Energy Conversion and Management 75 (2013) 175–183

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Parametric study of a single cycle two-stage structured packing counter flow air dehumidifier using two feeding desiccant solution lines

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ARTICLE INFO

Article history:
Received 16 April 2013
Accepted 12 June 2013

Keywords:
Counter flow dehumidifier
Liquid desiccant
Numerical solution
Structured packing bed
Desiccant cooling

ABSTRACT

The performance analysis of a two-stage air dehumidifier using two feeding lines of liquid desiccant solution is introduced in the present work. The process air is deeply dehumidified through two absorption counter flow stages through dehumidifier stages *a* and *b* using a single desiccant cycle. The theoretical model is validated and show good agreement to study the effect of different operating parameters on the performance of the proposed system. For different operating parameters (air and solution mass flow rates, inlet air humidity ratio and temperature, desiccant solution inlet concentration and temperature), the presented results reveal a great enhancement in dehumidification performance by using the proposed system. At the same desiccant solution mass flow and when the inlet air humidity ratio is changed from 0.016 to 0.024 $kg_v\ kg_{da}^{-1}$, an average increase of 49.2% in ε_y and 48.9 in MRR is achieved compared to a single stage air dehumidifier.

1. Introduction

As ever and still there is a great need for alternative sources for premises air conditioning other than conventional vapor compression systems in order to face energy crisis. Liquid desiccant system integrated with evaporative cooling system driven by solar energy or other heat sources was emerged as a potential alternative or as enhancement to conventional vapor compression systems for cooling and air conditioning. The key processes in liquid desiccant systems are dehumidification and regeneration. Numerous literatures were performed to investigate the performance of liquid desiccant dehumidifiers and regenerators [1–5]. Differential one-dimensional heat and mass transfer models are well established and solved to study the performance of packed bed dehumidifiers and regenerators. Factor and Grossman [6] introduced a theoretical model for a test column using LiBr solutions as liquid desiccant material. The temperature and concentration in the interface layer were assumed to be the bulk liquid temperature and concentration. They used overall heat and mass transfer coefficients for describing both heat and mass transfer process; respectively. For calcium chloride ($CaCl_2$), lithium chloride (LiCl) and cost effective liquid desiccant (CELD) solutions, the individual phase heat and mass transfer coefficients were calculated and correlated for various packing materials [7,8]. Ani et al. [9] introduced and studied a hybrid system using various packing height of the absorber component to determine the optimal performance of the whole system. Elsarrag [10] investigated theoretical and experimental investigations of the simultaneous heat and mass transfer to evaluate the moisture removal rate in a structured packed bed dehumidifier/regenerator.

Many researches [11–14] worked on packed dehumidifier/regenerator and presented the experimental testes and theoretical model on the chemical dehumidification of air by an aqueous lithium chloride desiccant in a packed bed dehumidifier/regenerator with random packing. Davoud and Meysam [15] presented an analytical solution of coupled heat and mass transfer processes in a packed bed liquid desiccant regenerator. This solution showed good accuracy when compared with reliable experimental data. Koronaki et al. [16] studied the performance of a counter flow liquid desiccant dehumidifier. A heat and mass transfer theoretical model of an adiabatic packed column has been developed, based on the Runge–Kutta fixed step method, to predict the performance of the device under various operating conditions. Good agreement was found between experimental tests and the theoretical model.

Liu et al. [17] gave analytical solutions of the air enthalpy and desiccant equivalent enthalpy field within the cross flow dehumidifier/ regenerator, where the air and desiccant are not mixed breadth wise (which means the transfer processes of the air and desiccant are both two dimensional). Dai and Zhang [18] introduced a mathematical model, able to determine the heat and mass transfer between the air and the falling film of liquid desiccant, and the analysis on Nusselt and Sherwood numbers at the liquid–air interface is performed considering the solution of 40% $H_2O/CaCl_2$.

Liu et al. [19] have developed mathematical models of the coupled heat and mass transfer processes in the dehumidifier or

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http://dx.doi.org/10.1016/j.enconman.2013.06.013

Nomenclature

A_c	cross sectional area of the structured packing, m^2
A	specific surface area to volume, $m^2\ m^{-3}$
C_p	specific heat at constant pressure, $kJ\ kg^{-1}\ K^{-1}$
D	packing diameter, m
d_{eq}	equivalent diameter of structured packing, m
H	enthalpy, $kJ\ kg^{-1}$
h_{abs}	is the heat of absorption, $kJ\ kg^{-1}$
h_{Go}	overall gas heat transfer coefficient, $W\ m^{-2}\ s^{-1}$
K_{Go}	overall gas mass transfer, $kg\ m^{-2}\ s^{-1}$
D_G	diffusivity of water vapor in air, $m^2\ s^{-1}$
Le	Lewis number, –
$\dot{m}$	mass flow rate, $kg\ s^{-1}$
P	pressure, Pa
$\dot{Q}$	total rate of heat transfer, W
$\dot{Q}_{abs}$	heat of absorption, W
Re_G	Reynolds numbers of gas side, –
Sc_G	Schmidt numbers of gas side, –
T	temperature, °C
X_s	desiccant solution concentration, $kg_d\ kg_s^{-1}$
Y	air humidity ratio, $kg_v\ kg_{da}^{-1}$

Subscripts

A	air
$cond$	condensed
C	cooled
D	desiccant
da	dry air
eq	equilibrium
P	packing
S	desiccant solution
V	vapor
1	inlet
2	exit

Greek symbols

ε_y	dehumidifier effectiveness, –
ε_p	packing porosity, –
α	thermal diffusivity, $m^2\ s^{-1}$

regenerator, and most of the models were solved numerically. Liu et al. [20] experimentally studied the performance of the cross flow dehumidifier, which has been less studied than the counter flow dehumidifier, although it is more applicable in practice. The effects of the dehumidifier inlet parameters, including air and desiccant flow rates, air inlet temperature and humidity ratio and desiccant inlet temperature and concentration, on the two indices were investigated. Correlations have been proposed to predict the cross flow dehumidifier performance, which give results in good agreement with the present experimental findings. Jason and Eric [21] presented a modeling and experimental results on a recently proposed liquid desiccant air conditioner, which consists of two stages: a liquid desiccant dehumidifier and an indirect evaporative cooler. They introduced fluid–thermal numerical models for each stage, experimental results of prototypes for each stage, and compared the numerical results with experimental data. Their model predicted the experiments within ±10%.

Liu et al. [22] studied the mass transfer performance of two commonly used liquid desiccants, LiBr aqueous solution and LiCl aqueous on the basis of the same solution temperature and surface vapor pressure. They reported that, The COPs of the liquid desiccant systems using these two desiccants are similar; while LiCl solution costs 18% lower than LiBr solution at current Chinese price.

Xiong et al. [23] introduced a two-stage solar powered cross-flow liquid-desiccant dehumidification system, for which two kinds of desiccant solution (lithium bromide and calcium chloride) are fed to the two dehumidification stages separately. Also the same authors Xiong et al. [24] have developed a novel two-stage cross-flow liquid desiccant dehumidification system assisted by $CaCl_2$ and LiCl solutions using exergy analysis method. From the previous study, there are a little researches [23,24] dealing with using two-stage air dehumidification system. Their basic study depended on using two separate cross-flow air desiccant cycles and also they did not introduce a parametric study for the effect of operating parameters on the performance of their systems.

In the present work, a theoretical model is developed and numerically solved for investigating the performance of a proposed two-stage counter flow air dehumidifier with two feeding streams of desiccant solution using a single desiccant solution cycle and compared to a single stage air dehumidifier. Using the same desiccant solution cycle ensures a more compact cycle compared to those discussed in [23,24]. The two-stage of the presented dehumidifier are denoted by first stage dehumidifier *a* and second stage dehumidifier *b* and an intermediate cooling by air to air heat exchanger is used between the two stages *a*, *b*. The fresh liquid desiccant solution is divided into two streams to feed both dehumidifiers *a*, *b* in a counter flow direction with the process air and using a single desiccant cycle. The effect of different operating parameters such as: process air temperature and humidity ratio, the desiccant solution temperature and concentration the air and desiccant mass flow rate is studied.

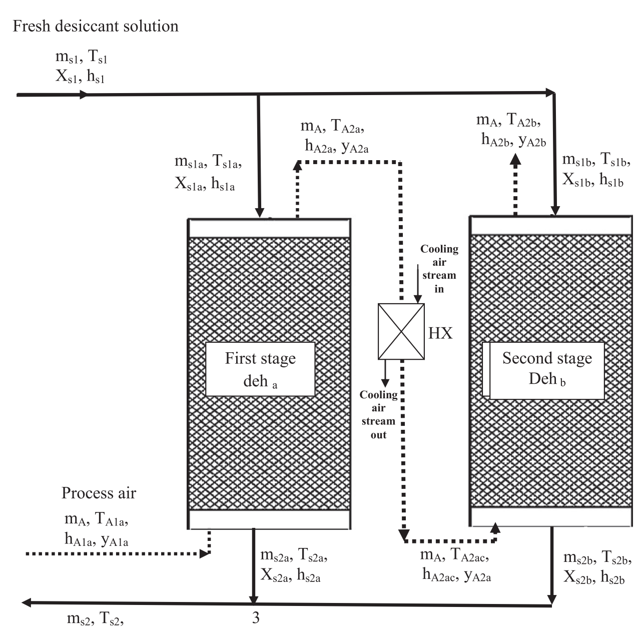

Fig. 1a. Schematic diagram for the proposed two-stage counter flow structured packing air dehumidifier.