Analytical Model For Sorber Bed Heat Exchangers Of Sorption Cooling Systems

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Summary: A new 2-D analytical solution is presented and validated using the data collected from our custom-built gravimetric large pressure jump test bed and two-sorber bed sorption test bed. The proposed closed-form 2-D transient solution includes all salient thermophysical and sorption properties, heat exchanger geometry, and operational conditions as well as the thermal contact resistance at the interface in sorber beds. It is shown that the optimum amount of thermally conductive additive in the sorbent depends on the geometrical and heat transfer characteristics of the sorber bed and the cycle time. Furthermore, it is shown that the sorber bed geometry, heat transfer characteristics, sorption composite composition and cycle time can have conflicting effects on specific cooling power and coefficient of performance and should be optimized simultaneously to establish an optimal design.

Keywords: Analytical modelling; coefficient of performance; sorption cooling systems; specific cooling power.

Introduction

A promising alternative to the conventional vapor compression refrigeration (VCR) system is sorption cooling system (SCS) in which sorber bed replace the compressors and low-grade thermal energy, is used to regenerate the sorber beds. Currently, the following challenges impede the widespread commercialization of SCS [1]: i) low specific cooling power (SCP), resulting from the poor heat transfer, and thus mass transfer, in sorber beds; ii) low coefficient of performance (COP) compared to VCR, due to the high thermal inertia of the sorber bed heat exchangers (HEX). To address these issues, sorber bed heat exchangers should be specifically designed and optimized. In this paper, we propose a new mathematical model for design and optimization of the sorber beds.

Method and Results

Finned-tube heat exchanger (HEX) is selected as the sorber bed type due to its relatively high SCP and COP [2]. The solution domain of the HEX, shown in Figure 1, can be used to predict the performance of the entire sorber bed. The following is the list of the assumptions used in the development of the present model: i) the heat transfer fluid is assumed to have a constant temperature along the solution domain; justifiable due to the relatively higher heat capacity of the heat transfer fluid [1]; ii) the boundaries of the sorbent and the fin, which are in contact with low-pressure refrigerant vapor, are assumed adiabatic. This is a fair hypothesis since the Biot number is low; iii) thermophysical properties of the sorbent and HEX are assumed constant. Averaged values over the range of operating conditions are used; iv) the convection term in the energy equation, which accounts for the sorbate convection inside the sorbent coating, is assumed negligible as the Peclet number, which represents the ratio of the convection to the diffusion term in the energy equation, is small [1]; v) the sorbent coated on the tube in the gap between the sorbent coatings on the fins, i.e. t_{fs} shown in Figure 1, is neglected as t_{fs} is much smaller than the fin height; vi) the pressure in the sorber bed was assumed uniform. Using the above-mentioned assumptions, the energy equation for the sorbent layer and the fin in Cartesian coordinates can be written as follows.

$$\frac{\partial T_i}{\partial t}=\alpha_{i,x}\frac{\partial^2 T_i}{\partial x^2}+\alpha_{i,y}\frac{\partial^2 T_i}{\partial y^2}+\frac{1}{\left(\rho c_p\right)_i}G_i(t),G_i\left(t\right)=\begin{cases}\rho_s h_{ads}\dfrac{d\omega}{dt}, & i=s\\ 0, & i=f\end{cases} \tag{1}$$

where, T is the temperature (K), α is the thermal diffusivity (m^2/s), ρ is the density (kg/m^3), c_p is the specific heat (J/kg K), ω is the water uptake (g/g). Governing energy equations were solved in the sorbent and HEX using the Eigenfunction Expansion Method [3]. The closed form of the dimensionless temperature is obtained as a series as follows.

$$\theta(\eta,\xi,Fo)=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}X_n(\eta)\psi_{nm}(\xi)\Gamma_{nm}(Fo),\ \theta=\frac{T-T_{fluid}}{T_0-T_{fluid}},\ \xi=\frac{y}{t_s+t_f},\ \eta=\frac{x}{b} \tag{2}$$

In Eq. (2) θ is dimensionless temperature, X and ψ are the spatial eigenfunctions in η and ξ directions, respectively, Γ is the temporal eigenfunction and Fo is dimensionless time. Our study indicates that the first 2 terms of the eigenfunction X (n=1 and 2) and one term of the eigenfunction ψ (m=1) yield an accuracy of 99% in the temperature calculation. Each run takes about 1.5 min on a 3.4 GHz PC, which is important for sorber bed optimization, which requires a large number of function evaluations.

A parametric study was conducted to investigate the effect of geometrical and heat transfer characteristics of the sorber beds including: fin height, fin thickness, sorbent thickness, fluid channel height, graphite flake content in the sorbent, and cycle time on SCP and COP of the sorber beds. It was found that sorber bed geometry, heat transfer characteristics of sorber beds and cycle time have counteracting effects on SCP and COP. Figure 2 shows this conflicting effect of graphite flake content in the sorbent. As such there is an optimum graphite flake content for SCP and COP since adding graphite flakes to the sorbent enhances its thermal diffusivity and reduces the active material fraction.

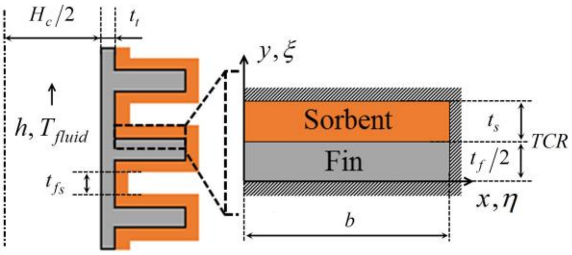

Figure 1. The solution domain for finned-tube sorber bed heat exchangers

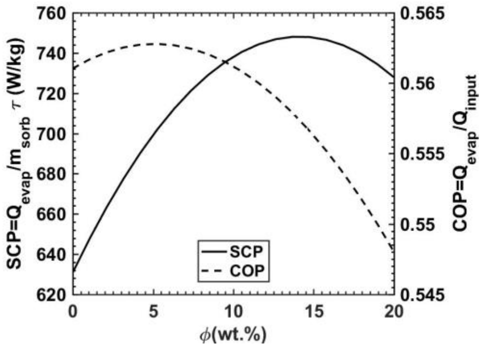

Figure 2. Variation of SCP and COP with graphite flake content in the sorbent, cycle time is 15 min

Conclusions

A novel accurate analytical closed-form solution was developed. The present analytical model provides a reliable and easy-to-use design and optimization tool for sorber bed heat exchangers of SCS.

References

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