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Performance study of desiccant coated heat exchanger air conditioning system in winter

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ABSTRACT

Conventional air source heat pump system faces several challenges when adopted in winter season. Solid desiccant air conditioning system can provide humidification and heating power simultaneously and can be driven by low grade thermal energy; it provides a good alternative for air source heat pump systems. However, conventional solid desiccant air conditioning system adopts desiccant wheel with high cost as core component, which hinders the development of such system. Recently, desiccant coated heat exchanger (DCHE) with low initial cost and high efficiency was developed and this paper aims to investigate performance of DCHE air conditioning system adopted in Shanghai winter season. Performance of the system is predicted by a developed mathematical model where supply air states, mass of humidification and coefficient of performance (COP) are adopted as performance indices to evaluate the feasibility and energy utilization ratio of the system. Effects of regeneration water temperature on system performance are analyzed. It is found that under the simulation condition, relatively low regeneration temperature (such as 20 °C) cannot meet the designed standard and relatively high regeneration temperature (such as 40 °C) provides too much extra heating power, thus moderate regeneration temperature around 30 °C is recommended. Meanwhile, switch time is a crucial operation parameter for the system to obtain satisfied supply air, switch time from 40 s to 80 s and from 70 s to 240 s are recommended for transient and average supply air states, respectively. Both mass of humidification and COP increase with increasing regeneration temperature under simulation condition. Also, influences of ambient air temperature and humidity ratio on system performance are discussed to study the feasibility of such system regarding different climatic conditions. Results show that higher humidity ratio of ambient air results in increased humidity ratio of supply air, temperature of ambient air has neglectable effect on supply air. In conclusion, DCHE air conditioning system can be adopted for winter operation with moderate selection of regeneration temperature as well as switch time.

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1. Introduction

In the central part of China, home heating system obtains more and more attention because of extreme weather and increased living standards. These areas are located in the middle and lower reach of Yangzi River as temperature climate zone, and there is no central heating system established. Statistic data shows the outdoor temperature is from −5 °C to 10 °C in these areas, it can be seen that there is still a need in home heating system to provide comfortable indoor environment under such condition.

Air source heat pump has been widely installed in central China for cooling in summer, and then this type of technology is naturally adopted in winter to produce heating power in these areas. It is shown that market of air source heat pump in China increased rapidly in past years [1]. However air source heat pump system faces several challenges when adopted in winter season. First, the system is mainly designed for cooling purpose based on refrigeration mode, the corresponding refrigerant, boiling and condensation processes are also designed under refrigeration mode, hence it cannot obtain optimal performance in winter. And the system sometimes has to adopt electrical heating to reach the required heating load, which causes extra energy consumption. Besides, such system cannot realize humidification. Outdoor air has low temperature as well as humidity ratio in winter, supply air from air source heat pump is heated with no humidification which causes dry indoor environment. Also, outdoor temperature greatly affects performance of such system and the system needs to perform defrost cycles under some winter conditions. In order to solve these problems, novel air conditioning systems are developed and

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Nomenclature

COP	coefficient of performance
d	humidity ratio, g/kg dry air
DCHE	desiccant coated heat exchanger
h	enthalpy, J/kg
M	mass flow rate of the stream, kg/s
Δm	mass of humidification, kg/h
Q	amount of heat, W
T	temperature, °C
Y	absolute humidity ratio of the air (kg water vapor/kg dry air)
a	air side
amb	ambient air condition
cw	cooling water flowing in DCHE
h	heating power
hw	hot/regeneration water flowing in DCHE
in	inlet
out	outlet
r	regeneration power
ra	air in humidification mode (regeneration air)
s	supply air state

Subscripts

1–8	reference numbers in Fig. 1

solid desiccant technology is one of them. This type of system generally uses a desiccant wheel to realize both dehumidification and regeneration/humidification processes simultaneously. There are two groups of working air in this system: one is process air which is dehumidified by desiccant material to provide dry air, another one is regeneration air which is heated by low grade energy and recover vapor from process air. In most cases, process air is adopted as supply air to conditioned space in summer to provide dehumidification capacity. When regeneration air is adopted as supply air, the needs of humidification and heating in winter can be met. Due to the thermal regeneration characteristic of solid desiccant, such system is always driven by low grade thermal energy such as solar energy or waste heat. For central China has good solar radiation even in winter, solar energy powered solid desiccant system seems to be a promising technology in these areas for heating and humidification.

Due to the merits of energy-saving and increasing supply quality of solid desiccant air conditioning system, extensive investigations have been conducted in past years. Most of the works focus on how to improve performance of the system under summer condition. For example, both Zouaoui et al. [2] and Rambhad et al. [3] made a review on recent progress on desiccant wheel cooling system, they determined the most suitable systems for comfort when considering hot and humid climate and pointed out that such system was promising in future. Ruivo et al. [4] investigated performance of hybrid solar desiccant wheel system with vapor compression system both by simulation and experimental testing in Spain summer. Saghafifar and Gadalla [5] proposed regenerative evaporative cooling combined with desiccant wheel cooling for extremely humid summer conditions. Different operation modes of desiccant wheel cooling system in summer with different locations are discussed by Ali et al. [6]. Pandelidis et al. [7] conducted a numerical analysis of three desiccant air-conditioning systems equipped with different indirect evaporative air coolers and concluded their application range. Koronaki et al. [8] adopted artificial neural network to analyze performance of a silica gel desiccant wheel. Fatouh et al. [9] tested performance of a hybrid desiccant wheel and vapor compression system, and the results revealed that the system reduced the compressor electric power and the number of electric unit (kW h) by 10.2%. Khalid et al. [10] and Angrisani et al. [11] analyzed performance of hybrid desiccant cooling system in Pakistan and Italy, respectively. In order to decrease the disadvantageous effect of adsorption heat, multistage desiccant wheel cooling system is investigated by several authors both by energy and exergy method [12–14]. Recently a novel component namely solid desiccant coated heat exchanger (DCHE) by coating desiccant material to the metal surface of conventional fin tube heat exchanger is proposed. Compared with conventional desiccant wheel, DCHE has the merits of low cost, high efficiency and free of removable component [15]. Performance of solar powered cooling system based on DCHE has been investigated under summer condition [16], results showed this type of cooling system can provide satisfied supply air under suitable operation parameters in terms of regeneration temperature and switch time. Also, there exist several works analyzing system performance in winter. Preisler and Brychta [17] tested a solar powered desiccant wheel air conditioning system in Vienna and results showed the electrical COP of the system in winter can reach 7.0. Antonellis et al. [18] showed that under southern Europe winter climate, rotary desiccant wheel heating system can properly match the latent load of the building. Both Beccali et al. [19] and Kawamoto et al. [20] investigated performance of a hybrid vapor compression and solar desiccant wheel system in winter. Beccali et al. [19] found that under typical winter condition with ambient temperature of 8–13 °C, the system could provide supply air with temperature of 16–20 °C. Kawamoto et al. [20] showed the system could increase the humidity ratio of supply air from about 2 g/kg to 6 g/kg. Chen et al. [21] adopted composite desiccant material and utilized condensation heat from heat pump system to realize the regeneration process. Experimental results showed the system can obtain satisfied results in winter. Performance of two-stage desiccant wheel air conditioning system was studied by Li, La and Deng et al. [22–25] and results showed system driven by solar energy could provide supply air with temperature of 21–23 °C and humidity of supply air was increased by 0.004 kg/kg.

A summary on previous literature review shows that solid desiccant cooling system develops from conventional ventilation mode to multistage mode and further to inter-cooling mode with use of DCHE. And performance of solar powered DCHE cooling system has been validated. However no study has been done to reveal performance of DCHE heating system in winter. This paper aims to analyze this. Shanghai located in central China is selected as the simulation site. A mathematical model developed previously by the same group [26] is adopted to predict system performance. Supply air state, mass of humidification and COP are adopted as performance indices. Effects of main operation parameters as well as climatic condition are evaluated and discussed.

2. Operation of DCHE air conditioning system in winter

The basic operation principle of DCHE air conditioning system in winter is shown in Fig. 1(a). DCHE as shown in Fig. 1(b) is the core component, which is fabricated by coating desiccant material to the metal surface of fin-tube heat exchanger, and two DCHEs are adopted in system to realize continuous supply of heating power.

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