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A high performance desiccant dehumidification unit using solid desiccant coated heat exchanger with heat recovery

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ABSTRACT

A new type of solid desiccant dehumidification cycle with internal heat recovery based sorptive material coated heat exchanger (SCHE) is proposed. This system can realize waste heat recovery from exhausted air in regeneration process, in which a heat recovery device (HRD) is adopted. The performance evaluation of the novel cycle is compared with that of the conventional cycle without HRD in terms of moisture and energy transfer. Based on the experimental results, the thermal coefficient of performance of the system has been improved to 1.2, almost twice the thermal coefficient of performance of the conventional cycle without HRD. The electrical coefficient of performance can reach about 13.83. When HRD is involved in the system, the supply air temperature is close to the inlet temperature of process air (ambient air), dehumidification capability meets the design requirements (lower than $8\,g\,kg^{-1}$) and the regeneration temperature can satisfy the regeneration requirement of low grade heat source. The thermal efficiency of the HRD is calculated as 0.88 on average. As a conclusion, SCHE with HRD system could be a potential alternative with effective operation which can be promoted in higher humidity and temperature areas.

1. Introduction

Solid desiccant dehumidification system is a promising alternative to the traditional electrical driven system [1,2]. Its significant advantages for energy saving and environmental protection has been recognized. The amount of energy consumption for air conditioning can be reduced, because of the separate handling of air latent and sensible energy load [3]. Besides, the solid desiccant dehumidification system can be operated by thermal energy source. The heat required to drive this system can come from different source, such as solar energy [4–7], waste heat of an industrial process [8] and other low temperature thermal energy source [9]. Up to now, the development of the solid desiccant dehumidification system evolves in various types [10] and combinations with other device for the hybrid desiccant cooling system [11]. Recently, most of the research works focus on achieving a high desiccant performance with a relatively lower regeneration requirement [12]. One representative concept is multi-stage dehumidification, which approaches isothermal dehumidification when infinite stages are adopted. Meanwhile, it was pointed out that if the adsorption heat can be moved away in dehumidification process, overall performance of desiccant system can be improved significantly [13].

In recent years, a new concept, namely solid desiccant dehumidification unit with SCHE was proposed to overcome the effect of adsorption heat [14]. The SCHE involves as main component a fin-tube air-to-water heat exchanger coated with silica gel. On the one hand, the moisture can be adsorbed by the coated materials during the dehumidification process, when cooling water is pumped into copper tubes of SCHE. On the other hand, the released adsorption heat can be effectively taken away by the circulating cooling water. After that, the SCHE can be regenerated by pumping hot water in regeneration process. The experimental results also proved that, the system with SCHE not only has the ability to process adsorption heat, but also inherits the merits of solid desiccant dehumidification system. In addition, it could be learned that the silica gel coated SCHE has a better performance than polymer one, according to the study on adsorption materials [15]. Also the computer simulations of the desiccant dehumidification system with SCHE are important to evaluate its potential quantitatively and to analyze the cycle configurations and performances under the varying working conditions and parameters [16]. An enhanced evaporatively cooled open

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Nomenclature

AV	air valve
c_w	specific heat of water (kJ kg^{-1} K^{-1})
COP	coefficient of performance
DE	dehumidification process
d	humidity ratio (kg moisture kg DA^{-1}, g kg^{-1})
Δd	moisture removal (kg moisture kg DA^{-1}, g kg^{-1})
h	enthalpy (kJ kg^{-1})
HRD	heat recovery device
HRHE	heat recovery heat exchanger
HRST	heat recovery storage tank
HST	high temperature storage tank
HT-RE	regeneration process at high temperature
$\dot{m}$	mass flow rate (kg/s)
Pre-RE	Pre-regeneration process
Q_C	total heat transfer performance of the system in cooling capacity (W)
Q_d	latent heat transfer performance of the system in cooling capacity (W)
Q_e	electrical power consumption (W)
$Q_{HRD,a}$	heat transfer rate of HRD on air side (W)
$Q_{HRD,W}$	heat transfer rate of HRD on water side (W)
Q_s	thermal capacity of the solar heating system (W)
RE	regeneration process
SCHE	sorptive material coated heat exchanger
T	temperature (°C)
WV	water valve

Greek symbols

γ	latent heat of evaporation (kJ kg^{-1})
η_{HRD}	thermal efficiency of HRD
τ	time (s)

Subscripts

a	air
AA	ambient air
DA	dry air
DE	dehumidification process
e	electrical
EA	exhausted air
RE	regeneration process
SA	supply air
s	solar collector

sorption cycle which can be driven by solar thermal heat is presented as an environmentally benign alternative to conventional air conditioning cycles [17].

An experimental setup of a desiccant dehumidification unit using fin-tube heat exchanger with silica gel coating is installed and investigated by Zhao et al. in 2014 [18]. In this unit, two solid desiccant (silica gel) coated heat exchangers (SCHE) were adopted and switched forth and back to provide continuous dehumidification capacity. Though the cycle was suitable for low regenerating temperature, however, the coefficient of performance was quite low. Great efforts had been made in improving the energy conversion efficiency, but a considerable amount of energy was still wasted in forms of exhausted air.

In this paper, a novel SCHE desiccant dehumidification system with HRD is proposed to improve its performance, especially the COP value. The high temperature waste heat can be directly utilized to drive the regeneration process. The system is designed for several scientific purposes, with the aim to test its energy and dehumidification performance in relation to the following main aspects:

- High dehumidification requirements (outside air humidity ratio of the site can be very high in the summer season of Shanghai, with peaks over 16 g kg^{-1}, while the required supply air humidity ratio is below 8 g kg^{-1});
- Low regeneration heating source temperature (50–80 °C);
- Higher COP performance with internal heat recovery.

2. System description

2.1. Overall experimental set-up

To investigate the performance of dehumidification system using SCHE with HRD, a test facility has been built and is presented in Figs. 1 and 2. Fig. 1 shows the schematic diagram and operation mode of the dehumidification system and Fig. 2 shows the actual view of the experimental set-up.

The designed system mainly consists of two subsystems, namely desiccant dehumidification subsystem and heat recovery subsystem. The desiccant dehumidification subsystem, which is reported in the literature [17], comprises two SCHEs (SCHE A and SCHE B). Fig. 3 gives the actual views of SCHE applied in the system, including the detailed views before and after coating. In addition, a cooling tower and a solar thermal system are employed to provide cooling water and hot water for dehumidification and regeneration process of two SCHEs, respectively. A 500 L solar thermal storage tank (ST) is used to storing the hot water, which is produced by solar vacuum tube collectors. The heat recovery subsystem, which includes a HRD and a 40 L heat recovery thermal storage tank (HRST), is installed at exhausted air outlet to withdraw extra heat from the discharged high temperature regeneration air for producing recovery water. The recycling heat can be used to pre-regenerate the SCHE for a while, which saves the consumption of heating source to improve system thermal COP. Table 1 shows a list of the main components of the experimental set-up with design data.

2.2. Thermodynamic description

The working principles and operation strategies of the novel desiccant system with and without heat recovery are depicted in Figs. 4 and 5, respectively. To facilitate the principle description, psychometric chart, which illustrates the approximate evolution of air treatment through the system under typical summer condition (ambient conditions: 35 °C, 40% RH), is demonstrated in Fig. 6. In example mode in Fig. 1, ambient air at state point (1) is passed through SCHE A, in which the moisture is removed due to the adsorption effect of the desiccant coating layer when the cooling water is pumped into the tubes. The adsorption heat is transferred from the desiccant to the cooling water, leading to a temperature reduction of the desiccant and process air. Therefore, SCHE A is now at a stage of dehumidification (DE) regardless of heat recovery, as shown in Figs. 4(a) and 5(a). If the adsorption heat can be taken away in time, the process air can theoretically remain isothermal to state point (2).

At the same time, hot water circulation at high temperature is used to regenerate SCHE B directly when there is no heat recovery in the SCHE system at regeneration stage (RE), as shown in Fig. 4(b). Process air (state point (3′)) at high temperature and humidity is exhausted after desiccant coating layer being regenerated. In another case, the RE stage is divided into two steps, pre-regeneration process (Pre-RE) and high temperature regeneration process (HT-RE) when heat recovery is involved in the novel SCHE system. During Pre-RE stage, the recovered heat is released at low temperature from HRST, which is used to preliminary regenerate SCHE B for a while, as shown in Fig. 5(b). The ambient air (state point (1)) is heated and humidified after passing through