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Experimental investigation on solar powered desiccant coated heat exchanger humidification air conditioning system in winter

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ABSTRACT

In this paper, a desiccant coated heat exchanger (DCHE) system driven by solar energy is built and tested under winter condition. The purpose of this experimental research is to explore the heating and humidification performance of DCHE system. Effects of hot water temperature, hot water mass flow rate and regeneration air flow flux are discussed as vital factors impacting system performance. Results show that increasing of heat water temperature as well as of hot water mass flow rate both have positive effects on humidification capacity and thermal coefficient of performance (*COP*) of the DCHE system. Moreover, the latter has a more remarkable influence. When a tradeoff is made between the performance of DCHE system and the thermal comfort of supply air, 40 °C and 0.4 kg/s are selected as optimum hot water condition. Under this operation condition, average humidity ratio of supply air is 5.15 g/kg, almost twice of ambient air. *COP* can reach 1.78 with a comfortable average temperature of supply air (28.3 °C). To provide a better supply air state under low humidify ratio of ambient air, small regeneration air flow flux is implemented, which effectively increases the humidity ratio of supply air with the decrease of *COP*.

1. Introduction

Desiccant coated heat exchanger air conditioning system is a recently developed solid desiccant technology which obtains more and more attention in the HVAC field. Compared with vapor compression (VC) system which is widely used at present, solid desiccant system has several obvious advantages. For example, it can control both sensible and latent loads under summer and winter condition, while VC system has limited capacity in moisture control through heat pump cycle, especially cannot meet the demand of humidification in winter [1,2]. Without the use of refrigerants containing more or less CFCs which generally applied to the VC system, solid desiccant technology has an environmentally friendly property. Moreover, after the Copenhagen Conference, how to reduce building energy consumption and greenhouse gas emission has aroused unprecedented attention [3,4]. The solid desiccant air conditioning system which usually selects silica gel as desiccant provides a promising alternative solution. Since silica gel with a relative low desorption temperature can take advantage of renewable energy and low-grade thermal energy [5], such as solar energy and waste heat, which can be used as the regeneration heating source instead of electricity. Solid desiccant technologies possess extensive application perspective in new energy utilization and industrial commercialization.

In recent years, a novel concept of desiccant coated heat exchanger (DCHE) air condition system has been proposed and developed in solid dehumidifying. DCHE is based on the traditional fin-tube heat exchanger with the reprocessing on the out surface coated by the desiccant materials. Comparing with rotary desiccant wheel that a common equipment in solid desiccant system, DCHE is chilled by inner cooling water flowing in the copper pipes of heat exchanger, and the adsorption heat can be timely taken away in the dehumidification process. This improvement can realize the approximately isothermal dehumidification and overcome the side effect of adsorption heat accumulation due to the structure limit of rotary desiccant wheel. Therefore, DCHE system effectively enhances the moisture removal obviously which leads to a better control of the latent load. Meanwhile, there is no rotatable part in DCHE system with longer service life and less noisy in operation.

Based on those superiorities of DCHE system, numerous researchers have great interests in theoretically and experimentally investigations in the field. Zhang et al. [6] built a heat and mass-transfer model of a DCHE and found that larger air velocity,

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Nomenclature

c	constant pressure specific heat (kJ/kg °C)
d	humidity ratio (g/kg)
Δd	moisture addition (g/kg)
h	enthalpy (kJ/kg)
M	mass flow rate (kg/s)
Q	quantity of heat (W)
T	temperature (°C)
t	time (s)

Abbreviations

AA	ambient air
COP	thermal coefficient of performance
DCHE	desiccant coated heat exchanger
EA	exhaust air
HVAC	heating, ventilation and air conditioning
SA	supply air
VC	vapor compression

Subscripts

a	air
ave	average
c	cooling water
e	effective
in	inlet
out	outlet
t	transient
w	water

bigger moisture content and lower temperature of desiccant were benefit to the overall mass-transfer coefficient, which correlated well to the experimental results. A mathematical model of SDCC (solar driven desiccant coated heat exchanger cooling) system was proposed by Ge et al. [7,8] and the numerical simulation results indicated the system possessing satisfied dehumidification performance with suitable regeneration temperature and switch time under summer condition. Bongs et al. [9] studied on an enhanced evaporatively cooled open sorption system using both experiments and simulation method and found that the moisture absorption increased 46% with the application of DCHE. In the experimentally research of DCHE, desiccant material is the primary factor affecting the performance of DCHE system. Aristov et al. [10,11] and Gonzalez et al. [12] demonstrated that halide salt could enhance the adsorption capacity of desiccant and make regeneration easier. By measuring and calculating the thermal conductivities and sorption characteristics, Zheng et al. [13,14] did in-depth researches on the heat and mass transfer mechanism of the composite materials. Shimooka et al. [15] studied the performance of FAM and experimental results showed the good adsorption character of FAM in low regeneration temperature. Freni et al. [16] introduced a SAPO-34 as a new desiccant. Through promoting coating technique, the adsorption rate and water loading of system significantly enhance and cooling power up to 675 W/kg_{ads}. Also, the researches on the innovative system designs of DCHE system had got lots of achievements. Aynur et al. [17–19] introduced DCHE into VRV (variable refrigerant volume) air conditioning system instead of the traditional heat exchanger, and better dehumidification capacity could be achieved with less energy consumption which was confirmed in the field performance test under both cooling season and heating season. Using more environmentally friendly water as working medium, Ge et al. [20] experimentally verified that DCHE could effectively handle both the sensible heat and the latent heat of process air in the dehumidification process. Further works by Zhao et al. [21] successfully introduced solar energy to drive DCHE system and used two paratactic DCHE units to provide continuous dehumidification capacity. Later, Zhao et al. [22] added internal heat recovery to build a new type of DCHE cycle and both the thermal and electrical coefficient of performance significantly increased (1.2 and 13.8, respectively), while providing better indoor thermal comfort in summer condition.

The dehumidification abilities of DCHE which is applied in summer condition have caught the main attention of scholars on no matter in experimentally or theoretically investigations. However, few researches on regeneration process of DCHE system have been done to meet the demand in winter. The main objectives of this paper are to utilize a solar powered desiccant coated heat exchanger humidification air conditioning system and to validate the heating and humidification performance under winter condition. What's more, how the different regeneration conditions (including hot water temperature, hot water mass flow rate and regeneration air flow flux) affect the humidification process are experimented and analyzed.

2. Description of experimental system

2.1. Operation principle and experimental setup

Fig. 1 shows photographic view of the experimental setup and main components. The DCHE air conditioning system consists of three main components: desiccant humidification unit, solar collecting unit and cooling unit. And its function covers humidification in winter and dehumidification in summer simultaneously.

As the core device of the system, DCHE is based on the traditional fin-tube heat exchanger, the size of which is 400 mm (length) × 150 mm (width) × 400 mm (height). After being soaked by desiccant and dried for 3–5 times, the surfaces of all pipes and fins of the heat exchanger are coated. Solid silica gel with 0.15 mm particle diameters and liquid silica gel are used as the desiccant materials in the experiment. And the final glue quantity of DCHE is 2.53 kg with 0.316 kg on per square meter. The detailed structural parameters of the heat exchanger and specifications of silica gel are shown in Table 1.

Solar energy is used as regeneration source in the experiment. The vacuum tube solar collector can supply 8.5 kW heating power with 22 m^2 area. The capacity of the matched tank is 500 L. Through adjusting heating time and mass flow rate of circulating water in solar collecting unit, the temperature of hot water can meet the experiment requirements in different sunlight intensity. The cooling water after the dehumidification process flows back to cooling tower. In the cooling tower, the temperature of water decreases by air cooling.

Two axial flow fans are installed at the outlet of air loops to better drive the air flow. And the fans are both equipped with a frequency converter. When the frequency is changed from 0 Hz to 50 Hz, the air flow flux can reach the maximum 400 m^3/h.

The cooling water and hot water are dominated by two pumps in the water loops. In the experiments, the mass flow rate of cooling water is constant at 0.32 kg/s. By adjusting the valve opening of the water loop, the water mass flow rate of hot water can be regulated. The maximum water mass flow rates of the cooling water and hot water provided by two pumps are 0.32 kg/s and 0.40 kg/s, respectively.

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