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Experimental investigation and analysis of composite silica-gel coated fin-tube heat exchangers

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ABSTRACT

Desiccant coated heat exchanger provides a promising option for desiccant cooling system, since it can handle sensible load and latent load simultaneously within one component. It is fabricated by coating desiccant material on the surface of conventional fin-tube heat exchanger. In order to enhance the performance of conventional silica gel coated heat exchanger (SGCHE), a novel composite silica gel coated heat exchanger (CCHE) is proposed and fabricated. An experimental setup is built to test and compare the dynamic performance of SGCHE and CCHE. Influences of main operation parameters including water temperatures and inlet air conditions on system performance are analyzed in terms of average dehumidification capacity (D_{avg}) and thermal coefficient of performance (COP_{th}). Optimization of cycle switch modes is also discussed. Experimental results show that CCHE has better dehumidification performance compared with SGCHE. In addition, precooling before dehumidification process is found to be advantageous to both D_{avg} and COP_{th}.

Etude expérimentale et analyse d'échangeurs de chaleur à tubes à ailettes enrobés d'un gel de silice composite

Mots clés : Froid déshydratant ; Déshydratant composite ; Echangeur de chaleur à tubes à ailettes ; Déshumidification ; COP thermique

1. Introduction

Nowadays, it is widely acknowledged that traditional fossil fuels will finally run out and the usage of this kind fuels also causes serious environmental pollution and CO_2 emission. Therefore, energy saving is considered as an important treasure for economic and social development. It is estimated that building accounts for a third proportion of the whole energy consumption in modern society, and more than half energy consumption in building is from heating, ventilation and air

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Nomenclature

c_P	specific heat, J kg^{-1} K^{-1}
COP_{th}	thermal coefficient of performance
D	moisture removal rate, g kg^{-1}
d	humidity ratio of air, g water vapor kg^{-1} dry air
h	enthalpy, kJ kg^{-1}
HR	humidity ratio, g kg^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
$\dot{m}$	mass flow rate, kg s^{-1}
Q	quantity of heat, kW
T	temperature, °C
t_e	effective time, s
t_s	sampling time, s
V	air velocity, m s^{-1}
ρ	density, g cm^{-3}

Subscripts and superscripts

a	air
ads	adsorption
avg	average
in	inlet
out	outlet
w	water

Abbreviations

CSG	composite silica gel
CCHE	composite silica gel coated heat exchanger
DCHE	desiccant coated heat exchanger
HVAC	heating, ventilation and air conditioning
SG	silica gel
SGCHE	silica gel coated heat exchanger
VC	vapor compression

conditioning (HVAC) systems (Wang et al., 2013). Therefore, energy saving in HVAC systems is very crucial to realize energy-saving society.

By consuming electric or renewable energy, HVAC systems alter the properties of air to more favourable conditions in terms of both temperature and humidity (Jiang et al., 2014b). Therefore, air conditioning load is divided into sensible and latent load. So far, sensible load can be processed by some sophisticated methods. However, the handling of latent load still remains as a research hotspot. The most widely used vapor compression (VC) cooling system handles the latent load by condensation dehumidification. It cools the process air temperature down to dew point, then condenses out the water vapor. This method leads to a low evaporation temperature (5–7 °C) and thus coefficient of performance (COP) of the system is limited to very low (around 3). In order to achieve energy saving in HVAC systems, some novel dehumidification methods have been proposed. Among which, desiccant dehumidifiers based on sorption principle (including absorption/adsorption) provide a promising alternative (Daou et al., 2006). So far, various types of desiccant dehumidifiers such as solid ones (Dhar and Singh, 2001; Zheng and Worek, 1993) and liquid ones (Dai and Zhang, 2004; Yin et al., 2007) have been developed and widely adopted.

However, during the application of desiccant dehumidifiers, sorption heat is found to weaken the dehumidification process. The released heat during sorption process leads to more irreversibility loss and forces higher regeneration temperature (Ge et al., 2010; Van den Bulck et al., 1988). Meanwhile, auxiliary heaters utilizing electric or renewable energy are needed, which increase system complexity. Therefore, multiple-stage systems are proposed to overcome the disadvantage for rotary wheel desiccant systems (Meckler, 1989; Zhang and Niu, 1999). In the meanwhile, internal-cooled dehumidifier has been proposed. The concept of internal cooling is realized by importing secondary fluid to overcome the side effect of sorption heat. This novel concept has been studied on packed bed dehumidifiers (Fathalah and Aly, 1996; Weixing et al., 2008) and liquid dehumidifiers (Khan, 1998; Lazzarin and Castellotti, 2007; Liu et al., 2007). More recently, series of studies have been conducted based on the most widely adopted fin-tube air–water heat exchanger. The novel dehumidifier is named desiccant coated heat exchanger (DCHE), which is fabricated by coating solid desiccant material onto the fin-tube of the heat exchanger. Water vapor in the process air is absorbed by the desiccant material, while adsorption heat can be taken away by the cooling fluid in the tube. In this case, DCHE can handle sensible and latent load simultaneously within one component. So far, two kinds of cooling fluid have been studied, namely water or refrigerant. For those with water, Ge et al. (2010) fabricated two DCHEs with silica gel and polymer. It is found that the DCHE coated with silica gel shows better performance, with bigger transient as well as average moisture removal and longer effective dehumidification time. Then a further study was conducted based on the whole desiccant cooling system utilizing two DCHEs by simulation (Ge et al., 2011). It is found that operation time in dehumidification is crucial for system performance. Also, DCHE system can only provide cooling power after a short operating duration from the initial dehumidification process. Furthermore, solar power has been introduced to generate the proposed system (Ge et al., 2012), the system can provide satisfied supply air to the conditioned indoor space from 8:00 to 17:00 in June and July, the biggest cooling powers are 2.9 kW and 3.5 kW, and corresponding solar COP are 0.22 and 0.24 respectively. The proposed system has been experimentally verified by Zhao et al. (2014), and results show that the system can provide stable and continuous dehumidification capacity. It is also found that cycle time is crucial for system performance. For those systems with refrigerant, Aynur et al. (2008) introduced a novel integrated desiccant heat pump. It is actually a traditional heat pump with two heat exchangers replaced by DCHEs. This novel system can reach a COP of 5–6 with low dehumidification capacity. Other studies (Aynur et al., 2010a,b; Jiang et al., 2013, 2014a) by integrating the novel desiccant heat pump with variable refrigerant flow systems also prove the application prospect of DCHE.

For desiccant cooling systems, the dehumidification performance largely depends on the sorption properties of desiccant materials (Golubovic et al., 2006; Zheng et al., 2014). Impregnation of hygroscopic salts has been proved to be the most effective but simplest to enhance water sorption of desiccant material, both in closed adsorption chillers (Daou et al., 2007, 2008; Saha et al., 2009) and opened desiccant