

Numerical investigation of coupled heat and mass transfer inside the adsorbent bed of an adsorption cooling unit

İsmail Solmuş ^{a,*,1,2}, D. Andrew S. Rees ^b, Cemil Yamalı ^a, Derek Baker ^a, Bilgin Kaftanoğlu ^c

^a Department of Mechanical Engineering, Middle East Technical University, 06531 Ankara, Turkey

^b Department of Mechanical Engineering, University of Bath, Claverton Down, Bath BA2 7AY, UK

^c Department of Manufacturing Engineering, Atılım University, 06836 Ankara, Turkey

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ABSTRACT

In this study, the influence of several design parameters on the transient distributions of temperature, pressure and amount adsorbed in the radial direction of a cylindrical adsorbent bed of an adsorption cooling unit using silica gel/water have been investigated numerically. For this purpose, a transient one-dimensional local thermal non-equilibrium model that accounts for both internal and external mass transfer resistances has been developed using the local volume averaging method. For the conditions investigated, the validity of the local thermal equilibrium and spatially isobaric bed assumptions have been confirmed. To improve the performance of the bed considered, efforts should be focused on reducing heat transfer resistances and intra-particle (interior) mass transfer resistances but not inter-particle (exterior) mass transfer resistances.

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Etude numérique sur le transfert de chaleur et de masse à l'intérieur du lit absorbant d'un système de refroidissement à adsorption

Mots clés : Adsorption ; Adsorbant ; Refroidissement ; Gel de silice

1. Introduction

Thermally driven adsorption chillers (TDAC) have received much attention in the recent years since they are environmentally friendly and can be operated with low-grade heat sources such as solar energy or waste heat. However, these systems are not competitive with electrically-driven refrigeration systems due to their high investment costs and low coefficient of performance. Therefore, extensive efforts have been exerted by researchers to improve their

^{*} Corresponding author. Tel.: +90 3122102563; fax: +90 3122102536. E-mail address: solmus@metu.edu.tr (İ. Solmuş).

¹ Currently, visiting researcher at the Department of Mechanical Engineering, University of Bath, Claverton Down, Bath BA2 7AY, U.K.

² On leave of absence from Department of Mechanical Engineering, Atatürk University, 25240 Erzurum, Turkey.

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Nomenclature	R universal gas constant, J mol $^{-1}$ K $^{-1}$
a specific surface area m^{-1}	Re _d Reynolds number
$c_{\rm best conscitut} I k a^{-1} K^{-1}$	$ m R_g$ specific gas constant for water vapor, J kg $^{-1}$ K $^{-1}$
D equivalent diffusivity in the adsorbent particles	r _i inner diameter of the adsorbent bed, m
D_e equivalent unrusivity in the adsorbent particles, $m^2 e^{-1}$	r _o outer diameter of the adsorbent bed, m
III 5 diffusivity of a description and $m^2 e^{-1}$	r _p radius of the adsorbent particle, m
D_g diffusivity of adsorbate gas, in s	T temperature, K
D_k Kilduseli diffusivity, ili S	t time, s
$D_{\rm m}$ molecular amusivity, m s	v_r velocity, m s ⁻¹
D_0 Telefence uniusivity, in s	X adsorption capacity, kg _w kg _{ad} ⁻¹
d_{pore} average pore diameter, m	X_{∞} amount adsorbed at equilibrium state, $kg_w kg_{ad}^{-1}$
E_a activation energy of surface diffusion, J mol ⁻¹	Greek symbols
h_{gs} interfacial heat transfer coefficient, W m ⁻² K ⁻¹	η dynamic viscosity, N m ⁻²
K_a apparent permeability, m ²	ho density, kg m ⁻³
K _d real permeability, m ²	$\epsilon_{\rm t}$ total porosity
K _E inertial term, m	ε_b bed porosity
K_{g_e} effective thermal conductivity for the gas phase,	ε_p particle porosity
$W m^{-1} K^{-1}$	τ tortuosity
K_{s_e} effective thermal conductivity for the solid phase,	σ collision diameter for Lennard-Jones potential
${ m W}~{ m m}^{-1}~{ m K}^{-1}$	Ω collision integral
k_m mass transfer coefficient within the adsorbent	Subscripts
particles, s ⁻¹	b boundary
k thermal conductivity, W m ⁻¹ K ⁻¹	c condenser
<i>m</i> rate of refrigerant adsorbed unit control volume,	ev evaporator
$kg_w m^{-3} s^{-1}$	a gas phase
M molar mass, kg mol ⁻¹	h regeneration
Nu _d Nusselt number	i initial
P pressure, Pa	s solid phase
Pr Prandtl number	sat saturation
Q heat of adsorption, J Kg_w^{-1}	

coefficient of performance and make them commercially viable.

The successful operation of a TDAC system depends strongly on the performance of its adsorbent bed filled with a porous material. The performance of an adsorbent bed is affected adversely by the heat and mass transfer limitations inside the bed, such as poor thermal conductivity of the solid adsorbent, and internal (intra-particle) and external (interparticle) mass transfer resistances. The internal and external mass transfer resistances are as the respective adsorbate gas flows inside the solid adsorbent particle and through the voids between the solid adsorbent particles. Over the past several decades, many researchers have proposed various mathematical models to investigate the heat or coupled heat and mass transfer mechanism inside the adsorbent beds of TDAC systems (Chahbani et al., 2002, 2004; Dai and Sumathy, 2003; Demir et al., 2009; Leong and Liu, 2004; Li and Wang, 2003; Maggio et al., 2006; Marletta et al., 2002; Mhimid, 1998; Wu et al., 2009; Zhang and Wang, 1999; Zhang, 2000). In these models, the equations have been developed for the heat transfer within a porous medium typically assuming a mobile gas (vapor) phase, an immobile solid phase (adsorbed adsorbate + adsorbent), and local thermal equilibrium between the gas and solid phases; the sole exception is the paper by Mhimid (1998). In the proposed conservation of mass equations, the mass transfer resistance within the solid adsorbent particles was typically accounted for and the internal mass transfer rate between the solid adsorbent and adsorbate gas phases (including sorption processes) was calculated using the solid diffusion (Chahbani et al., 2002) or linear driving force (Chahbani et al., 2002, 2004; Dai and Sumathy, 2003; Demir et al., 2009; Leong and Liu, 2004; Li and Wang, 2003; Maggio et al., 2006; Marletta et al., 2002; Mhimid, 1998; Wu et al., 2009; Zhang and Wang, 1999; Zhang, 2000) model. Darcy's law has been used widely to account for the external mass transfer through the voids between the solid adsorbent particles by convection (Dai and Sumathy, 2003; Demir et al., 2009; Leong and Liu, 2004; Mhimid, 1998; Wu et al., 2009; Zhang and Wang, 1999; Zhang, 2000). Additionally, in two instances the adsorbate gas velocity through the adsorbent bed was determined using Ergun's equation which includes inertial effects (Maggio et al., 2006; Marletta et al., 2002). On the other hand, in some previous studies, the pressure across the bed was assumed to be uniform as a result of a high permeability within the bed or the use of a high working-pressure refrigerant like ammonia (Chahbani et al., 2002, 2004; Li and Wang, 2003). Most of the previous studies, i.e. (Leong and Liu, 2004; Wu et al., 2009; Zhang and Wang, 1999; Zhang, 2000) and (Chahbani et al., 2002, 2004; Dai and Sumathy, 2003; Li and Wang, 2003; Maggio et al., 2006; Marletta et al., 2002), focused mainly on the effect of the heat and mass transfer limitations on the performance of the adsorption cooling systems in terms of COP and SCP, and only a two of studies, specifically (Demir et al., 2009) and (Mhimid,

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