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Optimization of a fin-tube type adsorption chiller by design of experiment

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ABSTRACT

This paper presents a numerical analysis of the performance of a fin-tube type adsorption chiller associated with heat and mass transfer mechanisms. A two-dimensional axisymmetric transient model is developed and 10 parameters are used to investigate their effects on the performance of an adsorption chiller and to obtain the optimized conditions of a fin-tube type adsorption chiller. Ten parameters found in many other studies, such as fin pitch, fin thickness, fin height, diffusion coefficient, particle size, cycle time, cycle ratio, temperature of hot water, fluid velocity and porosity, are used in this study. Based on the design of experiment, an orthogonal array of 10 parameters with three levels, $L_{27}(3^{13})$ is used for the analysis of variance (ANOVA) and through this method, each parameter's level of contribution is carefully examined. The result shows that fin thickness and the temperature of hot water are the dominant parameters for COP and SCP, respectively. The optimum conditions having the highest COP of 0.6782 and SCP of 217.68 W kg^{-1} are found through the result.

Optimisation d'un refroidisseur à adsorption de type à tubes à ailettes grâce à la conception d'une expérience

Mots clés : Refroidisseur à adsorption ; Optimisation ; Coefficient de performance ; Puissance de refroidissement spécifique ; Analyse de la variance

1. Introduction

Due to global warming and economic development, cooling demand has rapidly increased. However, vapor compression refrigerators using Freon gas have many problems, including the need for an excessive electric power supply and their contribution to the destruction of the environment. Therefore, many studies have focused on the development of eco-friendly refrigeration systems driven by heat rather than electricity (e.g., Chung et al., 2009; Chung and Lee, 2009, 2011; Kiplagat et al., 2012; Uddin et al., 2013; Ishugah et al., 2014; Hong et al., 2014).

An adsorption refrigerator is a promising cooling device and also an eco-friendly refrigeration system driven by a low-grade waste heat (60 °C–90 °C). Two adsorption beds are usually used in the adsorption refrigeration system. In the

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Nomenclature

C_p	Specific heat in constant pressure, J kg^{-1} K^{-1}
COP	Coefficient of performance, -
D	Diffusion coefficient, m^2 s^{-1}
D_i	Inner tube diameter, mm
d_p	Particle diameter, mm
e	Error, -
F	F validation, -
F_0	Ratio of mean squares of factor i to error, -
ΔH	Latent heat, J kg^{-1}
h	Convection coefficient, W m^{-2} K^{-1}
K	Permeability, m^2
L_0	Fin length, mm
M_{ads}	Mass of adsorbent, kg
Nu	Nusselt number, -
Pr	Prandtl number, -
Q	Heat transmitted, J
q	Water uptake, kg kg^{-1}
q^*	Equilibrium water uptake, kg kg^{-1}
q_{ave}	Mean water uptake, kg kg^{-1}
R	Radial distance from center of fluid, mm
R_i	Inner tube diameter, mm
R_m	Outer tube diameter, mm
Re	Reynolds number, -
r	Radial distance from center of particle, mm
S	Mean of squares, -
T	Temperature, K
t	Time, s
V	Variance, -
Z	Axial distance, mm
Z_0	Fin pitch, mm

Greeks

α	Thermal diffusivity, m^2 s^{-1}
ε	Total porosity, -
ρ	Level of contribution, - or Density, kg m^{-3}
ρ_0	Density per unit pressure, kg m^{-3} Pa^{-1}
μ	Viscosity, N s m^{-2}
φ	Degree of freedom, — or Relative pressure, -

Subscript

0	Initial state
A	Adsorbent
ads	Adsorption process
ave	Average
B	Adsorption bed
C	Copper
cycle	Cycle
con	Condenser
des	Desorption process
eva	Evaporator
f	Fluid
H	High
i	Inner
L	Low
M	Medium
o	Outer
P	Particle
v	Vapor
w	Water

adsorption process, cooling water at room temperature is used, and in the desorption process, low-grade heat such as solar energy, local heating, exhaust heat from an engine or discarded waste heat are frequently used. Consecutive cold energy can be obtained by switching the cooling and heating water from one adsorption bed to another. During this process, reversible exothermic and endothermic reaction processes occur on the adsorbent/adsorbate pairs in the adsorption bed. Therefore, removing the heat obtained from the adsorption beds during the adsorption process and improving the heat and mass transfer amount in the adsorption beds during the desorption process are crucial to the performance of the entire adsorption refrigeration system.

The wide spread use of this technology is not yet possible due to relatively low performance and large size compared to other refrigeration systems. Thus, many studies have been focused on improving system performance, especially the performance of adsorption beds, which is the most crucial component of the adsorption cooling system. COP (coefficient of performance) and SCP (specific cooling power) are commonly adopted as the indices of the performance. Li et al. (2004) considered a two-dimensional numerical model of a fin-tube type adsorber to determine the effects of fin pitch and fin height on the performance of an adsorption bed. Leong and Liu (2004) studied a zeolite/water adsorption chiller to investigate the effects of each parameter, including bed height, adsorbent particle size and porosity. In their study, it was shown that COP increases and SCP decreases as the bed height increases, and the effect of particle size and porosity are relatively small on the performance of an adsorption chiller. Despite the parameters being well investigated, the numerical model they used was for a simple-tube type adsorption chiller, which is difficult to use in practical application. Wang et al. (2005) carefully examined the effects of various parameters including cycle time, heat and mass recovery time and heating and cooling water temperature, however they used equilibrium model as intra-particle mass transfer equation, which may leads to serious error when estimating the performance of adsorption chiller. Kubota et al.'s research (2008) investigated the effect of certain parameters including hot water temperature, switching time and cycle time based on the optimized condition of adsorption chiller they found in their precious research. They found that switching time has negligible effect on COP and also COP slightly increases with increasing hot water temperature. However, COP obtained in their research is too low and the effects of significant parameters on SCP was not examined. Zhang and Wang (1999) developed a transient three-dimensional numerical model on a plate fin-tube type adsorption chiller to determine the effect of fin height and fin pitch on COP and SCP, respectively. They ascertained that there are optimum fin height and fin pitch ranges with the highest values of COP and SCP. Saha