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Experimental study on a new internally cooled/heated dehumidifier/regenerator of liquid desiccant systems

*Yonggao Yin**, *Xiaosong Zhang*, *Geng Wang*, *Lei Luo*

School of Energy and Environment, Southeast University, 2# SiPaiLou Road, Nanjing, Jiangsu 210096, China

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ABSTRACT

For providing good performance of dehumidifier and regenerator with certain dimensions, a new type of internally cooled/heated dehumidifier/regenerator based on the plate–fin heat exchanger (PFHE) was designed. To investigate the behavior of the new equipment, an experimental setup was established in an environment chamber with regulable temperature and humidity air. By the internally cooled dehumidification testing, effects of the cooling water temperature, the air flow rate and the desiccant temperature on the dehumidification performance and the cooling efficiency were presented. The behavior of internally cooled dehumidification process was compared with that of the adiabatic dehumidification process. The results suggested that the cooling efficiency decreased with the increasing of the cooling water temperature and desiccant with low temperature could bring more mass transfer coefficients. There is an optimal air flow rate to achieve the maximum absolute humidity decrease of the air. By the internally heated regeneration testing, effects of the air flow rate and the desiccant inlet temperature on the regeneration performance and air outlet parameters were discussed and also compared with those of the adiabatic regeneration process. It was concluded that the regeneration efficiency of internally heated regeneration was more than that of the adiabatic regeneration, and the internally heated regenerator could offer better thermal performance.

Nouveau déshumidificateur/régénérateur refroidi/chauffé de façon interne, utilisé pour les systèmes à déshydratant liquide: étude expérimentale

Mots clés : Conditionnement d'air ; Déshumidificateur ; Déshydratant ; Conception ; Échangeur de chaleur ; Régénérateur ; Tube aileté ; Expérimentation

* *Corresponding author*. Tel./fax: +86 25 83792722.
E-mail address: minigao_79@hotmail.com (Y. Yin).
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Nomenclature

A	mass transfer area (m^2)
e	cooling efficiency
G_a	flow rate of air ($m^3\,s^{-1}$)
G_s	flow rate of solution ($kg\,s^{-1}$)
h_D	mass transfer coefficient ($m\,s^{-1}$)
m	vapor removal rate ($kg\,s^{-1}$)
Q_h	heating power (kW)
r	vaporization heat ($kJ\,kg^{-1}$)
T	temperature (°C)
W	humidity ratio of the air ($kg\,kg^{-1}$)
X	mass concentration (%)

Greek letters

η	regeneration efficiency

Subscripts

a	air
c	cooling
equ	equilibrium
deh	dehumidification
in	inlet
out	outlet
reg	regeneration
s	desiccant solution
w	cooling water

1. Introduction

Liquid desiccant systems show great energy-saving potential so that much research on them has been conducted recently (Factor and Grossman, 1980; Gandhidsan, 2005). Liquid desiccant systems can be driven by low-grade heat (about 70–80 °C), such as solar energy, industrial waste heat (Pohl et al., 1998), and have no pollution to the environment. In addition, hybrid liquid desiccant systems combining with traditional vapor compression chilling units can bring much better thermal performance and obviously increase the coefficient of performance (COP) of the refrigeration systems. Dehumidification and regeneration processes are very important to liquid desiccant systems, and determine the thermal performance of the systems. In earlier experimental studies on liquid desiccant systems, most of them (Fumo and Goswami, 2002; Gommed and Grossman, 2004; Liu et al., 2006) focused on packed bed dehumidifiers and regenerators which could provide much contacting area for air and liquid desiccant, but the heat and mass transfer processes happening in them were adiabatic and with the progress of dehumidification/regeneration process the heat and mass transfer gradients would decrease greatly. Yin et al. (2007) conducted parameters' analysis on packed bed dehumidifier and regenerator experimentally and the results indicated that with the process progress the bottom of the regenerator showed very wick regenerative performance because the desiccant temperature at the bottom of the regenerator was very low. But internally cooled dehumidifiers and internally heated regenerators could provide more heat and mass transfer gradients and have the possibility to make dehumidifiers and regenerators miniaturization. Khan and Martinez (1998) studied numerically the performance of an internally cooled counter flow absorber using thin plate heat and mass exchanger cooled by direct evaporation with lithium chloride as desiccant. Enthalpy and humidity effectiveness were brought out to define the thermal performance of the absorber. It was found that the number of mass transfer units had great effect on the enthalpy and humidity effectiveness. Khan (1998) investigated numerically on an internally cooled dehumidifier using tube–fin exchanger with the air crossing flow. Jain et al. (2000) investigated a liquid desiccant system which was made up of a packed bed regenerator and an internally cooled dehumidifier and suggested that the improper wetness had important effect on the performance of dehumidifier and regenerator and gave the wetness factor. Saman and Alizadeh (2002) presented the experimental results using cross-flow type plate heat exchanger (PHE) as a dehumidifier/cooler. Many flow passages were separated by thin plastic plates, and one side of each thin plastic plate was for the desiccant solution/air passage; the other side is for water/air passage. So the indirect evaporation process in the water/air passage provided cooling to the dehumidification process. The experimental results indicated the effects of inlet parameters of air and solution on the PHE effectiveness. Yin et al. (2006) presented a model of internally cooled and adiabatic dehumidifier and carried out the parameters' comparative study on the two types of dehumidification processes.

However, none of these studies were carried out on the internally heated regeneration processes, and generally experimental studies on the internally cooled dehumidification processes were very limited and more investigation and relative data support are required for developing liquid desiccant systems. This study presented an experimental apparatus which could be used as an internally cooled dehumidifier and also as an internally heated regenerator depending on the operation conditions, and parameters' investigation on the internally cooled dehumidifier processes and internally heated regeneration processes was carried out.

2. Experimental apparatus and instrumentation

A plate–fin heat exchanger (PFHE) made of stainless steel is proposed to use for internally cooled/heated element of the dehumidifier/regenerator. The schematic diagram of the PFHE is shown in Fig. 1. There are seven water passages and six desiccant solution/air passages in every PFHE as shown in Fig. 1(b). Each solution passage is 298 mm in length and 12 mm in width. The cooling/heating water can enter into and leave the PFHE at the same side of the PFHE. Between two neighboring plates, there are three layers of fin side by side intercrossing, which can provide more contacting area for desiccant solution and air. The distance between fins is 4 mm. The dimensions of the PFHE are shown in Fig. 1(a)