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Effect of desiccant isotherm on the performance of desiccant wheel

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ABSTRACT

Numerical simulation has been conducted for the desiccant wheel, which is the crucial component of a desiccant cooling system. As the key operating/design parameters, the rotation speed and the area ratio of regeneration to dehumidification have been examined for a range of regeneration temperature from 50 °C to 150 °C. Optimization of these parameters is conducted based on the wheel performance evaluated by means of Moisture Removal Capacity (MRC). Simulations are focused on the effect of desiccant isotherm on the optimal conditions of these operating/design parameters. Also the effects of the outdoor air temperature and humidity on the optimum design parameters are examined.

Effet de la forme de l'isotherme déshydratante sur la performance d'une roue déshydratante

Mots clés : Conditionnement d'air ; Modélisation ; Roue déshydratante ; Simulation ; Transfert de masse ; Optimisation ; Variation de vitesse

1. Introduction

The design of heating, ventilating and air-conditioning (HVAC) systems for thermal comfort requires increasing attention, especially matters arising from recent regulations and standards on ventilation (Mazzei et al., 2005). The optimum level of indoor humidity is desired to be reached and maintained to ensure a comfortable and healthy environment. Desiccant cooling systems have advantages in environmental-conscious operation and separate control of sensible and latent cooling loads which lead to comfortable indoor air quality. In addition, the desiccant cooling system is

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Nomenclature

a	channel height (m)
A	area (m^2)
b	channel width (m)
c	channel wall thickness (m)
C_p	specific heat of dry air water ($J\,kg^{-1}\,K^{-1}$)
f_m	mass fraction of desiccant in the wheel
h	convective heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_m	mass transfer coefficient ($kg\,m^{-2}\,s^{-1}$)
H_{sor}	heat of adsorption ($J\,kg^{-1}$)
L	channel length (m)
$\dot{m}$	mass flow rate ($kg\,h^{-1}$)
MRC	moisture removal capacity ($kg\,h^{-1}$)
P	perimeter of flow channel (m)
P, P_s	pressure, saturated pressure (Pa)
r	radial coordinate
R	separate factor
t	time (s)
T	temperature (K)
u_a	air velocity ($m\,s^{-1}$)
Y	humidity ratio ($kg\,kg^{-1}$)
z	axial coordinate (m)
W	water content of the desiccant material ($kg\,kg^{-1}$)
W_{max}	maximum water content ($kg\,kg^{-1}$)
ϕ	relative humidity
θ	angular coordinate
ρ_a	air density ($kg\,m^{-3}$)

Subscripts

a	air
in	inlet
l	liquid
p	process
r	regeneration
v	vapor
w	desiccant

a heat-driven cycle and so it has the promise of being able to use low density energy such as natural gas, waste heat and solar energy, which attracts great attention with the onset of oil price increasing. The US-Department of Energy estimated that desiccant cooling systems could reduce annual energy consumption by 117.2 million MWh and carbon dioxide emissions by 6 million tons by 2010 (Pesaran et al., 1992).

The wheel is the most crucial component of the desiccant cooling system. Mathematical modeling of the wheel therefore plays an important role in enhancing the overall system performance. The optimum rotation speed and wheel thickness, and operating parameters such as air flow rate, relative humidity of inlet air and regeneration air temperature on the wheel performance have all been examined (Dai et al., 2001; Zheng and Worek, 1993; Zhang and Niu, 2002; Zhang et al., 2003; Ahmed et al., 2005; Chung et al., in press). The type and properties of the desiccant adopted is also closely linked to the performance enhancement. The commonly used solid desiccant is silica gel which has high performance but can be destroyed after rapid adsorbing a great deal of water and is not a heat-resistant material. The development of advanced desiccant materials is focused to improve sorption capacity and better moisture and heat diffusion rates as well as favorable equilibrium isotherms (Cui et al., 2005; Jia et al., 2006).

In the present study, a numerical model is used to study and discuss the performance of a desiccant cooling system in terms of its Moisture Removal Capacity (MRC). We focus on the effect of desiccant isotherm on the optimal values of the operating and design parameters such as the area ratio of regeneration to dehumidification, rotation speed and regeneration temperature. Also variations of the outdoor air temperature and humidity effects on the optimum design parameters are examined.

2. Numerical simulation

Assessing the great number of available options and their optimum combinations involved in the design of a desiccant wheel is a time-intensive task if using an experimental approach. Thus, modeling and numerical simulation can become highly effective tools in designing a desiccant wheel by effectively isolating one variable at a time and examining trends and causes.

Fig. 1(a) shows the schematics of a desiccant wheel. Because of geometric similarity and to avoid prohibitive computation costs, it is reasonable to represent the multiple annular layers of straight slots in the desiccant wheel by a "representative annulus" whose cross sectional view is presented in Fig. 1(b). In this way, the three cylindrical coordinates in the model (r, θ, z), the radial, angular and axial directions, respectively, can reasonably be reduced to a steady two-dimensional (θ, z) or unsteady one-dimensional (t, z) problem. In the present study, the unsteady one-dimensional model is developed for the coupled heat and mass transfer

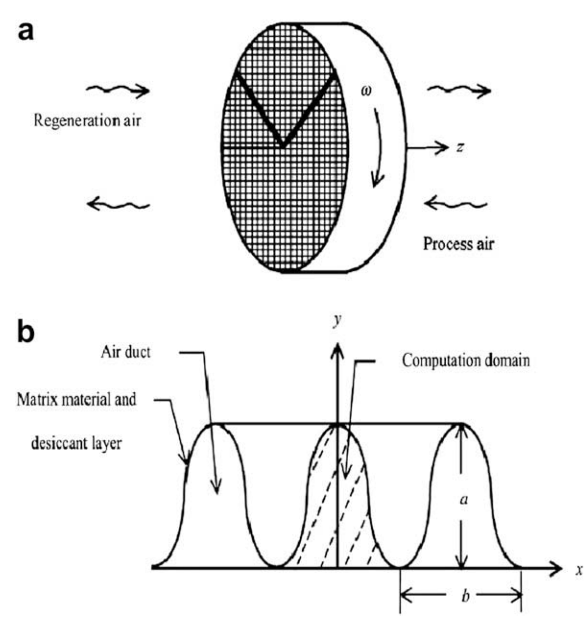

Fig. 1 – Schematics of (a) desiccant wheel and (b) computational domains (Zhang et al., 2003).