Applied Thermal Engineering 104 (2016) 386–393

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

The effect of fin design parameters on the heat transfer enhancement in the adsorbent bed of a thermal wave cycle

Ahmet Çağlar

Department of Mechanical Engineering, Akdeniz University, 07058 Antalya, Turkey

HIGHLIGHTS

- A transient analysis for 2D coupled heat and mass transfer model is carried out.
- A comparison between the adsorbent beds with finned- and finless-tube is performed.
- The effect of various fin configurations on the heat transfer is investigated.
- Results are presented in multicoloured plots in 2D domains.

ARTICLE INFO

Article history:
Received 15 November 2015
Revised 14 April 2016
Accepted 15 May 2016
Available online 17 May 2016

Keywords:
Thermal wave
Adsorbent bed
Heat transfer
Fin
Silica gel

ABSTRACT

A 2D coupled heat and mass transfer model is used to analyze both finless and finned tube-type adsorbent bed for a thermal wave adsorption cooling cycle. A comparison between the finless and finned tube adsorbent beds is made in terms of heat transfer inside the bed. A significant enhancement in the heat transfer is obtained using a finned tube such that the temperature of the adsorbent in the finned tube adsorbent bed is at most 47.8 K higher than that in the unfinned tube adsorbent bed. The effect of fin design parameters on the heat transfer inside the bed is also investigated using four different fin configurations. Defining a base-case for the fin geometry, fin thickness, fin radius and number of fins are increased. Increasing the fin thickness double increases temperatures only by 2–3 K and has not a significant effect on the heat transfer. Increasing the fin radius decreases temperatures by 10–17 K while increasing the number of fins enhances the heat transfer significantly. Results are presented in multicoloured plots in 2D domains. The working pair used in the simulations is white silica gel–water.

1. Introduction

Adsorption cooling technology being a heat driven system can be a sustainable solution as it can use waste or solar energy instead of electricity. There are many researches on adsorption cooling cycles [1–5]. Basic adsorption cooling cycles have a single adsorbent bed and hence intermittent operation and no thermal regeneration. Thermal wave cycles, which have at least two beds, are both continuous and regenerative. In thermal wave cycles, heat and mass recovery are used to increase specific cooling power (SCP) and coefficient of performance (COP).

There are several studies on thermal wave cycles. Lambert [6] modelled a new design solar powered thermal wave adsorption heat pump by combining a robust shell-and-tube configuration with the other heat exchanger components. Taylan et al. [7] modelled a thermal wave cycle without mass recovery, with isothermal mass recovery and with adiabatic mass recovery. Çağlar et al. performed a two dimensional coupled heat and mass transfer analysis of finned [8] and finless [9] adsorbent bed of a thermal wave cycle. Sward et al. [10] obtained the asymptotic maximum possible performance for a thermal wave cycle by using the local equilibrium assumption. Critoph [11] proposed the first convective thermal wave adsorption cycle that achieves heat transfer enhancement by storing heat between adsorption and desorption phases in a packed bed of inert material. Tierney [12] investigated theoretically the effects of heat capacity and thermal conductivity of both refrigerant and adsorbent bed on SCP and COP study in convective thermal wave cycles. Sun and Chakraborty [13] proposed new insights into the adsorption kinetics providing an explanation for calculating the rate of water vapour uptakes on various silica gel layers in the design of adsorption beds.

Researchers on thermal wave cycles are generally focused on the heat and mass transfer improvements in the adsorbent bed of the cycle as heat and mass transfer inside the bed dominantly

E-mail address: acaglar@akdeniz.edu.tr

http://dx.doi.org/10.1016/j.applthermaleng.2016.05.092
1359-4311/

Nomenclature

A_i	HTF tube inner surface area, m^2
A_o	HTF tube outer surface area, m^2
b	HTF tube thickness, m
c	specific heat, J/(kg K)
d	fin distance, m
D_o	reference diffusivity, m^2/s
E_a	activation energy of surface diffusion, J/mol
h_i	convective heat transfer coefficient between tube and fluid, $W/(m^2\,K)$
h_o	wall heat transfer coefficient between tube and adsorbent, $W/(m^2\,K)$
k	thermal conductivity, W/(m K)
P	pressure, Pa
r	radius, m
R	universal gas constant, J/(mol K)
R_v	ideal gas constant for water vapour, J/(kg K)
t	time, s
T	temperature, K
$\mathbf{u}$	vapour velocity vector, m/s
X	amount of water vapour adsorbed by adsorbent per unit mass of adsorbent, kg_w/kg_s
v_f	HTF velocity, m/s
V	volume, m^3

Greek symbols

ε	total porosity
κ	permeability, m^2
μ	dynamic viscosity, kg/(m s)
ρ	density, kg/m^3

Subscripts

c	condenser
e	equilibrium
f	heat transfer fluid
l	liquid
p	particle
s	(solid) adsorbent
sat	saturation
t	tube
v	vapour

influences the system performance. A significant increase in COP can be obtained when the enhancement of heat transfer, and mass transfer to a certain extent, is achieved. In the literature, several studies were conducted to solve poor heat and mass transfer problems. Methods used to solve these problems can be broadly categorized into two types: adsorbent bed design and adsorbent material improvement. Adsorbent bed design includes extended surfaces, coated beds and heat pipe technology while adsorbent material improvement includes using additives and consolidated bed. The effects of several design and operating parameters including cycle time, adsorber radius, heating temperature, permeability and heat transfer parameters on COP and SCP for a straight tube adsorber in the case of both axial and radial gas flow were investigated by Amar et al. [14] using two different adsorbent/refrigerant pairs. A two-dimensional model to analyze axial heat transfer in the fluid and radial heat conduction in the adsorbent bed of a thermal wave cycle was used by Sun et al. [15]. Chakraborty et al. [16] presented both the steady-state and dynamic behaviours of silica gel with various sizes and layers in a two-bed solid sorption cooling system using a transient distributed model.

In thermal wave cycles, the most important parameter affecting the thermal regeneration and performance of the cycle is thermal wave structure. Thermal wave is a temperature front formed in the adsorbent bed and be expected to be straight in radial direction for a cylindrical bed geometry progressing together with the heat transfer fluid. Shelton et al. [17,18] first described that thermal wave length should be as short as possible to maximize the thermal regeneration between two beds. To obtain a straight temperature front and maximum thermal regeneration, heat transferred from the heat transfer fluid to the adsorbent material inside the adsorbent bed of thermal wave cycles should be maximized. The methods used to achieve these objectives can be categorized as the improvement of adsorbent bed design and the improvement of adsorbent material. In this research, the method of extended surfaces which is in the category of the adsorbent bed design is used. The heat transfer from/to heat transfer fluid to/from adsorbent material is improved by extended surfaces using fins. The effect of fin design parameters such as fin thickness and fin length on the heat transfer inside the bed is investigated. On the other hand, 1D models are generally used to solve the poor heat transfer and uneven thermal wave problems in the literature. Moreover, a few studies based on a 2D model explores only operating parameters and have no presentation in a 2D domain. There is a gap in 2D post-processing of the heat transfer inside the adsorbent bed changing the design parameters. The 2D coupled heat and mass transfer model investigating the effect of fin design is the novelty of the present study. Furthermore, results are presented with multicoloured plots in 2D domains. This enables researchers to see the changes in heat transfer and thermal wave inside the bed readily. The comparison between finned and finless bed is also presented in this study.

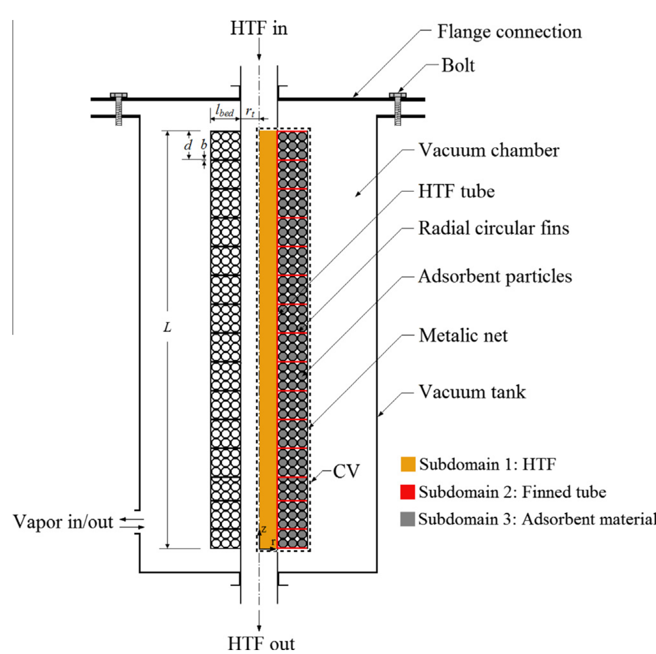

Fig. 1. Finned tube adsorbent bed in the vacuum chamber.