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Investigation on capacity matching in a heat pump and hollow fiber membrane-based two-stage liquid desiccant hybrid air dehumidification system

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ABSTRACT

The heat pump and hollow fiber membrane-based two-stage liquid desiccant hybrid air dehumidification system is promising recently because solution droplets can be prevented from crossing over into the process air. The quasi-isothermal processes are realized by two-stage dehumidification processes and the system performance is improved. In this study, a novel capacity matching index (*CMI*) is introduced to evaluate the energy capacity matching of the system through modeling study. It is found that *CMI* is usually lower than 1 under the typical hot and humid weather condition like South China and the demand and supply of energy in the system is mismatching. As inlet air temperature rises, the dehumidification rates, *CMI*, *EER* and *COP* all decrease. But *CMI* is almost constant with different inlet air humidity. The influence of air inlet temperature to dehumidifiers and regenerators on the system performance is also investigated. The higher the inlet temperature of dehumidifiers is, the larger the *CMI*, *EER* and *COP* are. The dehumidification rates and *CMI* both grow with an increase in the inlet temperature of regenerators. It is beneficial for energy balance of the system and high moisture loads, but the side effect is that the *EER* and *COP* both decrease.

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Étude de la correspondance de puissance entre une pompe à chaleur et un système de déshumidification d'air hybride bi-étagé à déshydratant liquide à base de membrane en fibre creuse

Mots clés : Pompe à chaleur ; Membrane en fibre creuse ; Déshydratant liquide ; Bi-étagé ; Correspondance de puissance

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Nomenclature

COP	coefficient of performance of the system
CMI	capacity matching index
D_{mem}	diffusivity of membrane [m^2s^{-1}]
EER	energy efficiency ratio of heat pump
H	specific enthalpy [$kJkg^{-1}$]
M	dehumidification rate [kgh^{-1}]
NTU	Number of Transfer Units
q	heat transfer capacity [kW]
T	temperature [°C]
V	volumetric flow rate [m^3s^{-1}]
W	power consumption [W]

Greek letters

ρ	density [kgm^{-3}]
ω	humidity ratio [g moisture kg air^{-1}]
λ	thermal conductivity [$Wm^{-1}°C^{-1}$]

Subscripts

a	air
aux	auxiliary
com	compressor
cond, cond1, cond2	condenser, condenser 1 and condenser 2
deh, deh1, deh2	dehumidification, dehumidifier 1 and dehumidifier 2
dem	demand
eva, eva1, eva2	evaporator, evaporator 1 and evaporator 2
fan	fan
i	inlet
o	outlet
pump	pump
reg, reg1, reg2	regenerator, regenerator 1 and regenerator 2
tot	total

1. Introduction

Air dehumidification is the major building energy consumption especially in hot and humid climate like South China (Marini, 2013; Xu et al., 2014). The liquid desiccant air dehumidification technology has become promising in recent years (Liu et al., 2009; Zhang, 2012a). It is an alternative choice to control air humidity mainly due to its high dehumidification capacity with less energy consumption (Zhang, 2012a).

The liquid desiccant droplet entrainment encounters in the traditionally direct-contacting liquid desiccant air dehumidification. To solve this problem, a novel hollow fiber membrane contactor has been employed extensively for realizing liquid desiccant air dehumidification (Moghaddam et al., 2014). The membrane contactor is assembled by a collection of hollow fiber membranes and it is similar to a traditional shell-and-tube heat exchanger. Liquid desiccant flows in the tube side and air stream flows across the fibers in the shell side (Abdel-Salam et al., 2014), and they can be separated from each other by the semi-permeable membranes. Only water vapor can permeate through the membranes, while liquid desiccant and other unwanted gases are prohibited from crossing-over. The heat pump and membrane-based liquid desiccant hybrid air dehumidification has become more and more popular recently due to its high performance (Abdel-Salam et al., 2014; Moghaddam et al., 2014; Zhang and Zhang, 2014). The cooling capacity from an evaporator is used to cool the desiccant to enhance its dehumidification ability and the heat from a condenser is used to regenerate the desiccant. Both the cooling and heating power of the heat pump are utilized in the system and the high energy efficiency is realized. However, the temperature of desiccant solution goes up and it results in the system performance degradation because of the absorption heat released in the isenthalpic air dehumidification processes (Zhang et al., 2016a).

A heat pump and membrane-based two-stage liquid desiccant hybrid air dehumidification (HPMTLDAD) system is presented to alleviate the shortcoming of temperature rise (Zhang et al., 2016b). In the technology, the cooling-dehumidification and the heating-regeneration processes are not only single stage and they are doubled to two stages. The high temperature and concentration differences between the liquid desiccant and the process air in membrane modules can be kept with the quasi-isothermal dehumidification process. Thus, the high heat and mass transfer capacity is realized (Xiong et al., 2009; Zhang and Niu, 1999). In practice, LiCl solution is corrosive and it is harmful to metallic heat exchangers at higher regeneration temperature. Hence, the heat pump directly cools and heats the air instead of the desiccant solution for metal anticorrosion. The performance of the HPMTLDAD system is greatly improved compared with the traditional single stage process (Zhang et al., 2016b).

The control and optimization strategy of liquid desiccant air dehumidification systems has gained considerable attention recently (Ge et al., 2011; Gong et al., 2010; Mohammad et al., 2016; Zhang et al., 2013). It is found that the dehumidification capacity of a liquid desiccant system is more sensitive to the variation in the solution inlet temperature (Mohammad et al., 2016). The supply air temperature, air humidity ratio and water temperature are also key control set points for the system operation (Ge et al., 2011). Moreover, allocations of heat and mass transfer areas between the dehumidification and regeneration of the two stages are optimized for better performance (Zhang et al., 2016b). The energy capacity matching of the components is also important for the system performance (Jeong et al., 2010; Tu et al., 2014). However, the balance of supplied and required energy between the heat pump and membrane modules is not easy to achieve in such complex two-stage system. The capacity matching in heat pump driven single stage air conditioning system has been investigated (Abdel-Salam and Simonson, 2014; Niu et al., 2012). But the study of capacity matching in the HPMTLDAD system is not seen.

In this article, a novel energy index is introduced to evaluate the energy capacity matching of the HPMTLDAD system and it is analyzed under design operating conditions. Air temperatures on the inlet of dehumidifiers and regenerators of the two stages are important operating and control parameters. Influences of them on the capacity matching and system performance

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