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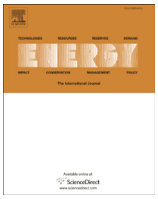

Experimental study on performance of silica gel and potassium formate composite desiccant coated heat exchanger

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In this paper, composite silica gel and potassium formate as typical organic weak acid salts is proposed to use in desiccant coated heat exchanger (DCHE). An experimental study on dynamic adsorption performance of desiccant coated metal sheet samples is conducted to obtain results with different proportions of silica gel and potassium format. A DCHE testing platform is then used to compare thermodynamic performance between single silica gel coated heat exchanger (SCHE) and composite potassium formate and silica gel coated heat exchanger (PSCHE). It is found that impregnating potassium formate into porous silica gel is an effective method to improve adsorption capacity, and 75% saturated potassium formate solution is recommended to constitute composite desiccant under experimental conditions. Compared with SG coated sheet, on average the maximum adsorption mass of SG&0.75PF coated sheet increases 2–3 times. Besides, PSCHE can obtain about 20% higher moisture removal capacity compared with SCHE under experimental condition, meaning the utilization of composite silica gel and potassium formate desiccant can effectively improve dehumidification capacity. PSCHE also can obtain 50% higher total cooling capacity compared with SCHE.

1. Introduction

Traditional vapor compression system adopts condensation dehumidification to remove latent and sensible heat load together. Evaporation temperature needs to be lower than dew point temperature in such system, resulting in lower COP. Condensation dehumidification also causes bacteria breeding problem and sometimes auxiliary reheating is required for commercial building. Solid desiccant cooling system provides solution to those problems by adopting solid desiccant/adsorbent which adsorbs water vapor from humid air to handle the latent heat load and using evaporative cooling for temperature control. Meanwhile, solid desiccant is regenerated by thermal energy and then low grade thermal energy can be adopted to drive the operation, making solid desiccant cooling system a very promising air conditioning technology.

Today, rotary desiccant wheel cooling system is the major type of solid desiccant system and desiccant material is widely recognized vital to determine dehumidification capacity and regeneration temperature of the whole system [1,2]. Development of solid desiccant material can be summarized into two folds. The first group is mainly on porous physical adsorbents such as silica gel, molecular sieve and some newly developed materials like FAM, MOF etc., in which silica gel is the most common one and extensive research works have been conducted. Pesaran and Mills [3] revealed the mechanism of silica gel adsorbing water vapor: surface diffusion is the dominant mode of moisture transfer in micro porous silica gel such as RD gel (regular density silica gel); while for macro porous silica gel, for example ID gel (intermediate density silica gel), both Knudsen and surface diffusions are important mechanism. Ordinary diffusion can be negligible for the silica gel at atmospheric pressure. Hamed [4] constructed an inclined-fluidized bed using silica gel as desiccant material to investigate the adsorption and desorption characteristics in the equipment. Krishna et al. [5] conducted an experimental testing on silica gel desiccant wheel in 1980s and revealed the effects of ambient air, regeneration temperature and rotation speed. Angrisani et al. [6] tested a commercial silica gel desiccant wheel and pointed out that with optimal selection of operation parameters, regeneration temperature of 65 °C can realize regeneration process. O'Connor et al. [7] investigated silica gel desiccant wheel under passive mode with regeneration temperature of 48.5 °C and showed that a

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Nomenclature

c_p	Specific heat, kJ/(kg K)
d	Humidity ratio, g/kg
h	Enthalpy, kJ/kg
h_{fg}	Evaporation latent heat of water vapor, kJ/kg
M	Mass flow rate, kg/s
Q_c	Cooling capacity(sensible/latent heat load removal capacity), kW
T	Temperature, °C
RH	Relative Humidity, %

Subscript

a	Air
avg	Average value
in	Inlet
t	Transient value at time *t*
out	Outlet

Abbreviation

COP	Coefficient of Performance
DCHE	Desiccant Coated Heat Exchanger
PSCHE	potassium formate combing Silica gel Coated Heat Exchanger
SG	Silica Gel
PF	Potassium Formate
SCHE	Silica gel Coated Heat Exchanger

dehumidification ratio of 55% can be achieved. Besides, more researches are carried out using simulation method. For example, Ahmed et al. [8] established a one-dimensional mathematical model which considers the mass diffusion in silica gel was established. The model was adopted to analyze the effects of wheel thickness, wheel speed, wheel porosity, etc. on system performance. The proffered wheel thickness, effective air flow rate, average regeneration air fraction area and wheel speed were found to be in the range of 0.26–0.18 m, 1–5 kg/min, 0.8–0.3 and 15–60 r/h respectively if regeneration temperature is between 60 and 90 °C. Cejudo et al. [9] developed two types of mathematical model for calculating silica gel performance: a conventional physical model based on mass and energy balance, and a neural network model based on black box training with real data. The neural network model consisted of a four-input–four-output network that calculates the outlet conditions from inlet ones. Real data was used to validate the model and to train the neural network. In the case of the neural network model, the temperature and humidity ratio calculated for the outlet air were in accordance with the experimental data. Jeong and Mumma al. [10] and Beccali et al. [11] built empirical models to estimate the sensible and latent effectiveness of silica gel wheel. In addition to silica gel, some researchers also investigated other porous physical adsorbents to get better performance: White et al. [12] investigated desiccant wheels containing zeolite and super-adsorbent polymer and compared their performance with a conventional silica gel desiccant wheel, it was found that the super-adsorbent polymer desiccant wheel achieved greater dehumidification than the silica gel wheel when dehumidifying high relative humidity air with low temperature (50 °C) regeneration air and the zeolite desiccant wheel was generally less effective at dehumidifying air and had a higher pressure drop. Al-Alili et al. [13] used new zeolite desiccant (FAM) with unique S-shape isotherm to fabricate desiccant wheel and obtained its efficiency under different conditions.

Another fold is developing composite desiccant based on two different desiccant materials. Chen et al. [14,15] developed the desiccant wheel by combining silica gel with two types of polymers. Results showed that under optimal ratio composite wheel exhibited a sorption capacity 41% higher than silica gel wheel, and the composite desiccant wheel can be regenerated by 40–50 °C condensation heat. Also, performance of composite desiccant wheel fabricating by compound physical and chemical adsorbents is investigated. Compared with physical adsorbents, chemical adsorbents like haloids are found having higher adsorption capacity and lower regeneration temperature, but the instability hinders the further utilization in desiccant wheel. Composite desiccant wheel is fabricated by impregnating chemical adsorbents into the pores of porous physical adsorbents. Zhang et al. [16] fabricated silica gel and calcium chloride desiccant wheel and results showed that the moisture removal of compound desiccant wheel increased 10% compared to that of silica gel wheel. Jia et al. [17,18] also developed the composite desiccant wheel fabricated with silica gel-lithium chloride composite material and results indicated that the novel compound desiccant wheel under practical operation can remove more moisture from the process air by about 20%–40% over the desiccant wheel employing regular silica gel. Gordeeva et al. [19] made a comprehensive review on the development of composite physical and chemical adsorbents and pointed out those composite desiccants were promising solid sorbents for various adsorption heat transformation cycles including desiccant cooling.

Recently a novel solid desiccant configuration called desiccant coated heat exchanger (DCHE) is proposed, which is fabricated by directly coating solid adsorbent to metal outer surface of conventional fin tube heat exchanger. Because the heat exchanger can provide an inner cooling source for outer coating, DCHE can realize isothermal even temperature-decreasing dehumidification process compared with desiccant wheel, which also results in improved adsorption capacity of desiccant with lower adsorption temperature and leads to lower regeneration temperature [20]. On the other hand, unlike desiccant wheel, two DCHEs are required to realize continuous dehumidification process due to the limitation of this configuration [21]. Performance of DCHE is mainly dependent on desiccant material and finding the optimum desiccant materials for use in DCHE is currently a very active research areas [22]. Kumar et al. [23] tested a practical solar driven DCHE system using silica gel, they found that evacuated tube solar water heater can provide sufficient thermal energy to drive system operation: in summer season, the system can cool down the process air with an average temperature of 8.5 °C; in winter season, the system can heat up the process air with an average temperature increase of 13.3 °C and in humidity ratio of 1.9 g/kg. Zhang et al. [24] derived the overall mass-transfer coefficient for desorption and adsorption processes of silica gel coated heat exchanger. Ge et al. [20] compared the dynamic performance of silica gel and polymer coated heat exchanger and found that silica gel coated heat exchanger has better dehumidification capacity. Chang et al. [25] compared another two DCHEs coating with silica gel and sodium polyacrylate and showed under the experimental condition, sodium polyacrylate one performs better.

Current researches mainly utilize single physical adsorbents such as silica gel, polymer etc. in DCHE [20–25], with main objective on obtaining dynamic operation characteristics. Based on the experiences in desiccant wheel, it is likely that composite desiccant material could improve performance of DCHE, thus several researchers adopted composite silica gel and lithium chloride desiccant in DCHE and validated the enhanced dehumidification capacity [26,27]. However, since DCHE uses metal matrix instead of ceramic or fiber as desiccant wheel, haloids within