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Theoretical and experimental studies on isothermal adsorption and desorption characteristics of a desiccant-coated heat exchanger

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ABSTRACT

Dynamic characteristics of desiccant–coated heat exchangers (DCHEs) were experimentally measured by wind tunnel. The surface of the DCHE was coated with polymer sorbent desiccant. The isothermal adsorption and desorption experiments were conducted under the condition where the temperatures of the air and brine passing through the DCHE were identical.

The experimental results were compared to that obtained from theoretical calculations. A diffusion model predicting the distribution of moisture concentration and temperature in the desiccant layer was introduced. The equivalent diffusion coefficient of the water inside the desiccant layer was determined from the experimental results.

The adsorption and desorption speeds were at the maximum values at the beginning of the sorption processes, and then they gradually decreased. The equivalent diffusion coefficient was dependent on the temperature. Assuming the temperature dependence of the diffusion coefficient, the calculated sorption performance correlated well with that obtained from the experimental results.

Études théoriques et expérimentales sur les caractéristiques d’adsorption et de désorption isothermes d’un échangeur de chaleur enrobé de déshydratant

Mots clés : Déshydratant ; Échangeur de chaleur ; Adsorption ; Transfert de masse ; Transfert de chaleur ; Coefficient de diffusion

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Nomenclature

c	specific heat [J·kg^{-1}·K^{-1}]
c_p	specific heat at constant pressure [J·kg^{-1}·K^{-1}]
D_d	equivalent mass diffusion coefficient [m^2·s^{-1}]
E_a	activation energy [J·g^{-1}]
f_e	function of moisture content in desiccant
h	heat transfer coefficient [W·m^{-2}·K^{-1}]
h_m	mass transfer coefficient [kg·m^{-2}·s^{-1}]
l	cross-sectional perimeter [m]
m_a	air mass flow rate [kg·s^{-1}]
m_{ad}	mass flux [kg·m^{-2}·s^{-1}]
M_v	mass transfer rate [kg·s^{-1}]
q	heat flux [W·m^{-2}]
R	gas constant [J·g^{-1}·K^{-1}]
RH	relative humidity of air [%]
S	cross-sectional area [m^2]
S_{ad}	total amount of mass transfer [kg]
t	time [s]
T	temperature [K]
u	velocity [m·s^{-1}]
V_b	volumetric flow rate of brine [m^3·s^{-1}]
w_d	moisture content in desiccant [kg·kg^{-1}]
X	absolute humidity [kg·kgDA^{-1}]

Non-dimensional numbers

Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
Sc	Schmidt number
Sh	Sherwood number

Greek symbols

δ_d	thickness of desiccant layer [m]
δ_w	thickness of flat tube wall [m]
γ	latent heat of water [J·kg^{-1}]
λ	thermal conductivity [W·m^{-1}·K^{-1}]
ρ	density [kg·m^{-3}]

Subscripts

a	air
ad	air to desiccant
b	brine
bw	brine to flat tube wall
dw	desiccant to flat tube wall
d	desiccant
i	inlet
o	outlet
w	flat tube wall

1. Introduction

An air conditioner controls the air temperature in a room with high efficiency. Appropriate temperature and humidity are required for comfortable air conditions. Typically, in a conventional air conditioning system, a refrigeration cycle can perform cooling dehumidification; however, an additional humidifier is necessary for humidification. During the cooling dehumidification process, the air conditioner lowers the air temperature below its dew point, and dehumidifies the air by condensing the moisture. The air is then reheated. These processes, lowering the air temperature below its dew point and then reheating, cause a decrease in the efficiency of the air conditioning system. As for the humidification process, the humidifier needs liquid water. Waterless humidification is preferable, because water management presents several problems.

Desiccants have been used for humidity control, with high efficiency. Desiccants can adsorb or desorb the water directly from the air, which saves energy. Moreover, waste or renewable heat can be utilized for the generation of desiccants, which further enhances the efficiency of the system as a whole (Balaras et al., 2007; Guo et al., 2017).

One of the ways of using desiccants in the air conditioning is the desiccant rotor. The desiccant is located on the wall of the rotor, which usually has a honeycomb structure. The rotor rotates, and adsorbs and desorbs moisture consecutively. Many researchers have focused on the desiccant rotor both experimentally (Eicker et al., 2012; Ge et al., 2008a) and in theoretical simulations (Lee and Kim, 2014; Ruivo et al., 2011). The performance of the rotor is influenced by several working conditions, such the rotation speed and generating temperature, or by inherent conditions such as its structure and the desiccant itself. Therefore, it is important to compare the performance of the rotor under different conditions. Chung et al. (2009) investigated the optimization of working conditions of desiccant rotors, notably rotation speed and generation temperature. Golubovic et al. (2006) compared the performance of several zeolites with different sizes of molecular sieves for desiccant rotors. Yamaguchi and Saito (2013) investigated the desiccant rotor by constructing the theoretical model assuming mass diffusion in the air channel and desiccant wall, and compared the calculation results to their experimental results.

Given that the mechanism of desiccant rotors involves isenthalpic adsorption and desorption processes, the air temperature increases during the adsorption process because of the condensation heat of water. The relative humidity of air decreases with an increase in the temperature, thus, the adsorption performance degrades. An additional cooler is required to lower the air temperature before the air is supplied to the room. During the desorption process, on the other hand, the air temperature decreases because of the evaporation heat of the water. The relative humidity of the air increases and the desorption performance decreases. An additional heater is required at the inlet of the rotor to enhance generation of the desiccant by increasing the air temperature.