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Theoretical and experimental study on characteristics of a novel silica gel–water chiller under the conditions of variable heat source temperature

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Abstract

In this paper, a transient model of a silica gel–water adsorption chiller, which is developed in Shanghai Jiao Tong University (SJTU), is developed in order to simulate the evaporating, condensing, and adsorption temperature. Furthermore, this model is verified by a series of experiments. The theoretical studies and experimental data show that the coefficient of performance (COP) is influenced significantly by the variation rates of the heat source temperatures. The results also show that when this chiller is driven by solar energy, a buffer tank should be adopted in the system in order to get better performance when solar insolation is low, and should not be utilized when solar insolation is high, otherwise low COP will be gotten for the reason of the consumption of high electric energy.

Keywords: Chiller; Adsorption system; Water; Silica gel; Modelling; Operation; Transient; Experiment; Performance; COP

Etude théorique et expérimentale sur les caractéristiques d'un refroidisseur innovant fonctionnant au gel de silice sous des conditions de source de chaleur à température variable

Mots clés : Refroidisseur de liquide ; Système à adsorption ; Eau ; Gel de silice ; Modélisation ; Fonctionnement ; Régime transitoire ; Expérimentation ; Performance ; COP

1. Introduction

An adsorption cooling system, which is driven by low-grade heat sources, has the benefits of economical efficiency, energy-saving and environmental protection. Thus adsorption refrigeration technology attracts more and more interests in recent years because of increasing concerns about the shortage in energy resources and global environmental issues.

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Nomenclature

a	constant in Van der Waals equation (Pa m^6 kg^{-2})
A	area (m^2)
b	constant in Van der Waals equation (m^3)
C_p	specific heat (kJ kg^{-1} K^{-1})
D_{so}	diffusion coefficient (m^2 s^{-1})
D	diameter (m)
E_a	activation energy (J mol^{-1})
E	energy consumed (kJ)
h_a	desorption/adsorption heat (kJ kg^{-1})
h	heat transfer coefficient (kW °C^{-1} m^{-2})
h_f	friction loss (m^2 s^{-2})
k	characteristic parameter of adsorption
K_t	variation rate of temperature (°C min^{-1})
K_{sap}	coefficient of adsorption in D–A equation
l	length (m)
L	latent heat of refrigerant (kJ kg^{-1})
$\dot{m}$	flow rate (kg s^{-1})
M	mass (kg)
n	characteristic parameter of adsorption
P	pressure (N m^{-2})
Q_{heat}	heating power (kW)
Q_{rad}	radiate intensity of solar (kW m^{-2})
Q_r	cooling capacity (kW)
R	gas constant (J kg^{-1} K^{-1})
R_p	averaged diameter of absorbent particle (m)
R_m	thermal capacity ratio of mental to adsorbent
t	time (s)
t_0	hours of daylight (s)
T	temperature (°C)
v	specific volume (m^3 kg^{-1})
x	adsorption capacity (kg kg^{-1})
x_∞	adsorption capacity for equilibrium (kg kg^{-1})
x_0	characteristic parameter of adsorption (kg kg^{-1})
y	temperature impact effect
η	efficiency of solar collector
ρ	density (kg m^{-3})
λ	friction factor
ε	surface roughness (m)

Subscript

a	adsorbent
ad	adsorption
ave	temporal averaged value
b	desorber/adsorber
con	condensation/condenser
chill	chilled water
cool	cooling water
des	desorption
eva	evaporation/evaporator
end	last time
f	fluid
heat	hot water
in	inlet
ini	initial time
m	metal
me	methanol
out	outlet
remain	remained fluid
s	saturation
sc	solar collector
sys	system
v	vapor
w	water
wt	buffer tank

Compared with most conventional single-stage absorption chillers [1], the prominent advantage of silica gel–water adsorption chillers is that they can be driven by heat sources with low temperatures, which are below 85 °C, without corrosion and crystallization trouble. Furthermore, an adsorption chiller does not have to consume electric energy to drive solution pump, which can enhance the energy utilization efficiency. In the field of silica gel–water adsorption chillers, Saha et al. [2] develop a silica gel–water adsorption cooling system driven by solar energy or waste heat with the temperatures between 50 and 75 °C, and the COP is reported to be 0.36 when the heat source temperature is 55 °C. In 2002 Saha et al. [3] come up with a silica gel–water multi-bed cooling system driven by waste heat. For a two-bed system, the optimal COP is obtained when the heat source temperature is about 55 °C, while for a multi-bed system, the optimal COP is obtained when the heat source temperature is about 85 °C. Alam et al. [4] develop a four-bed cooling system with mass recovery, which has higher COP than traditional two-bed systems, when the heat source temperature is lower than 70 °C, and Boelman et al. [5,6] theoretically and experimentally study a small-scale adsorption chiller produced by NACC and conclude that the cooling capacity of the system is 12.63 kW and COP reaches 0.4 with the heat source temperature at 85 °C. Chua et al. [7–9] study a two-bed cooling system without heat regeneration and the results show that the minimum averaged entropy production rate is gotten in the condenser under the condition of the maximum averaged entropy production rate in the adsorber. It is also reported that the cooling capacity of a four-bed system is 70% higher than that of the two-bed system, while the cooling capacity of a six-bed system is 40% higher than that of the four-bed system. Tangkengsirisin et al. [10] study the influence of different color silica gels on the performance of silica gel–water cooling systems driven by solar energy.

In recent years, a novel silica gel–water adsorption chiller, which has the large potential of commercialization