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A heat pump driven and hollow fiber membrane-based liquid desiccant air dehumidification system: A transient performance study

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ABSTRACT

Heat pump driven and hollow fiber membrane based liquid desiccant systems have been adopted for air dehumidification because of their capabilities to prevent liquid desiccant droplets from crossing over into the process air and to achieve high energy efficiencies. Due to the transient operating conditions like load and weather conditions, a transient model for the novel system is proposed in this study. Based on experiments and model simulations, the transient behaviors of the system are analyzed both at the start-up and in the normal operation periods. It is found that the initial concentration of the liquid desiccant and the volume of solution stored in the container play key roles at the start-up period, while the initial temperature has less influences. Adjusting the compressor speed is a feasible way to track the load and weather fluctuations. The model developed in this work is necessary for the control and optimization of the air dehumidification technology.

Système de déshumidification d'air à déshydratant liquide entrainé par une pompe à chaleur et à base de membrane en fibre creuse: Une étude de performance transitoire

Mots clés : Pompe à chaleur ; Membrane en fibre creuse ; Déshydratant liquide ; Système de déshumidification d'air ; Performance transitoire

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Nomenclature

A	area [m^2]
c	specific heat [kJ kg^{-1} K^{-1}]
c_p	specific heat at constant pressure [kJ kg^{-1} K^{-1}]
CMI	capacity matching index
COP	coefficient of performance of the system
d	diameter [m]
EER	energy efficiency ratio of heat pump
h	heat transfer coefficient [kW m^{-2} K^{-1}]
h_r	refrigerant side convective heat transfer coefficient [kW m^{-2} K^{-1}]
h_s	solution side convective heat transfer coefficient [kW m^{-2}K^{-1}]
H	specific enthalpy [kJkg^{-1}]
k	mass transfer coefficient [ms^{-1}]
l	length [m]
m	mass flow rate [kg s^{-1}]
M	mass [kg]
n	compressor revolving speed [rpm]
NTU	number of heat transfer units
p	pressure [Pa]
P	perimeter [m]
Q	heat transfer capacity [kW]
r	latent heat of phase change [kJ kg^{-1}]
SDP	specific dehumidification power [gh^{-1} m^{-2}]
t	time [minute]
T	temperature [°C]
V	volumetric flow rate [m^3 s^{-1}], volume [m^3]
W	power consumption [kw]
x, y, z	spatial coordinates [m]
x_0	width of dehumidifier [m]
X	solution concentration [kg kg^{-1}]
y_0	length of dehumidifier [m]
z_0	height of dehumidifier [m]
$\triangle t$	time step [minute]

Greek letters

η	dehumidification efficiency
λ	thermal conductivity [kJ K^{-1}]
ρ	density [kg m^{-3}]
φ	relative humidity
ω	humidity ratio [kg kg^{-1}]

Subscripts

a	air
ac	auxiliary solution cooler
com	compressor
con	continuity
cond	condenser
cool	cooling
deh	dehumidifier
end	end
eva	evaporator
fan	fan
heat	heating
i	inlet, inside
Lat	latent heat
load	load
o	outlet, outside
pump	pump
output	output
pb	pool boiling
r	refrigerant
reg	regenerator
s	solution
sc	solution container, sub-cool
se	solution heat exchanger
sen	sensible heat
sh	super heat
su	start-up
st	state
tot	total
tp	two-phase
w	wall, water

Superscript

*	dimensionless
0	initial
i	number

1. Introduction

Air dehumidification is a major task for air conditioning industry, especially in hot and humid climates like South China, where moisture load accounts for 20–40% of the total load for air conditioning (Zhang, 2012a). Of the various air dehumidification technologies, liquid desiccant air dehumidification becomes a promising choice because of its high dehumidification potential, capability of waste heat reclamation, and the ability to realize energy storage. Thus, extensive researches have been conducted in this direction (Audah et al., 2011; Mei and Dai, 2008; Moghaddam et al., 2014; Xiong et al., 2010; Zhang, 2012a).

The shortcoming of liquid desiccant is that it is corrosive. The traditional way of moisture removal by a direct contact of process air with liquid solution in a packed bed is problematic because some liquid droplets may cross over into the process air. The polluted air stream is harmful to the occupants, similar to the effect of salt fog. To solve this problem, in recent years, a new technology, the so-called membrane-based liquid desiccant air dehumidification was proposed (Huang et al., 2012; Zhang et al., 2012; Zhang and Yang, 2012). In this technology, the process air and the liquid desiccant are separated from each other by the semi-permeable membranes. A bundle of hollow fiber membranes is packed in a shell to form a shell-and-tube heat exchanger-like contactor, as shown in Fig. 1. Liquid desiccant flows in tube side, and process air flows in shell side across the fibers arranged in a cross-flow (Zhang, 2012b). The water vapor can permeate through the membranes but liquid solution and other gases are prohibited from crossing-over. A heat pump is used in the system to cool and heat the desiccant solution for dehumidification and regeneration respectively (Zhang