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Mass transfer performance of the LiCl solution dehumidification process

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ABSTRACT

The driving force of the solution dehumidification process is investigated in this work, in which the parameters without the solute are used. The isothermal and non-isothermal equilibrium curves under some thermal conditions are calculated for the dehumidification process related to the LiCl solution as desiccant. Experiments based on the obtained equilibrium curves were performed for the structured packing tower with a height of 0.2 m and 0.3 m respectively. The temperature variation for the solution decreased with an increase in the solution flow rate and increased with an increasing airflow rate. But the temperature variation for the air did not display a marked trend. The average driving force and the overall mass transfer coefficients are calculated. The average driving force is investigated for different solution flow rates. The overall volumetric mass transfer coefficient increased with an increasing solution flow rate.

1. Introduction

For a traditional air conditioning system, the latent load may be handled by reducing the thermostat set-point well below the dew-point temperature to increase the condensation. As such, the air is reheated to bring the temperature back to the required value. This air-handling process is energy-inefficient [1]. Liquid desiccant dehumidification system reduces the water vapor content in moist air by means of the water vapor pressure difference between the moist air and the desiccant [2]. This is an efficient way to avoid the overcool/reheat scheme in the traditional air-handling process.

The characteristic of desiccants has a decisive effect on the system performance. The triethylene glycol (TEG) was used as a desiccant during the earlier times. It was then replaced by some salt solutions due to its high viscosity and volatility. McNeeley [3] and Kaita [4] tested the thermophysical properties of LiBr at different temperatures and concentrations. Liu et al. [5] summarized the features of LiBr and LiCl and experimentally compared their dehumidification performance, indicating LiCl solution was better than LiBr solution in the dehumidification process. Gong et al. [6] and Li et al. [7] tested the mixed solution of $CaCl_2$ and LiCl and investigated its dehumidification capacity. Conde [8] summarized the main parameters of $CaCl_2$ and LiCl and provided the relationship between such parameters as relative vapor pressure, density, viscosity, temperature and the desiccant mass concentration, which is important for the dehumidification applications.

Some of the relevant research works about the theoretical and experimental performance of different types of dehumidifiers are addressed here. Chen et al. [9] presented the mathematical models of an adiabatic dehumidifier, by applying the efficiency-heat transfer element method, and calculated the outlet parameters under several initial conditions. Dai and Zhang [10] and Khan and Sulsona [11] utilized a number of simplified models for cross-flow dehumidifiers and investigated the relationship between the relevant parameters. Liu et al. [12] and Gao et al. [13] established a cross-flow dehumidifier experimental setup and analyzed the influence of the inlet parameters on the dehumidifying performance. Zhang et al. [14] also investigated the dehumidifying performance of cross-flow dehumidifiers by using several different desiccants. In order to improve the overall system performance, the liquid desiccant dehumidification system was also coupled with such cooling systems as the vapor absorption system [15], cogeneration system [16] and heat pump system [17].

Counter-flow dehumidifier has a better performance in comparison with downstream and cross-flow type. Ren et al. [18,19] utilized a one-dimensional mathematical model of an adiabatic dehumidifier to analyze the coupled heat and mass transfer process. Li et al. [20] carried out a counter-flow dehumidifying experiment, by using $CaCl_2$ as a desiccant, and analyzed the influence of the solution flow and concentration on the outlet humidity of the air. Gu et al. [21] and Liu et al. [22] performed a similar set of experiments using LiCl as a desiccant. Babakhani and Soleymani [23] found a mathematical relationship between the dehumidification effectiveness and the mass transfer unit, and compared the results with some experimental data. Gandhidasan [24] obtained a correlation for the dehumidification

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Nomenclature

a	specific surface area ($m^2 \cdot m^{-3}$)
d	air humidity ratio ($kg_{H2O} \cdot kg_{DA}{}^{-1}$)
h	specific enthalpy ($kJ \cdot kg^{-1}$)
k	single phase mass transfer coefficient ($kg \cdot m^{-2} \cdot s^{-1}$)
K	overall mass transfer coefficient ($kg \cdot m^{-2} \cdot s^{-1}$)
m	mass flow rate ($kg \cdot s^{-1}$)
M	mass flow rate without solute ($kg \cdot s^{-1}$)
N	mass flux rate ($kg \cdot m^{-2} \cdot s^{-1}$)
p	pressure (Pa)
Q	energy change rate (kW)
x	mass concentration of water in the liquid phase ($kg_{H2O} \cdot kg_l{}^{-1}$)
X	mass concentration without water solute in the liquid phase ($kg_{H2O} \cdot kg_{Licl}{}^{-1}$)
y	mass concentration of water in the gas phase ($kg_{H2O} \cdot kg_g{}^{-1}$)
Y	mass concentration without water solute in the gas phase ($kg_{H2O} \cdot kg_{DA}{}^{-1}$)
ΔY	the average driving force based on the mass concentration without the solute ($kg_{H2O} \cdot kg_{DA}{}^{-1}$)

Greek symbols

ε	mass concentration of LiCl in the solution
π	relative vapor pressure of the solution
ρ	density ($kg \cdot m^{-3}$)
φ	relative humidity (%)

Subscripts

DA	dry air
e	equilibrium status
g	air/gas
H_2O	water
i	inlet
l	liquid/solution
m	average
o	outlet
V	vapor

capacity under some inlet and outlet conditions. To improve the heat and mass transfer performance of the desiccant, Ali et al. [25–27] studied the dehumidification process by adding nanoparticle suspensions into the desiccant for different configurations. Their simulation results established that nanoparticles had a significant effect on improving the dehumidification process.

Prior works have mainly focused on the relationship between the macro parameters for the solution and the air. Relatively little attention has been given to the mass transfer driving force in the dehumidification process. The fitting curves based on the experimental data are discrete and non-universal. The equilibrium curves on the basis of equilibrium states are universal and can be used to design a dehumidification experiment and to analyze the mass transfer driving force.

In this work, the dehumidification process is analyzed while accounting for the mass transfer. The equilibrium curves for the dehumidification process using LiCl as the desiccant and the driving force based on these curves are obtained. The temperature variation for the solution and the air and the overall volumetric mass transfer coefficient based on the solution and moist air mass flow rate while carrying out LiCl solution dehumidification experiments are also analyzed. Our work can improve and enhance the dehumidification technology for air conditioning applications.

2. Mass transfer analysis for solution dehumidification

When the vapor pressure of an aqueous solution is less than the partial pressure of the water vapor of the moist air, the water vapor can transfer from the moist air to the solution. The greater the pressure difference, the higher the transfer rate for the water vapor. The parameters for the counter flow dehumidification process are shown in Fig. 1 [28].

Here z_1 and z_2 are the bottom and top position of the dehumidifier; m_{l1} and m_{l2} are the mass flow rate of liquid phase L with x_1 and x_2 being the corresponding mass concentration of water in the liquid phase. Similarly, m_{g1} and m_{g2} are the mass flow rate of gas phase G with y_1 and y_2 being the corresponding mass concentration of water vapor in the gas phase.

2.1.1. Mass transfer equation

Without chemical reaction, the mass balance equation of water in counter flow dehumidification process can be written as [28]:

$$m_{g1}y_1 + m_{l2}x_2 = m_{g2}y_2 + m_{l1}x_1 \tag{1}$$

The parameters without solute are used for simplifying the equations. So the mass concentrations without solute are written as

$$Y = \frac{y}{1-y} \tag{2a}$$

$$X = \frac{x}{1-x} \tag{2b}$$

The mass flow rate without solute can be written as

$$M_l = m_l \cdot (1-x) \tag{3a}$$

$$M_g = m_g \cdot (1-y) \tag{3b}$$

Substituting Eqs. (2a), (2b), (3a), and (3b) into Eq. (1), we obtain the following mass balance equation for water.

$$M_g Y_1 + M_l X_2 = M_g Y_2 + M_l X_1 \tag{4a}$$

$$\frac{M_l}{M_g} = \frac{Y_1 - Y_2}{X_1 - X_2} \tag{4b}$$

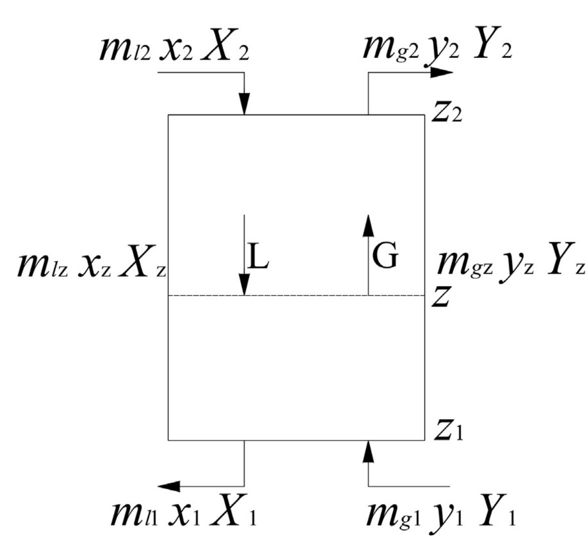

Fig. 1. Pertinent parameters for the counter flow dehumidification process.