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Experimental investigation of solar driven desiccant air conditioning system based on silica gel coated heat exchanger

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ABSTRACT

A silica gel coated heat exchanger based air conditioning system driven by the evacuated tube solar water heater has been experimentally investigated. The system has been operated for two different modes namely cooling with dehumidification mode and heating with humidification mode in summer and winter season respectively. The system performance is analyzed in terms of regeneration rate, dehumidification rate and thermal coefficient of performance (COP_{th}). Experimental results demonstrated that, for cooling and dehumidification mode, the process air is cooled by an average temperature of 8.5 °C. A better dehumidification rate can be achieved by using pre-cooling before dehumidification process. Post-cooling after dehumidification process is found to be advantageous for cooling capacity and COP_{th}. For heating with humidification mode, the process air is heated by an average temperature of 13.3 °C with an average increment in humidity ratio of 1.9 g/kg. It is found that the average COP_{th} of the system is 0.45 and 0.87 for cooling and heating mode respectively.

Étude expérimentale de système de conditionnement d'air solaire à déshydratant basée sur un échangeur de chaleur enrobé de gel de silice

Mots clés : Chauffe-eau solaire à tube sous vide ; Échangeur de chaleur enrobé de gel de silice ; Tour de refroidissement ; Système de refroidissement évaporatif direct: échangeur de chaleur

1. Introduction

In recent years, with the rapid development of technology and society, the need for air conditioning has been on increase in residential, commercial buildings and industrial processes. Conventional vapour compression systems are used to fulfil that requirement of air conditioning. These systems consume a large amount of high grade energy which imposes a major crisis to the energy and environment. Thus, it strives the need for the

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Nomenclature

A_d	dehumidification rate [kg/hr]
A_p	area of solar collector [m^2]
COP_{th}	thermal coefficient of performance
DCHE	desiccant coated heat exchanger
DEC	direct evaporative cooling unit
HEX	heat exchanger
h_{in}	enthalpy of process air at inlet of the system [kJ/kg]
$h_{in\,(HEX)}$	enthalpy of process air at inlet of the heat exchanger [kJ/kg]
$h_{in\,(SCHE)}$	enthalpy of process air at inlet of the SCHE [kJ/kg]
h_{out}	enthalpy of process air at outlet of the system [kJ/kg]
$h_{out\,(HEX)}$	enthalpy of process air at outlet of the heat exchanger [kJ/kg]
$h_{out\,(SCHE)}$	enthalpy of process air at outlet of the SCHE [kJ/kg]
I	solar intensity [W/m^2]
$\dot{m}_a$	mass flow rate of process/regeneration air [kg/s]
Q_c	cooling capacity [W]
Q_s	solar energy [W]
R_c	regeneration rate [kg/hr]
SCHE	silica gel coated heat exchanger
t_{DE}	dehumidification time period
t_R	regeneration time period
$Y_{in\,(SCHE)}$	humidity ratio of process air at inlet of SCHE [kg/kg]
$Y_{out\,(SCHE)}$	humidity ratio of process air at outlet of SCHE [kg/kg]

recent growing interest in alternative air conditioning systems, such as solar powered desiccant air conditioning system. In recent years, numerous researchers have experimentally and theoretically investigated the solar powered/assisted desiccant air conditioning systems. In very recent years, a new concept of desiccant coated heat exchanger air conditioning system has been developed and investigated. Ge et al. (2010) experimentally compared silica gel and polymer coated fin-tube heat exchangers. It was found that the DCHE overcome the adsorption heat during desiccant dehumidification process and achieve good dehumidification performance under given conditions. The SCHE performed better as compared to the polymer coated heat exchanger. Ge et al. (2011) developed a mathematical model to predict the performance of SCHE cooling system under ARI summer condition and optimized the copper tube external diameter and distance between the fins. Ge et al. (2012) proposed and developed a mathematical model of solar driven DCHE cooling system by combing the mathematical models of different components to investigate the performance of the system. Two desiccant coated heat exchangers were used to produce a continuous supply of air conditioning with an optimum switch time of 2 minutes. It was found that the system provided satisfied air conditioning to indoor space. Ge et al. (2013) developed a mathematical model of a self-cooled solid desiccant cooling system by the combination of DCHE and regenerative evaporative cooler. A switch time period of 50–900 s was used to cool down desiccant coated heat exchanger before dehumidification process. Three different optimal switch times have been used for different regeneration temperatures. Zhao et al. (2014) experimentally investigated a solar driven SCHE dehumidification unit to provide continuous dehumidification. Effect of cycle time and ambient conditions were also evaluated. It was found that the required regeneration temperature was in the range of 50–80 °C. Dehumidification capacity and thermal coefficient of performance were increased with increase in the inlet air humidity ratio. The cycle time influenced significantly the system performance. Li et al. (2015) experimentally and theoretically investigated the heat and mass transfer characteristics of a desiccant-coated fin-tube heat exchanger. It was found that the air velocity, temperature and moisture content of the desiccant affect the average overall mass-transfer coefficient. Wang et al. (2016) investigated a solar powered self-cooled solid desiccant cooling system based on desiccant coated heat exchanger and regenerative evaporative cooler. In the system, the performance of the evaporative cooler was increased by using dry air produced by desiccant coated heat exchanger. The results show that the COP of the system was increased by 6% by using regenerative evaporative cooler. The concept of pre-cooling of process air before dehumidification process was found to be advantageous for adsorption capacity of desiccant material. Hu et al. (2015) experimentally investigated and analyzed a SCHE to evaluate the effect of water temperature, air temperature, air humidity ratio and air velocity on average dehumidification rate and thermal coefficient of performance. It was found that the average dehumidification rate and coefficient of performance could be increased by pre-cooling of process air before dehumidification process. Jiang et al. (2015) proposed and fabricated a composite silica gel coated heat exchanger. It was found that pre cooling before dehumidification process increased the dehumidification capacity of desiccant material and thermal COP of the system. Khalid et al. (2009) presented the results of experimental and simulation investigation of a solar assisted pre-cooled hybrid desiccant cooling system. The results demonstrate that the COP of the system was increased by using indirect evaporative cooler for pre-cooling and direct evaporative cooler for post-cooling of process air. Some researchers worked on solar driven desiccant cooling/heating system. Li et al. (2011) studied a two stage rotary cooling/heating system which was driven by evacuated glass tube solar air collectors. The results demonstrated that the system could provide satisfied supply air for winter and summer air conditioning. Li et al. (2012) experimentally investigated a solar driven desiccant cooling/heating system. For hot and humid air condition, the system supplied air at 22 °C and 60% RH with a moisture removal capacity of 8–9 g/kg. In winter, the system produced hot and humid air with a temperature increment of 13 °C. Some researchers worked on regeneration of silica gel. Sant and Jiang (1993) reported that regeneration rate of the desiccant material can be increased by increasing the regeneration temperature. Pramuang and Exell (2007) found that regeneration rate and the regeneration efficiency were greatly affected by the solar radiation, but slightly affected by initial moisture content of silica gel. The silica gel can be regenerated at a regeneration temperature of 40 °C.