg)
2.10-3.98 m2/s	41.0	0.044	0.1240	22.5	0.30-0.40

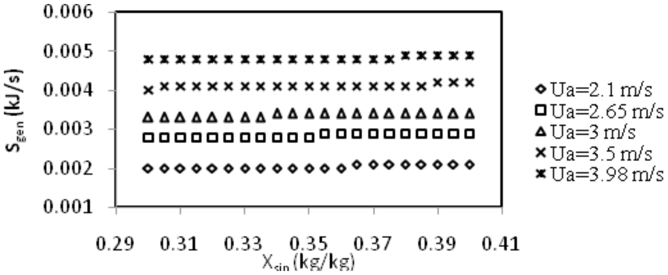

Figure5. Effect of inlet desiccant solution concentration on entropy generation

Some experimental tests were designed to study the effect of mass flow rate of solution, entering the dehumidifying column, on entropy generation. The settings of these tests are presented in Table4. The results show that the increase in flow rate of desiccant solution decreases the amount of entropy generation (Figure 6).

Table4. Experimental inlet conditions

Air			Desiccant solution		
Ua(m^2/s)	$T_{a,i}$ (°C)	$\omega_{a,i}$ (kg/kg)	$G_{s,i}$ (kg/s)	$T_{s,i}$ (°C)	$X_{s,i}$ (kg/kg)
2.10-3.98 m2/s	38.0	0.038	0.0590-0.1250	23.0	0.3600

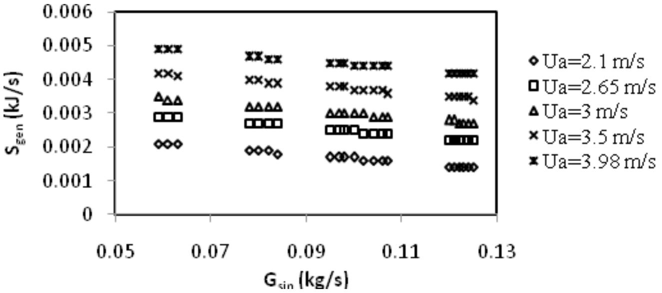

Figure6. Effect of inlet desiccant solution flow rate on entropy generation

A review of the published literature showed that most of the previous investigations were about heat and mass balance equations between the air flow and liquid desiccant; the effect of the inlet parameters on the moisture removal rate, heat and mass transfer coefficients has also been investigated in other papers but the effect of inlet parameters on the entropy generation has not been evaluated yet.

5. Conclusions

According to the second thermodynamic law, entropy balance equation for the dehumidification column was written; based on this equation, entropy generation was calculated in various experimental situations. The effects of inlet parameters to the desiccant dehumidification column on the entropy generation were also evaluated. The result showed that the amount of entropy generation is highly dependent to the values of inlet parameters to the desiccant dehumidification column; entropy generation increases with the increase in the flow rate, temperature and humidity ratio of the air. On the other hand, increase of the temperature and flow rate of the solution leads to decrease in the entropy generation. Also, it would be evident that the solution concentration has no significant effect on the entropy generation.

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