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Research Paper

Experimental and comparison study on heat and moisture transfer characteristics of desiccant coated heat exchanger with variable structure sizes

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HIGHLIGHTS

- Three types of novel DCHEs with variable structure sizes are tested and compared.
- Ranks of influence factors in experiments are obtained by using Taguchi method.
- Higher surface compactness of DCHE means higher heat and mass transfer capacity.
- Heat and mass transfer coefficients are functions of pressure drop.

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ABSTRACT

Desiccant-coated heat exchanger (DCHE) is a novel component for handling both sensible and latent heat assisted by desiccant materials. In this paper, three types of DCHEs with the same transfer surface area, DCHE A (fin pitch 2 mm, fin depth 44 mm), DCHE B (fin pitch 3 mm, fin depth 66 mm) and DCHE C (fin pitch 4 mm, fin depth 88 mm), are fabricated to make out the relationships between structure sizes and performance characteristics. The transient heat and moisture transfer performance, as well as the pressure drop passing through DCHEs, are tested and compared in depth. By using Taguchi method, the ranks of influence factors in heat and mass transfer performances are obtained. With the same transfer surface area but different surface compactness, three DCHEs show different heat and mass transfer capacities and different pressure drops. DCHE A with the highest surface compactness shows the highest heat and mass transfer capacity, while the highest pressure drop is shown as deficiency. DCHE C with the smallest surface compactness shows the highest heat recovery efficiency and the lowest pressure drop. Heat transfer coefficient of DCHE A is 14.9% greater than DCHE B, 19.6% greater than DCHE C in dehumidification process. The moisture adsorbed value of DCHE A is 9.6% greater than DCHE B, 18.2% greater than DCHE C. Pressure drop of DCHE A is 50% larger than DCHE B, and 90% larger than DCHE C. The correlations of Nusselt number and Euler number of three DCHEs are summarized by fitting the experimental data.

1. Introduction

Nowadays, the load of power consumption of air-conditioning system enhances due to the heavy demand of high indoor air quality [1]. The construction, operation and maintenance of buildings accounts for 40% of the total global energy consumption, which means exploitation of alternative energy sources and energy savings become key issues [2]. In buildings, controlling indoor humidity at an appropriate level is crucial since this directly affects building occupants' thermal comfort and the operating efficiency of building air conditioning installations [3]. In recent years, there have been extensive interests on desiccant air conditioning as an alternative method to achieve air temperature and humidity control in occupied space due to its benefits of high energy efficiency [4]. Solid desiccant, as a common type of dehumidification system, represents a viable and beneficial alternative, thanks for their low electricity consumption and usage of low-grade heat source [5]. According to the configured methods, solid desiccant dehumidification systems can be divided into the rotary desiccant wheel [6], the fluidized bed [1] and desiccant coated heat exchanger [7].

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Nomenclature

A	the total heat transfer area, m^2
A_O	the minimum free-flow area for an inline arrangement, m^2
A_{fr}	the frontal area, m^2
α	the surface area density, m^2/m^3
B	mass transfer driving force, dimensionless
c_p	specific heat, J/(kg·K)
d	humidity ratio of air, kg water vapor/kg dry air
D	hydraulic diameter, m
$D_{w,a}$	the diffusion coefficient of vapor in air, kg/(m·s)
ε	effectiveness of heat exchanger, dimensionless
ε_m	effectiveness of moisture removal, dimensionless
g	mass transfer coefficient, kg/(m^2·s)
g_c	proportional constant of Newton's second law of motion, $g_c = 1$ in International System of Units, dimensionless
h	enthalpy, kJ/kg
$\hbar^2$	the experimental data obtained for optimization of control factors
k	heat transfer coefficient, W/(m^2 · K)
n	the number of test runs, dimensionless
m	mass flow rate, kg/s
ΔM_{DE}	the dehumidification results per unit time air, kg/h
P	pressure, Pa
Q	quantity of heat, W
RH	relative humidity,%
T	temperature, °C
V	the total volume of the heat exchanger, m^3
v	air velocity, m/s
η	heat recovery efficiency, dimensionless
γ	adsorption heat, kJ/kg
τ	operating cycle time, s
ρ	density, kg/m^3
σ	the ratio of minimum free-flow area to frontal area, dimensionless
μ	the dynamic viscosity coefficient, N · s/m^2.
λ	the heat conductivity coefficient, W/(m K)

Subscripts and superscripts

a	air
avg	average
d	desiccant
DE	dehumidification process
i	imagined surface
in	inlet
l	latent
max	maximum
min	minimum
out	outlet
RE	regeneration process
s	contact surface
w	water
∞	infinity area

Abbreviations

DCHE	desiccant coated heat exchanger
Eu	Euler number
NTU	number of transfer unit
Nu	Nusselt number
Pr	Prandtl number
Red	Reynolds number
Sc	Schmidt number
Sh	Sherwood number
SNR	Signal to noise ratio

Desiccant coated heat exchanger (DCHE), which is fabricated by coating desiccant to conventional heat exchanger, has obtained more attention due to its benefits of handling both sensible and latent heat with the assistance of desiccant materials. Compared with other solid desiccant dehumidification components, DCHE overcomes the negative effect of adsorption heat by cycling cooling water in the heat exchanger, hence the overall performance of dehumidification can be improved significantly [8]. In DCHE, heat and moisture transfer occur simultaneously and interact with each other intensively in dehumidification and regeneration process [9]. Latent and sensible load of process air can be handled separately to provide comfortable supply air [10]. Moreover, the heat required to drive the regeneration process can come from low-grade heat resources, such as solar energy [11], waste heat of an industrial process [12], and rejected condensation heat from the air conditioning systems. The temperature difference between heat source and cold source temperature can dramatically decrease to approximately 30 °C [13]. By using waste heat recovery from exhausted air in regeneration process, the thermal coefficient of performance could be improved to 1.2, while the electrical coefficient of performance can reach about 13.83 [14]. Besides, DCHE can be operated all year round, for dehumidifying and cooling air in summer, and heating and humidifying air in winter [15]. Because of DCHE's low initial cost and high efficiency, combining DCHE with conventional air conditioning system can provide comfort air and be driven by low grade thermal energy, proving DCHE can be a good alternative for air source heat pump systems compared with desiccant wheel [16].

The most significant performance indexes of DCHEs are dehumidification amount and coefficient of performance. Important enhancements have been demonstrated to improve indicators from the following aspects like desiccant materials, structure of heat exchanger and simulation analysis. Zheng et al. [17] in 2014 reviewed a total of 72 desiccant materials present in the literature for solid desiccant cooling systems, and the results showed that desiccant materials with "S type curve" adsorption isotherms can perform better. Zheng et al. [18] in 2015 conducted a study of four LiCl (10–40 wt%) supported silica gel composites for DCHE, and compared it with pure silica gel. Tatlier [19] in 2017 investigated the performances of zeolite and MOF coatings for adsorption cooling applications by modeling studies, revealing the superiority of the triazolyl phosphonate MOF over the zeolites, NaX, LiX and NaA. Different materials coated on different heat exchanger are tested, such as fin-tube air-to-water heat exchanger [7], crossflow air-to-air heat exchanger [20], finned flat-tube aluminum heat exchanger [21] and so on.

The other important aspect for improving the DCHE performance is the analysis and optimization of the heat and moisture transfer process. Because of desiccant coating and interior heat resource, the coupled heat and mass transfer characteristics is different from conventional fin and tube heat exchanger [22]. Li et al. [9] in 2015 presented a theoretical model to investigate the heat and mass transfer inside a DCHE, to account for heat conduction and mass diffusion in the desiccant felt as well. Ge et al. [23] in 2011 proposed a one dimensional gas side resistance model for a silica gel coated air to water heat exchangers. Munz et al. [20] in 2013 proposed and simulated a solar powered desiccant based cooling and dehumidification system. A 2-dimensional thermodynamic model implemented in Modelica was used to simulate the system performance.

The heat and mass transfer correlations are also gradually built. The correlations of Chilton-Colburn j-factor for the heat transfer and