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Study of Heat Transfer for a Fixed Bed of Cylindrical Particles

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Abstract

In the present paper appear to continue a study on heat transfer by convection in a fixed bed of particles. Were studied cylindrical particles made of alumina, with geometrical characteristics well defined by the ratio H/D =8/3,2 mm. The particles are situated inside the tube of a coaxial heat exchanger . Were established the criterial relationship $Nu = C \cdot \mathrm{Re}^m \cdot \mathrm{Pr}^n$ *for calculating the partial coefficient of heat transfer fluid - solid particles by convection.*

Key words: *heat transfer, cylindrical particles beds, convection*

Introduction

Beds of particles are used in oil processing industry for making catalytic processes, combustion processes, processes of mass transfer and heat transfer processes. This paper is part of a comprehensive study on heat transfer in the fixed layer of particles [1-3]. Chosen for this study were cylindrical particles with well defined geometrical ratio H / De = 8 / 3, 2 mm, made of alumina. The study was conducted on a coaxial heat exchanger tube, made of steel. For the same type of particles have been studied and fluid-dynamic aspects [4].

Experimental part

Cylindrical particles used in the study were placed in the inner tube of heat exchanger to circulate warm water flow, and countercurrent flow of cold water circulated through the annular space of the heat exchanger. In table 1are presented the geometrical characteristics of cylindrical particles used.

Rates were measured for both streams (hot and cold) and their temperatures at both entry and exit of the heat exchanger. All physical properties of water (density, dynamic viscosity, specific heat, thermal conductivity) were calculated from the average temperature for this criterion as data processing.

Table 1. Geometric characteristics of the filling [5]

Characteristic cylindrical particle	Symbol	Value
Height, mm	H	8
Diameter, mm	d	3,2
Particle area $\cdot 10^6$, m^2	$A = a_p$	96,51
Particle volume$\cdot$ 10^8, m^3	v_p	6,4
Particle surface area, m^2/m^3	$a = \frac{a_p}{v_p}$	1508
Equivalent volume diameter $\cdot 10^3$, m	d_0	4,96
Surface area of the filling, m^2/m^3	$\sigma = a(1-\varepsilon)$	656
Sphericity	ψ	0,802

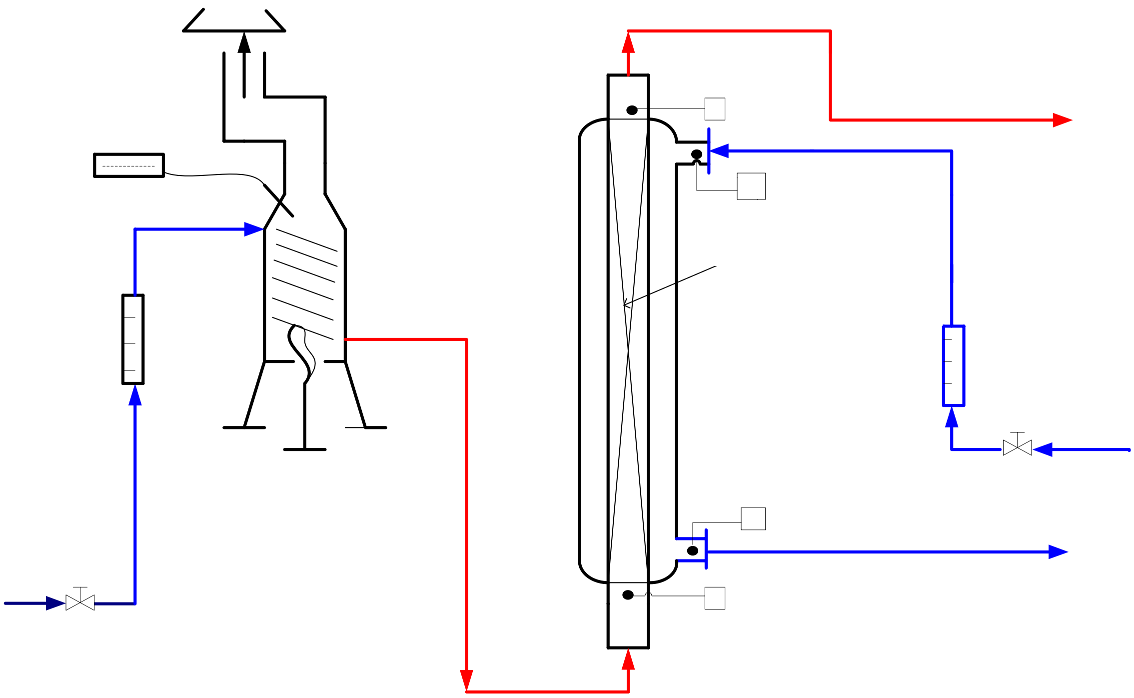

Fig 1. Experimental scheme
1 - heat exchanger, R1, R2 - rotameters, 2 - furnace, 3 - gas lamp, 4 - temperature recorder;
5 - thermocouple, 6 - electronic thermometers; SU - filling bed

Flue gas

Calculation algorithm

Algorithm for calculating the optimal correlation of experimental data is presented below. 1. Calculation of heat transfer coefficient partial annular space, through which cold water was made with criteria relationship (1), which was deducted for heat exchanger shown in specific working conditions [2]. Knowing the value of Nusselt number in criteria relationship (1), calculating the partial heat transfer coefficient on the outside, α_e, for the annular space.

$$Nu_{cold} = 0{,}543 \cdot \mathrm{Re}_{cold}^{0{,}717} \cdot \mathrm{Pr}_{cold}^{0{,}33} \tag{1}$$

2.Outer wall temperature, t_{pe}, calculation with equation (2):

$$t_{pe} = t_r + \frac{Q_{waste}}{\alpha_e \cdot A_e} \tag{2}$$

3. Determination of the inner surface temperature for the hot fluid, t_{pi}, is the expression of heat flux transferred by conduction through the cylindrical wall and the relationship of the calculation is :

$$t_{pi} = t_{pe} + \frac{Q_{waste} \cdot \dfrac{1}{\lambda_{steel}} \cdot \ln \dfrac{d_e}{d_i}}{2 \cdot \pi \cdot H} \tag{3}$$

4. Determination of heat transfer coefficient partially inside, α_i, between the warm fluid that goes through the bed of particles and the wall is done with the relationship (4):

$$\alpha_i = \frac{Q_{waste}}{A_i \cdot (t_c - t_{pi})} \tag{4}$$

5. Determination, based on experimental data processing, form a relationship criteria:

$$Nu_{warm} = C \cdot \mathrm{Re}_{warm}^{m} \cdot \mathrm{Pr}_{warm}^{n} \tag{5}$$

Results and discussion

Measurements and experimental data led to results presented in Tables 2-3.

Applying a regression program, the results were set constant values *C* and exponents *m* and *n* in equation (5): C = 0.228, m = 0.658, n = 0.33. The criteria relationship obtained is:

$$Nu_{warm} = 0{,}228 \cdot \mathrm{Re}_{warm}^{0{,}658} \cdot \mathrm{Pr}_{warm}^{0{,}33} \tag{6}$$

The relationship for calculated partially heat transfer coefficient inside, α_i, becomes:

$$\alpha_i = 0{,}228 \cdot \frac{w_{warm}^{0,658} \cdot \rho_{warm}^{0,658} \cdot c_{p,warm}^{0,33} \cdot \lambda_{warm}^{0,67}}{\mu_{warm}^{0,328} \cdot d_{ech}^{0,342}} \qquad (7)$$

Table 2. Sizes calculated values for cold fluid - cylinder filling with H / D = 8/3,2 mm

No. det.	$m_r \cdot 10^3$, kg/s	Δt_r, ^{0}C	$Q_{rec.}$, W	$w_{cold} \cdot 10^3$, m/s	Pr_{cold}	Re_{cold}	Nu_{cold}	α_e, $W/m^2 \cdot {}^0C$	t_{pe}, ^{0}C
1	12.59	26	1368	4.38	5.97	181	41	688	47
2	11.63	24	1166	4.05	6.13	163	38	642	44
3	12.48	9	470	4.33	7.47	147	38	623	27
4	9.15	10	383	3.18	7.37	109	30	501	26
5	6.10	12	306	2.12	7.18	74	23	379	30
6	6.37	23	612	2.22	6.21	88	25	415	45
7	9.40	37	1451	3.28	5.19	153	34	590	62

Table 3. Sizes calculated values for the warm fluid - cylinder filling with H / D = 8/3,2 mm

No. det.	$m_c \cdot 10^3$, kg/s	Δt_c, ^{0}C	Q_{waste}, W	$w_{warm} \cdot 10^3$, m/s	Pr_{warm}	d_{ech}, m	Re_{warm}	t_{pi}, ^{0}C	α_i, $W/m^2 \cdot {}^0C$	Nu_{warm}	$Nu_{calc.}$
1	22.2	16	1483	42.4	3.38	0.00345	486	48.2	3787	20.16	19.97
2	26.9	11	1235	51.3	3.61	0.00345	556	44.7	4004	21.49	22.29
3	19.9	7	582	37.7	5.46	0.00345	284	27.1	2928	16.40	16.42
4	20.7	5	433	39.2	5.60	0.00345	290	26.7	3025	16.99	16.79
5	11.1	9	415	20.9	5.07	0.00345	169	30.0	2004	11.14	11.35
6	8.2	26	893	15.7	3.43	0.00345	178	46.1	1852	9.87	10.36
7	15.5	29	1877	29.8	3.22	0.00345	347	64.0	3045	15.78	15.74

If changes are plotted with the experimentally determined Nusselt number - calculated Nusselt number is observed placing items near the first bisectrix. The deviation of calculation lies within acceptable limits for criteria relationships of the heat transfer coefficients. This correlation is shown in Figure 2.

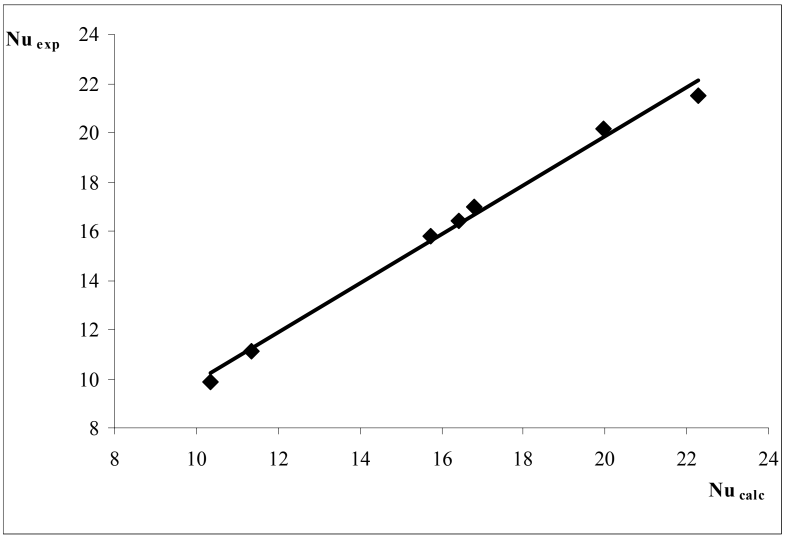

Fig. 2. Corelations between Nusselt number

Conclusions

Algorithm was established for the determination of the partial heat transfer coefficients in the coaxial tube exchanger, in which solid particles are located inside the cylindrical shape with the ratio H/De = 8/ 3,2 mm. Relationship was derived criteria for Nu = f (Re, Pr) and relationship to partial coefficient of heat transfer fluid - fixed bed of particles, tubular heat exchanger. To set the value for standard deviation calculation for Nu, which ranged (- 4,73 % - + 1.18%), which established relations recommended for use in reactor design with a fixed layer of particles. The values of the partial heat transfer coefficients are obtained by the hot fluid, ranging from 1852 -4004 W/m^2 ^{0}C hot water at speeds of 1.57 • 10^{-2} -5.13 • 10^{-2} m/s.

Notations

α_i, α_e – the partial coefficients of heat transfer at the inside and outside of the central tube, W/m^2•° C;
d_{ech} - the equivalent diameter of the bed, m;
Q_{waste} – the heat flow waste for the warm water, W;
A_e – the area of the external surface of the inner tube, m^2;
t_c, t_r - the average temperature of warm fluid and cold, ° C;
λ_{steel} – the thermal conductivity of steel, λ_{steel} = 40 W / m • ° C;
t_{pe}, t_{pi} - the temperature of the wall at the inlet and outlet of the exchanger, ° C;
d_e, d_I – the inner and outer of the small tube, mm;
H - the heat exchanger height, m.

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Studiul transferului de căldură pentru un strat fix de particule cilindrice

Rezumat

În lucrarea de față se prezintă continuarea unui studiu privind transferul de căldură prin convecție într-un strat fix de particule. S-au studiat particule cilindrice din alumină, cu caracteristici geometrice bine definite, cu raportul $H / D = 8/3{,}2$ *mm. Particulele sunt situate în interiorul tubului interior al unui schimbător de căldură cu tuburi coaxiale. S-a stabilit o relație criterială de forma* $Nu = C \cdot \mathrm{Re}^{m} \cdot \mathrm{Pr}^{n}$ *pentru calculul coeficientului parțial de transfer de căldură prin convecție între fluid şi particulele solide.*