

Study of Heat Convective Transfer for a Fixed Bed of Ring Particles

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Heat transfer in fixed bed of particles depends on many factors, most important of which are physical properties of solid particles and fluid which crosses the layer, the geometry of system and operating conditions. In the present paper is presented a study on heat transfer by convection in a fixed layer of ring particles, made of ceramic material, with geometric characteristics well defined by the ratio $H/D = 1.12$ mm through which is circulating a heat carrier - the water, situated in a heat exchanger with coaxial tubes. Sought to establish a relationship criteria for calculating the partial coefficient of heat transfer fluid - solid particles by convection, which express the dependence of fluid physical properties and geometrical sizes of particles used.

Keywords: ring particles, partial coefficient of heat transfer, convection, heat exchanger with coaxial tubes

In petrochemical and oil processing units are frequently used beds of particles for catalytic processes, combustion processes and mass and heat transfer. The purpose of the present paper has been to develop a further study regarding heat transfer in fixed bed of particles based on a previous research [1]. Opportunity of this paper is the fact that the literature provides information mainly for the fluidized bed of particles [2, 3]. For fixed bed of particles, most investigations provide only the criteria equations and there are not always specified strict application fields [4-7].

Since is permanent to improve heat transfer and this is achieved by replacing and filling materials for this study were chosen the ring particles with the ratio $H/D = 10.3/9.2$ mm, made of ceramic material, without taking into account the chemical reactions that occur.

The study was conducted on a heat exchanger with coaxial tube with a length of 1 m and outer diameters of the tubes: $D_e = 76$ mm for the large tube and $d_e = 33$ mm for the small tube. Wall thickness of both tubes was 3.5 mm. This heat exchanger is made of steel.

Experimental part

These experimental examinations were carried out in an own design installation, shown in figure 1, in which the main element is a heat exchanger tube with coaxial tubes.

In addition to the main equipment, heat exchanger, the scheme also includes:

- a furnace for heating heat carrier which crosses the bed of solid particles, which provides a variation range in the temperature field (52 - 88) °C; the feed furnace was made with the fuel gas network;

- two rotameters with floating measuring fluid flow : for hot water to the exchanger and cold water in the annular space of heat exchanger;

- electronic thermometers at the entrance and exit of the exchanger for measuring the flow temperatures.

Ring particles used in the study were placed in the tube inside the heat exchanger through which was circulated a stream of circulating hot water, and in reverse current, was circulated a stream of cold water through the annular space of the heat exchanger.

In table 1 is presented geometrical characteristics of the ring particles used.

The flow rates for the two streams (hot and cold) and temperatures were measured for both the inlet and outlet of the heat exchanger. All physical properties of water (density, dynamic viscosity, specific heat, thermal conductivity) were calculated at the average temperature for processing the data in criteria form.

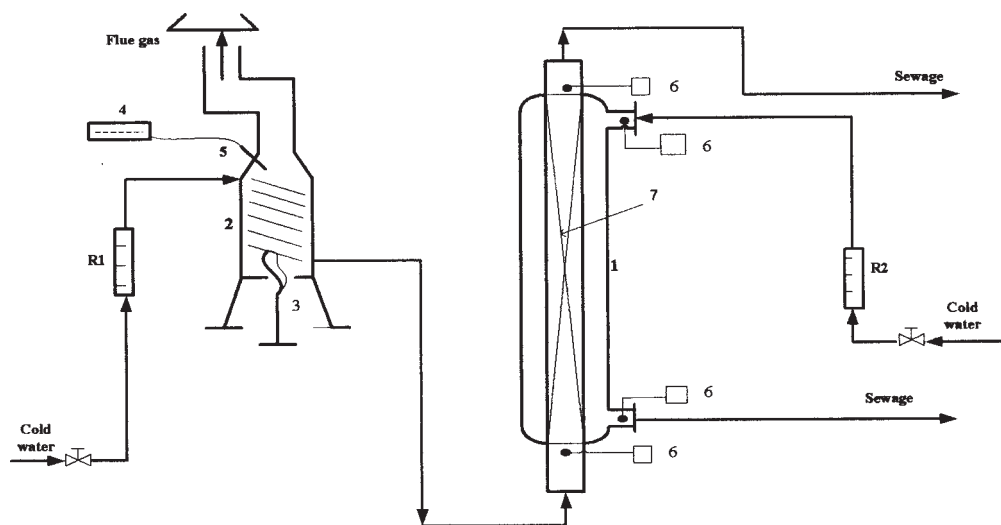


Fig. 1. Experimental scheme: 1 - Heat exchanger, R1, R2 – rotameters; 2 - furnace, 3 - gas nozzle, 4 - temperature recorder; 5 - thermocouple; 6 - electronic thermometers; 7 - bed of ring particles

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Geometrical characteristics	Symbol	Value
Height, mm	H	10.3
Outside diameter, mm	D _e	9.2
Inside diameter, mm	d _i	5.8
Particle area·10 ⁶ , m ²	A = a _p	565.5
Particle volume· 10 ⁸ , m ³	v _p	41.2
Surface of specific particle, m ² /m ³	$a = \frac{a_p}{v_p}$	1371
Equivalent volume diameter· 10 ³ , m	$d_0 = 1,24 \cdot v_p^{1/3} d_0$	9.23
Spherical shape	$\psi = 4,84 \cdot \frac{v_p^{2/3}}{a_p}$	0.4740
Diameter equivalent layer·10 ³ , m	d _{ech}	1.48
Porosity	ε	0.337
Surface of specific filling, m ² /m ³	$\sigma = a \cdot (1 - \varepsilon)$	909

Table 1
GEOMETRICAL CHARACTERISTICS OF RING FILLING USED [9]

Algorithm for calculating

Algorithm for calculating the optimal correlating experimental data is presented below.

Calculation of partial coefficient of heat transfer for the annular space, through which is circulating the cold water, was made with the relationship criteria (1), which was derived for the heat exchanger shown in the specific conditions of work [8]:

$$Nu_{cold} = 0,543 \cdot Re_{cold}^{0,717} \cdot Pr_{cold}^{0,33} \quad (1)$$

where:

$$Nu_{cold} = \frac{\alpha_e \cdot l_c}{\lambda_{cold}} \quad (2)$$

$$l_c = D_i - d_e \quad (3)$$

$$Re_{cold} = \frac{l_c \cdot w_{cold} \cdot \rho_{cold}}{\mu_{cold}} \quad (4)$$

$$Pr_{cold} = \frac{c_{p,cold} \cdot \mu_{cold}}{\lambda_{cold}} \quad (5)$$

$$w_{cold} = \frac{4 \cdot V_{cold}}{\pi \cdot (D_i^2 - d_e^2)} \quad (6)$$

Knowing the value of Nusselt number relationship criteria (1), is calculated the partial coefficient of heat transfer at the outside, α_e, for the annular space of heat exchanger.

Calculation of the temperature of outside wall with the relationship:

$$t_{pe} = t_r + \frac{Q_{delivery}}{\alpha_e \cdot A_e} \quad (7)$$

where:

$$Q_{delivery} = m_{hot} \cdot c_{p,hot} \cdot \Delta t \quad (8)$$

$$A_e = \pi \cdot d_e \cdot H \quad (9)$$

$$t_r = \frac{t_{r1} + t_{r2}}{2} \quad (10)$$

Table 2
MEASURED VALUES AND VALUES OF PHYSICAL PROPERTIES FLUIDS

No. det.	V _c , l/h	V _r , l/h	tc ₁ , °C	tc ₂ , °C	tr ₁ , °C	tr ₂ , °C	tc, °C	tr, °C	ρ _{tc} , kg/m ³	ρ _{tr} , kg/m ³	λ _{hot} , W/m·°C	λ _{cold} , W/m·°C	c _{p,hot} , J/kg·°C	c _{p,cold} , J/kg·°C	μ _{hot} ·10 ⁶ , kg/m·s	μ _{cold} ·10 ⁶ , kg/m·s
1	90	50	52	38	14	27	45	20.5	990.11	997.57	0.6375	0.5995	4172.7	4182.5	587	988
2	86	50	55	40	14	32	47.5	23	989.1	997.01	0.6407	0.6039	4172.8	4180.6	564	933
3	80	50	59	42	14	36	50.5	25	987.83	996.53	0.6444	0.6074	4173.2	4179.2	540	891
4	69	40	62	44	14	39	53	26.5	986.73	996.14	0.6473	0.6099	4173.8	4178.2	525	861
5	50	51	71	41	14	42	56	28	985.35	995.75	0.6506	0.6124	4174.9	4177.4	510	832
6	75	48	64	45	14	41.5	54.5	27.75	986.05	995.81	0.6490	0.6124	4174.2	4177.51	517	836
7	41	40	88	47	14	52	67.5	33	979.44	994.30	0.6616	0.6204	4181.1	4175	499	744

Table 3
SIZES MEASURED BY THE COLD FLOW

No. det.	$m_{\text{cold}} \cdot 10^3$, kg/s	Δt_r , °C	Q_{receives} , W	$w_{\text{cold}} \cdot 10^3$, m/s	Pr_{cold}	Re_{cold}	Nu_{cold}	α_e , W/m ² ·°C	t_{pe} , °C
1	13.86	13	753	4.82	6.90	175	42	694	40.6
2	13.85	18	1042	4.82	6.46	185	42	713	43
3	13.84	22	1273	4.82	6.13	194	43	728	45.6
4	11.07	25	1156	3.85	5.90	161	37	630	48.2
5	14.11	28	1650	4.91	5.67	212	45	762	49.7
6	13.28	27.5	1525	4.62	5.71	199	43	728	49.4
7	11.05	38	1753	3.85	5.00	185	39	673	60.4

Table 4
SIZES MEASURED BY THE HOT FLOW

No. det.	$m_{\text{hot}} \cdot 10^3$, kg/s	Δt_c , °C	Q_{delivery} , W	$w_{\text{hot}} \cdot 10^3$, m/s	Pr_{hot}	ε	$d_{\text{ech}} \cdot 10^3$, m	Re_{hot}	t_{pi} , °C	α_i , W/m ² ·°C	Nu_{hot}	$Nu_{\text{calc.}}$
1	24.8	14	1446	47.1	3.84	0.337	1.48	350	42	5854	13.62	13.74
2	23.6	15	1479	45.0	3.67	0.337	1.48	347	44	5881	13.61	13.48
3	22.0	17	1557	41.9	3.50	0.337	1.48	337	47	5631	12.96	13.10
4	18.9	18	1421	36.1	3.38	0.337	1.48	299	50	5110	11.71	12.27
5	13.7	30	1714	26.2	3.27	0.337	1.48	222	51	4488	10.62	10.23
6	20.5	19	1629	39.2	3.25	0.337	1.48	329	51	5531	12.73	12.45
7	11.2	41	1912	21.5	3.15	0.337	1.48	185	62	4420	9.91	9.65

Determination inside wall temperature of the hot fluid, t_{pi} , is made with the expression of heat flux transferred by conduction through the simple cylindrical wall and the relationship of calculation is:

$$t_{pi} = t_{pe} + \frac{Q_{\text{delivery}} \cdot \frac{1}{\lambda_{\text{steel}}} \cdot \ln \frac{d_e}{d_i}}{2 \cdot \pi \cdot H} \quad (11)$$

Determination the partial coefficient of heat transfer at inside, α_i , between the hot fluid which crosses the bed of particles and the wall is made with the relationship:

$$\alpha_i = \frac{Q_{\text{delivery}}}{A_i \cdot (t_c - t_{pi})} \quad (12)$$

where:

$$A_i = \pi \cdot d_i \cdot H \quad (13)$$

$$t_c = \frac{t_{c1} + t_{c2}}{2} \quad (14)$$

Setting, based on experimental data, a form of relationship criteria:

$$Nu_{\text{hot}} = C \cdot Re_{\text{hot}}^m \cdot Pr_{\text{hot}}^n \quad (15)$$

where:

$$Nu_{\text{hot}} = \frac{\alpha_i \cdot d_{\text{ech}}}{\lambda_{\text{hot}}} \quad (16)$$

$$Re_{\text{hot}} = \frac{d_{\text{ech}} \cdot w_{\text{hot}} \cdot \rho_{\text{hot}}}{\mu_{\text{hot}}} \quad (17)$$

$$Pr_{\text{hot}} = \frac{c_{p,\text{hot}} \cdot \mu_{\text{hot}}}{\lambda_{\text{hot}}} \quad (18)$$

$$w_{\text{hot}} = \frac{4 \cdot V_{\text{hot}}}{\pi \cdot d_i^2} \quad (19)$$

Results and discussion

Measurements performed and experimental data processing have led to results presented in tables 2-4.

Applying a regression program for the results obtained were established the values of constant C and of the exponents m and n from relation (15):

$$\begin{aligned} C &= 0.624, \\ m &= 0.452, \\ n &= 0.33. \end{aligned}$$

The obtained relationship criteria is:

$$Nu_{hot} = 0,624 \cdot Re_{hot}^{0,452} \cdot Pr_{hot}^{0,33} \quad (20)$$

The relation for the partial coefficient of heat transfer from the inside, α_i , becomes:

$$\alpha_i = 0,624 \frac{w_{hot}^{0,452} \cdot \rho_{hot}^{0,452} \cdot c_{p,hot}^{0,33} \cdot \lambda_{hot}^{0,67}}{\mu_{hot}^{0,122} \cdot d_{ech}^{0,548}} \quad (21)$$

If the change is graphically determined, the experimental Nusselt number with the relationship (20), the Nusselt number determined by the relationship (16) is observed placing items near the first bisecting line. Practically, the deviation of calculation is placed in acceptable limits for the relationships criteria of the coefficients of heat transfer. This variation is shown in figure 2.

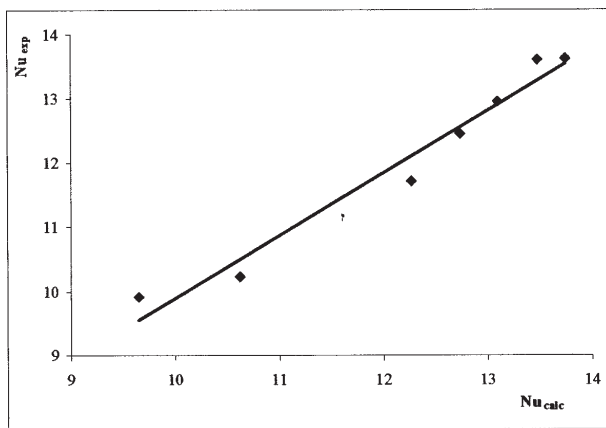


Fig. 2. Variation of number $Nu_{exp} = f(Nu_{calc})$ for ring filling

Conclusions

In this work was the experimental design of its own, where the main element is a heat exchanger with coaxial tubes.

It was established algorithm for calculating the partial coefficients of heat transfer of double pipe heat exchanger, in which at the inside, are the solid ring particles.

There were inferred the relationship criteria for $Nu = f(Re, Pr)$ and the relationship for the partial coefficient of heat transfer fluid - fixed bed of particles in the double pipe heat exchanger. It was set the value for mean deviation calculation for Nu , which was in the range $(-4.54 \div 2.73 \%)$, that recommend the established relations for being used in reactors design with fixed bed of particles, relations valid for a laminar flow for the areas Pr_{hot} (3.15 - 3.84) and Re_{hot} (185 - 350).

It is noted that for such particles, the values of the partial coefficient of heat transfer liquid - solid particles by

convection are between $(4420 - 5881) W / m^2 \cdot ^\circ C$, for speeds of hot water between $(21.5 \cdot 10^{-3} - 47.1 \cdot 10^{-3}) m / s$.

Notations

- α_p, α_e - the partial coefficients of heat transfer at the inside and outside the central tube, $W/m^2 \cdot ^\circ C$;
- d_{ech} - equivalent diameter of the bed, m;
- w_{hot}, w_{cold} - flows speed, hot and cold, m / s;
- $Q_{delivery}$ - the heat flow delivery for the hot water, W;
- A_e - the area of the external surface of the inner tube, m^2 ;
- A_i - the area of the surface on the central tube on the inside face, m^2 ;
- t_c, t_r - the average temperature of hot fluid and cold, $^\circ C$;
- V_{hot}, V_{cold} - volumetric flows of hot fluid and cold fluid, m^3 / s ;
- m_{hot} - the mass flow of hot fluid, kg / s;
- ρ_{hot}, ρ_{cold} - the density of hot water and cold water, at the average temperature, kg/m^3 ;
- μ_{hot}, μ_{cold} - the dynamic viscosity of hot water and cold water, at the average temperature, $kg/m \cdot s$;
- $\lambda_{hot}, \lambda_{cold}$ - the thermal conductivity of hot water and cold water, at the average temperature, $W / m \cdot ^\circ C$;
- λ_{steel} - the thermal conductivity of steel, $\lambda_{steel} = 40 W / m \cdot ^\circ C$;
- $c_{p,hot}, c_{p,cold}$ - the specific heat of hot water and cold water, at the average temperature, $J / kg \cdot ^\circ C$;
- t_{c1}, t_{c2} - the temperature of hot flow at the inlet and outlet of the exchanger, $^\circ C$;
- t_{r1}, t_{r2} - the temperature of cold flow at the entrance and exit of the exchanger, $^\circ C$.

References

1. POPA, M., ONUȚU, I., Contribution to heat transfer study in reactors with fixed particles bed, Buletinul Universității Petrol-Gaze din Ploiești, Volum LX, Seria Tehnică Nr.4B/2008, ISSN 1224-8495, p.113
2. JINESCU, G., VASILESCU, P., PÂRVULESCU, O.C., Rev. Chim. (Bucuresti), **55**, nr.8, 2004, p. 619
3. SCOTT, S.A., DAVIDSON, J.F., DENNIS, J.S., HAZHURST, A.N., The devolatilisation of particles of a complex fuel (dried sewage sludge) in a fluidized bed, Chemical Engineering Science, **62**, 2007, p. 584-598
4. GUARDO, A., COUSSIRAT, M., RECASSENS, F., LARRAYOZ, M.A., ESCALER, X., CFD study on particle-to-fluid heat transfer in fixed bed reactors : Convective heat transfer at low and high pressure, Chemical Engineering Science, **61**, 2006, p.4341
5. MOISE, A., TUDOSE, R., GHÎȚUN, M, Transferul de căldură între un agent termic gazos și un strat granular fix, Termotehnica românească, Editura Gheorghe Asachi, Iași, 1996, p.17
6. IONIȚĂ, L., NAGY, I., MUNTEAN, O., Rev. Chim. (Bucuresti), **42**, no.8-9, 1991, p. 424
7. PETRESCU, S., FRUNZĂ, A., PETRESCU, C., Heat Transfer at Convective Solid Melting in Fixed Bed, proceedings of World Academy of Science, Engineering and Technology, **30**, July, 2008, ISSN 1307-6884, p.622
8. POPA, M., ONUȚU, I., Studiul transferului de căldură într-un schimbător de căldură de tip tub în tub, Editura Universității din Pitești, 2009, ISSN 1453-1151, p.44
9. JINESCU, G., Procese hidrodinamice și utilaje specifice în industria chimică, Editura Didactică și Pedagogică, București, 1983

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