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Research paper

On heat and moisture transfer characteristics of a desiccant dehumidification unit using fin tube heat exchanger with silica gel coating

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HIGHLIGHTS

- On the basis of experimental results, we analyze the heat and moisture transfer performance of SCHE.
- The empirical formula on *Nu* and *Sh* of SCHE are deducted using L–M method.
- Using those formulas, we can predict the results in terms of heat and moisture transfer performance of SCHE.

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ABSTRACT

In this paper, the heat and moisture transfer characteristics of a desiccant dehumidification unit using fin-tube heat exchanger with silica gel coating have been experimentally investigated. The present study focuses on the analysis of air side heat and moisture transfer performance in dehumidification mode. The empirical formula on Nusselt and Sherwood numbers were deducted and curve fitted from the test results under various operation conditions, using the non-linear least square method. The typical operation condition is that the air side Reynolds number ranges between 220 and 550 and tube side cooling water flow rate is about 7.7 L/min. Further tests indicate that the correlations of Nusselt and Sherwood number on air side of the unit agree well with the test results, and the mean errors are about ±10% and ±12%, respectively. Finally, the improvements of the operation and configuration parameters of this novel heat and moisture transfer components are discussed with those formulas. It is found that the correlated formulas provide the theoretical basis and practical experience for design and optimization of the desiccant dehumidification unit using fin tube heat exchanger with silica gel coating.

1. Introduction

Since Dunkle [1] constructed the first solid desiccant dehumidification and cooling rotary wheel in 1965. The solid desiccant dehumidifiers [2–8] have been proven to be a very effective method for dehumidification, and the desiccant materials for these applications [9,10] have been widely studied. Running in open cycle, the solid desiccant dehumidification possess the merits of energy conservation and environment friendly because it can be driven by low grade heat source, e.g., solar energy and waste heat. In the past decades, various solid desiccant dehumidifiers have been developed and employed to improve the energy utilization and dehumidifying efficiency. La et al. [11,12] developed a new type multiple stages desiccant wheel cooling system and pointed out that the overall performance of the system can be improved significantly if adsorption heat can be taken away from dehumidification process. In order to overcome the influence of the adsorption heat, the work done by Lazzarin and Castellotti [13] was found to be the application of self-regenerating heat pump desiccant firstly. It was a self-regenerating liquid desiccant cooling system which was able to dehumidify, heating or cooling the ambient air by an electric heat pump as part of the equipment. The provided cooling did not only balance the exothermic effect of the absorption heat that allowed the dehumidification, but also, if necessary, it could give an additional effect that produces cool dry air. Moreover, T.N. Aynur and Y.H. Hwang [14] developed a new self-regenerating

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Nomenclature

a	pore radius of the adsorbent (m)
A	total air side surface area of the SCHE (m^2)
A_f	fin surface area of the SCHE (m^2)
A_w	water side surface area on tube of the SCHE (m^2)
C	constant
C_p	specific heat (kJ(kg K))
$COAH$	coefficient of adsorption heat
D	mass diffusion coefficient ($m^2\ s^{-1}$)
d	moisture removal (kg moisture kg DA^{-1})
D_A	combined ordinary and Knudsen diffusivity ($m^2\ s^{-1}$)
D_{AB}	overall diffusion coefficient ($(kg(m^2\ s)^{-1}$)
D_{AK}	the Knudsen diffusivity ($m^2\ s^{-1}$)
D_{AO}	the ordinary diffusivity ($m^2\ s^{-1}$)
De	hydraulic diameter (m)
D_0	constant for surface diffusion calculation ($m^2\ s^{-1}$)
D_S	the surface diffusivity ($m^2\ s^{-1}$)
D_{VA}	mass diffusion coefficient of water vapor ($kg(m^2\ s)^{-1}$)
g	mass transfer coefficient ($kg(m^2\ s)^{-1}$)
H	height of SCHE (m)
h	heat transfer coefficient ($kW(m^2\ K)^{-1}$)
i	enthalpy (kJ kg^{-1})
J_d	mass transfer coefficient on air side and desiccant layer ($kg(m^2\ s)^{-1}$)
K_m	overall mass transfer coefficient ($kg(m^2\ s)^{-1}$)
L	length of SCHE (m)
m	constant
$\dot{m}$	mass transfer rate (kg s^{-1})
M_v	mass transfer rate of moisture (kg moisture s^{-1})
M_w	the molecule weight of water (kg $kmol^{-1}$)
n	constant
Nu	Nusselt number
P_a	the pressure in atmospheres (Pa)
Pr	Prandtl number
P_{vs}	the saturation vapor pressure (Pa)
Q	heat transfer rate (kW)
q_{st}	adsorption heat (kJ kg $adsorbate^{-1}$)
Re	Reynolds number
RH	relevant humidity
Sc	Schmidt number
$SCHE$	solid desiccant coated heat exchanger
Sh	Sherwood number
T	temperature (K)
u	flow velocity (m s^{-1})
W	width of SCHE (m)
w_d	humidity ratio in desiccant (kg moisture kg $adsorbent^{-1}$)
X	air humidity ratio (kg moisture kg DA^{-1})

Greek symbols

α	fluid thermal diffusivity ($m^2\ s^{-1}$)
γ	vaporization heat of water (kJ kg^{-1})
δ	thickness (m)
ε_d	total porosity
λ	thermal conductivity ($kW(m\ K)^{-1}$)
ν	fluid kinematic viscosity ($m^2\ s^{-1}$)
ξ	tortuosity factor

Subscripts

a	process air
DA	dry air
d	desiccant
f	fin
i	interface effect of desiccant coating
in	inlet
out	outlet
t	tube
v	vapor
w	water

heat pump desiccant unit which was less complex compared to the system described by Lazzarin and Castellotti. The unit, in which two heat exchangers covered with adsorption material were employed, could be operated as a stand-alone system and in conjunction with the VRV system. As far as low grade source is concerned, more and more solar energy or waste heat driven desiccant cooling system were studied in recent years. A solar-assisted desiccant cooling system (SADCS) was investigated to handle the cooling load of typical office in the subtropical Hong Kong [15]. In addition, a micro-trigeneration system with a desiccant-based air handling unit was designed and tested in southern Italy [16]. Thermal energy from MCHP (micro combined heat and power) can be transferred directly to the AHU (air handling unit) to regenerate the desiccant wheel.

Besides, a novel concept of solid desiccant coated heat exchanger (SCHE) was further developed to realize the inner cooling dehumidification [17]. The adsorption heat generated during the dehumidification process can be taken away in time by cycling cooling water in the tube. Experimental results also showed that desiccant coated heat exchanger system not only included the merits of solid adsorption desiccant dehumidification system but also had great potential to archive simple structure, convenient process and low manufacturing cost compared to self-regenerating heat pump desiccant unit [18]. Several works on simulation have been carried out to assess the performance of SCHE under given conditions. In recent years, Ge et al. [19] completed a new mathematical model concerning the complicated heat and mass transfer in SCHE. The model was helpful for predicting the performance of this unit. However, it is not adequate for designing and application of such kind of novel heat and moisture transfer unit using the numerical method. In many cases, it would be better if the heat and mass transfer coefficients are known in advance.

Therefore, it is necessary to propose a new correlative expression about the heat and mass transfer coefficients for SCHE. In the present work, the Nusselt and Sherwood numbers of SCHE under typical operation conditions were investigated. A non-linear least square method was introduced to calculate the air side Nusselt and Sherwood numbers based on the experimental results. .The new correlated expression can meet the demands of optimal design and application of SCHE, and improve the prediction results for simulation.

2. SCHE and the experimental setup

2.1. Working principle

Fig. 1 illustrates the working principle of the SCHE, the cooling or hot water flows through the tube to move adsorption heat or supply regeneration heat from/to the desiccant material (silica gel) which is coated in aluminum fins with glue. In addition, moisture is transported between the air and the coated desiccant layer. Within the SCHE, heat and moisture transfer can interact each other