Heat transfer in fluidized and fixed beds of adsorption chillers

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Abstract. An innovative idea, shown in the paper constitutes in the use of the fluidized bed of sorbent, instead of the conventional, fixed-bed, commonly used in the adsorption chillers. Bed-to-wall heat transfer coefficients for fixed and fluidized beds of adsorbent are determined. Sorbent particles diameters and velocities of fluidizing gas are discussed in the study. The calculations confirmed, that the bed-to-wall heat transfer coefficient in the fluidized bed of adsorbent is much higher than that in a conventional bed..

Nomenclature

c   constant representing the mixing of gas in the vicinity of wall, -
C   specific heat capacity, J kg^{-1} K^{-1}
U   heat transfer coefficient, W m^{-2} ^{K}-1

Subscripts
b   bed
bub   bubble
e   effective
fl   fluidized bed
fx   fixed bed
g   gas
mf   at minimum fluidizing conditions
s   solid
w   wall region

Superscripts
0   for stagnant gas conditions

Greek Symbols
δ fraction of bed in bubbles, -
ε void fraction in a bed at minimum fluidizing conditions, -
λ thermal conductivity, W m^{-1} K^{-1}
ρ density, kg m^{-3}
v_b velocity of a bubble rising through a bed, m s^{-1}
v_0 superficial gas velocity, m s^{-1}

Acronyms
AC   Adsorption Chiller

1 Introduction

The main disadvantages of conventional fixed-bed adsorption chillers are low coefficients of performance (COP) [1–4].

One of the well-known method, allowing to improve the heat transfer coefficient between the bed and the immersed heating surface, widely used in energy boilers, is using fluidized bed [5–15]. A similar idea appears concerning to adsorption chillers [1,2,16]. Wang et al. [17] proposed to use a fluidized – bed adsorber/desorber for the adsorption refrigeration system. The authors pointed out that the fluidized adsorbent can enhance the heat and mass transfer, leading to the increase the specific cooling power.

A periodic operating silica gel fluidized bed unit to adsorb/desorb moisture in air-conditioning systems was proposed by Chen et al. [18] The authors reported possibility to increase the adsorption and desorption processes in that the fluidized bed system compared with the unit equipped with a packed bed.

An inclined-fluidized bed in the adsorption and desorption operations was carried out by Hamed [19]. Rogala et al. considered air-fluidized systems developing a method for the prediction of silica gel-water adsorption [20].

The objective of the paper is to study the wall-to-bed heat transfer coefficient in fluidized and fixed beds of adsorption chillers.

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2 Material and methods

The re-heat two-stage adsorption chiller (AC) was considered in the study. This AC comprises of four adsorbent beds, evaporator, and condenser [21,22]. Silica gel and water stand for a working pair. The scheme of the adsorption chiller is shown in Fig. 1.
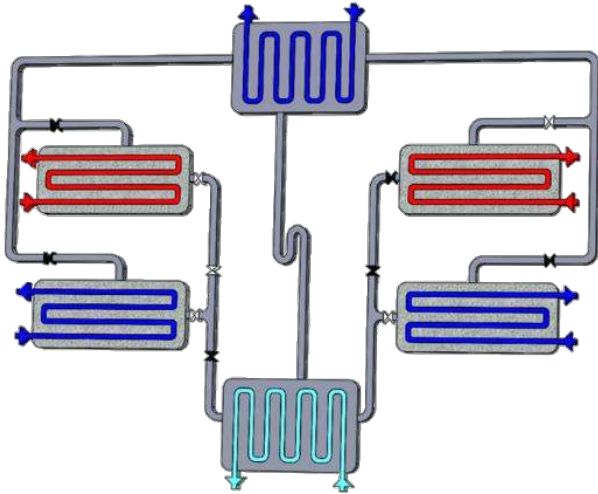

Fig. 1. The re-heat two-stage adsorption chiller.

The operational parameters of the chiller in standard operating conditions are as follows: flow rates of hot and cooling water in the adsorber: 0.5 kg s^{-1}, temperatures of cooling and chilled water: 30 °C and 14 °C, respectively. Further details of the chiller can be found elsewhere [21,22]. Three different materials are considered during the study: silica-gel, zeolite, and carbon nanotubes. According to Kunii and Levenspiel (1991) a heat transfer coefficient for the wall region with flowing gas and the fixed bed can be described as follows:

$$U_{fx} = U_w^0 + c_w(C_g \rho_g v_0) =$$

$$= \frac{2\lambda_{ew}^0}{d_p} + c_w(C_g \rho_g v_0) \qquad (1)$$

where: $c_w = 0.05$.

The heat transfer coefficient between the heat exchanger surface and a fluidized bed can be written, as follows [23]:

$$U_{fl} = \frac{1-\delta}{\dfrac{1}{U_{fx}} + 1.13\left[\lambda_e^0 \rho_s \left(1-\varepsilon_{mf}\right) C_s n_w / \left(1-\delta_w\right)\right]^{0.5}} \qquad (2)$$

where:

$$\delta = \frac{v_0 - v_{mf}}{v_b - v_{mf}},$$

$$v_b = 0.711\left(g d_{bub}\right)^{0.5}$$

Taking into account the above equations, we can assess heat transfer coefficients in the wall region of fixed and fluidized bed with flowing gas, i.e. water vapor as an adsorbate, U_{fx}, and U_{fl}, respectively.

3 Results and discussion

The influence of superficial gas velocity on heat transfer for fixed and fluidized bed of silica gel, zeolite, and carbon nanotubes are given in Table 1.

The obtained results reveal, that the bed-to-wall heat transfer coefficient during fluidization is much higher than the one for a fixed bed.

The influence of superficial gas velocity on bed-to-wall heat transfer coefficient for different shares of carbon nanotubes in the bed of silica gel particles is given in Table 2.

Similar calculations are performed for a mixture of zeolite and carbon nanotubes. The obtained data can be found in Table 3.

As it can be seen from the tables, even a small amount of carbon nanoparticles significantly improve the bed-to-wall heat transfer coefficient for both and fluidized bed.

4 Conclusions

Fixed and bubbling fluidized bed conditions are considered in the paper. The model allows conducting a numerical study and describes the behaviour of heat transfer in the fixed and fluidized bed for a wide range of operational sceneries.

The proposed design concept allows significantly increase the heat transfer coefficient between adsorption bed and the surface of a heat exchanger as well as the bed conductance.

The use of a fluidized bed will help improve the coefficient of performance and cooling capacity of the chiller.

Table 1. Heat transfer coefficients for basic solids.

v_0	$d = 50\ \mu m$		$d = 100\ \mu m$		$d = 150\ \mu m$	
	U_{fx}	U_{fl}	U_{fx}	U_{fl}	U_{fx}	U_{fl}
Carbon nanotubes						
m s^{-1}			W m^{-2} K^{-1}			
0.030	126.36	478.07	63.19	463.35	42.14	453.93
0.100	126.45	554.02	63.28	526.12	42.22	509.43
0.500	126.93	372.89	63.77	297.52	42.71	262.65
Silica gel						
m s^{-1}			W m^{-2} K^{-1}			
0.030	21.81	341.44	10.92	305.59	7.29	280.89
0.100	21.89	377.06	11.01	327.29	7.38	294.37
0.500	22.38	175.31	11.49	128.12	7.87	103.99
Zeolite						
m s^{-1}			W m^{-2} K^{-1}			
0.030	13.69	280.18	6.87	243.09	4.59	219.05
0.100	13.78	305.42	6.95	255.86	4.68	225.17
0.500	14.26	131.53	7.44	92.35	5.16	73.53

Table 2. Heat transfer coefficients for silica gel and carbon nanotubes particles.

v_0	$d = 50\ \mu m$		$d = 100\ \mu m$		$d = 150\ \mu m$	
	U_{fx}	U_{fl}	U_{fx}	U_{fl}	U_{fx}	U_{fl}
Silica gel (90%) wt. and carbon nanotubes 10% (wt.)						
m s^{-1}			W m^{-2} K^{-1}			
0.030	55.41	580.99	27.72	539.33	18.49	509.95
0.100	55.49	651.70	27.80	590.11	18.58	547.99
0.500	55.98	336.42	28.29	258.72	19.06	217.34
Silica gel (80%) wt. and carbon nanotubes 20% (wt.)						
m s^{-1}			W m^{-2} K^{-1}			
0.030	60.90	617.72	30.47	574.47	20.32	543.59
0.100	60.99	693.68	30.55	629.50	20.41	585.16
0.500	61.47	361.06	31.04	278.42	20.89	234.18

Table 3. Heat transfer coefficients for zeolite and carbon nanotubes particles.

v_0	$d = 50\ \mu m$		$d = 100\ \mu m$		$d = 150\ \mu m$	
	U_{fx}	U_{fl}	U_{fx}	U_{fl}	U_{fx}	U_{fl}
Zeolite (90%) wt. and carbon nanotubes 10% (wt.)						
m s^{-1}			W m^{-2} K^{-1}			
0.030	55.41	619.21	27.72	573.01	18.49	541.49
0.100	55.49	693.03	27.80	625.14	18.58	579.94
0.500	55.98	352.03	28.29	269.40	19.06	226.03
Zeolite (80%) wt. and carbon nanotubes 20% (wt.)						
m s^{-1}			W m^{-2} K^{-1}			
0.030	60.90	651.35	30.47	604.17	20.32	571.34
0.100	60.99	730.11	30.55	660.48	20.41	613.35
0.500	61.47	374.99	31.04	288.01	20.89	241.94

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