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Experimental investigation on solar powered self-cooled cooling system based on solid desiccant coated heat exchanger

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ABSTRACT

The objective of this paper is to validate the practical performance of a novel self-cooled solid desiccant cooling system which consists of DCHE (desiccant coated heat exchanger) and regenerative evaporative cooler. In the system, part of the outlet air from the desiccant coated heat exchanger is pumped into the evaporative cooler to produce cooling water adopted in the dehumidification process. The heating water required in the regeneration process is coming from the vacuum tube solar collector system. An experimental setup is designed and built to test the performance of the new system. The average moisture removal D_{ave} and thermal coefficient of performance COP_{th} are utilized as the performance indices. It is found that the SDCHE (self-cooled solid desiccant coated heat exchanger) system has better moisture removal capacity compared with the solid desiccant coated heat exchanger system, and higher thermal coefficient of performance COP_{th} is also obtained by SDCHE system. The average moisture removal D_{ave} and COP_{th} of SDCHE system are about 17% and 6% higher than that of DCHE system under similar operating condition. While other parameters remaining the same, the moisture removal D_{ave} and thermal coefficient of performance COP_{th} increases significantly with increasing inlet humidity ratio.

1. Introduction

Nowadays, rapid development of society and economy bring great pressure on the environment. The world faces more and more serious environmental problems such as global warming effect and haze. Study of any field should consider causing less pollution to the environment, research on air conditioning technology is also no exception. Up to now, the widely adopted air conditioning technology for buildings is vapor compression system which consumes lots of electricity and releases greenhouse gases. Solid desiccant cooling systems operating on the principle of adsorption dehumidification and evaporative cooling are recognized as one of promising air conditioning technologies. The outstanding merits of the system include being environment-friendly, saving energy and controlling humidity and temperature separately [1]. Up to present, lots of researches have been carried out in several areas. The characteristics of the desiccant materials were demonstrated by Zheng et al. [2,3]. Results showed that the materials had great influence on the performance of the desiccant dehumidifiers. Also, some mathematical models and experimental setups were established. Mass studies were concentrating on evaluating the performance of desiccant air conditioning system [4,5]. Collier et al. [6] advised that, to obtain better system performance, staging the regeneration process is an alternative approach. Desiccant-based air conditioning system is compared with conventional vapor compression system by Lee et al. [7]. The performance of the systems was experimentally studied. The results confirmed that the solid desiccant-based hybrid air conditioning systems have strong potential to give substantial energy savings as compared to conventional vapor compression system in most commonly encountered situations.

It can be concluded that the rotary desiccant wheel is widely adopted in solid desiccant air conditioning system up to now. Recently, it is proposed that due to the release of adsorption heat in dehumidification process within desiccant wheel, it is difficult to achieve inner-cooling dehumidification process like liquid desiccant air conditioning system. Goldsworthy et al. [8] combined the desiccant wheel with indirect evaporative cooler to optimize the system and achieve substantial energy saving. In order to overcome

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Nomenclature

c	constant pressure specific heat (kJ/kg·°C)
d	humidity ratio (g/kg)
h	enthalpy (kJ/kg)
M	mass flow rate (kg/s)
Q	quantity of heat (W)
T	temperature (°C)
t	time (s)
Δx	the absolute error related to the variables
Δy	absolute
$\Delta y/y$	relative error (%)
Abbreviations	
AV	air valve
EV	electromagnetic valve
COP_{th}	thermal coefficient of performance
D	moisture removal rate
DCHE	desiccant coated heat exchanger
EC	evaporative cooler
FTHE	fin-tube heat exchanger
SDCHE	self-cooled solid desiccant coated heat exchanger
t_e	effective time
Subscripts	
a	air
ave	average
c	cooling water
h	heating water
in	inlet
out	outlet
w	water

this disadvantage DCHE (desiccant coated heat exchanger) is proposed. Several air conditioning systems have been proposed and investigated based on this novel dehumidification component. Ge et al. [9] proposed a novel SDCC (solar driven desiccant coated heat exchanger cooling) () system and established a mathematical model which is found that the system can provide satisfied supply air to conditioned indoor space from 8:00 to 17:00 in June and July. Experiments were developed by Ahmed et al. [10,11] to validate that both sensible heat and latent heat of the process air can be removed in DCHE system. Ayner et al. [12,13] utilized DCHE instead of the conventional heat exchanger in heat pump system, and field testing showed that more latent load can be handled with less energy consumption. But the most important problem in these studies is that, the temperature of the cooling water is not low enough to handle the sensible heat. Regenerative evaporative cooler integrated with desiccant dehumidification process has been demonstrated by La et al. [14] to be an effective measure to reduce the temperature of the supply air. Finocchiaro et al. [15] researched on DEC (desiccant and evaporative cooling) system for building air conditioning. The obtained results showed that the air-to-air packed wet heat exchangers associated with the exhaust air stream can efficiently cool the air stream after the adsorption process in the desiccant wheel without any change in moisture content. In order to improve the evaporative cooling capacity of the system and to obtain lower outlet temperature in DCHE system, a SDCHE (self-cooled desiccant-coated heat exchangers cooling system) is developed by integrating desiccant coated heat exchanger and regenerative evaporative cooler. Ge et al. [16] established a mathematical model to simulate the system performance and validated that the system can provide satisfied supply air to conditioned room while conventional system cannot, also under simulation condition, cooling power of SDCHE system increased by about 30% compared with conventional DCHE cooling system.

This paper aims to further validate the practical performance of this novel SDCHE system, two experimental systems driven by solar energy of both DCHE and SDCHE are built up and tested. The practical performances of the two systems are analyzed and compared.

2. Experimental setup

2.1. Operation principle of experimental systems

The operation principle of the SDCHE system is shown in Fig. 1. As seen, cooling water used in SDCHE system is produced by the evaporative cooler, while the tap water is used as cooling water in DCHE system. Heating water utilized in SDCHE and DCHE system is from the vacuum tube solar collector. Cooling water is utilized to pre-cool and inter-cool the process air in the dehumidification process. Heating water is adopted to regenerate the coated desiccant in the regeneration process. Both DCHE system and SDCHE system operate and switch between dehumidification and regeneration modes like conventional desiccant system. In dehumidification mode: ambient air (state 1(1′)) is dehumidified and cooled in desiccant coated heat exchanger to state 2(2′); then for SDCHE system, part of the outlet air from the desiccant coated heat exchanger with low humidity ratio as well as temperature is directly supplied to the conditioned space and another part is pumped into the evaporative cooler to cool the cooling water (state 5 to 6) which is used as cooling source in desiccant coated heat exchanger to remove sensible load as well as adsorption heat; but for DCHE system, all outlet air is directly supplied to the conditioned space, and the tap water is utilized as cooling source. In regeneration mode: the humid desiccant on the heat exchanger is heated by the heating water from the vacuum tube solar collector and regenerates; the heat and humidity are taken away by the ambient air (state 1(1′)) which is discharged with increased temperature and humidity ratio (state 3(3')).

Based on this principle, an experimental setup is established as shown in Fig. 2. Experimental system consists of two main components (DCHE, evaporative cooler), two water loops (cooling water, heating water) and three air loops (ambient air, supply air, regeneration air). The operation of the system includes two modes: one is DCHE A operating in dehumidification process and DCHE B operating in regeneration process, another is DCHE A operating in regeneration process and DCHE B operating in dehumidification process. Control and operation of the system are described as following: when EV2 and EV8 are open, cooling water produced by evaporative cooler is pumped into the tube of DCHE B; AV2 and AV6 are open, ambient air (state 1(1′)) is inhaled into DCHE B and is dehumidified and cooled to state 2 (state 1(1′) to state 2(2′)), which is supplied to evaporative cooler and conditioned room. Meanwhile, EV3 and EV5 are open, heating water produced by solar collector is pumped into the tube of DCHE A; AV3 and AV7 are open, ambient air (state 1(1')) is inhaled into DCHE A, and the desiccant materials coated to the surface is regenerated to state 3. When the dehumidification and regeneration process occurring in DCHE B and DCHE A comes to the end, EV1, EV7, AV4 and AV8 are open, DCHE B is switched to regeneration process, and EV4, EV6, AV1 and AV5 are open, DCHE A is switched to dehumidification process.