Fluid-Dynamics Characteristics Concerning the Fixed Bed Usage of Ring Particles

MARIA POPA*, ION ONUTU
Petroleum Gas University of Ploieşti, Faculty of Oil Technology and Petrochemistry, 39 Bucureşti Bld., Ploiesti, Romania

The paper shows a study on the fluid-dynamics characteristics of the fixed bed of ring particles, associated with certain characteristics of the heat transfer in such systems. Water was used as working fluid circulating through a fixed bed of ring particles. The fluid circulates with low velocity, making possible a certain pressure drop, given by the friction of the fluid with the surface of the solid particles, by the trajectories imposed to each electricity wave by the presence of the particles and turbulence resulted from the flow over obstacles. For this study were chosen two types of ceramic ring particles. They are characterized by defined ratio H_p / D_e = 10.3 / 9.2 mm and 5.4 / 4 mm. The friction factor was calculated from experimental data with Fanning's relation and the value obtained was compared with the theoretical value obtained from Ergun's relation.

Keywords: ring particles, pressure drop, exchanger with coaxial tubes, fluid-dynamics characteristics

The literature presents few data on fixed beds of particles, the studies being mainly devoted to fluidized beds [1-4]. For determination of the heat transfer coefficients there are presented simplistic mathematical models and only the criteria relationships are applied.

Fluid-dynamic aspects usually accompany the study of the, exploring issues of heat transfer and, although is given minor importance in terms of the role of filling, the pressure drop that occurs in this beds is important for correct dimensioning of the equipment where the working fluids are circulating.

Several studies were made on fixed layers of different particles and the results are presented in works [5- 8]. The particle were chosen different both in terms of the materials they are made of and from geometrical point of view. They presented the study on calculating heat transfer partial coefficient by convection, both for coaxial exchanger tube without filling and with different types of fillings. Also, based on experimental data, there were highlighted differences that arise from applying different calculation relationships recommended by the literature.

Given that the fillings structure used has undergone many transformations to improve the transfer phenomena in the present study there were used the fillings that are different from those commonly used in literature. There were chosen for this study ring ceramic particles with well defined H / D ratio , compared with Raschig rings, commonly used in the ratio H / D = 1.

Experimental part

In this paper have been studied two types of ceramic ring particles with defined ratio H_p / D_e = 10.3 / 9.2 mm and 5.4 / 4 mm, for which were initially examined aspects of heat transfer and results are presented in the paper [5] and fluid-dynamics aspects of these ring particles are presented in this paper.

The experimental determinations were made in the experimental scheme presented in the paper [5], that add a new element, a manometer with U-shaped tube. This new experimental scheme is presented in figure 1.

All geometrical characteristics of the ring particles used in experimental determinations are presented in table 1.

During the experimental determinations, the ring particles were placed inside the small tube of the heat exchanger, through which a hot water flow was circulated, in countercurrent with cold water, within the annular space of the exchanger.

The experimental determinations of pressure drops were made keeping the same flow of hot liquid which crosses the packing, as in the study on heat transfer.

The variations of the friction factor with Re number inside the small tube of heat exchanger were graphically shown, the friction factor being determined both experimentally and theoretically.

The variation of the pressure drop with the hot flow was also graphically represented. In each case, the representation of the variation of the friction factor and Reynolds number is accompanied by the corresponding dependence equation.

The calculation algorithm

In the chemical industry, in order to improve the heat and mass transfer within the industrial equipment (columns, reactors) various types of packing are used. The calculation relations for pressure drops when the fluids flow through the beds of packing, although deriving from Fanning's relation for pipelines' flow, are different as they include a series of parameters specific to the beds, but also to the particles that constitute the packing, shown in table 1.

The flow resistance of the fix bed of packing can be expressed by Fanning's relation [9]:

$$\Delta p = f_f \cdot \frac{l}{d_e} \cdot \frac{w^2}{2} \cdot \rho \qquad (1)$$

Taking into account the characterization of the particle beds, the pressure drop of the packing is obtained using the relation:

$$\Delta p = f_f \cdot \rho \cdot w_0^2 \cdot \frac{l}{d_p \cdot \psi} \cdot \frac{1-\varepsilon}{\varepsilon^3} \qquad (2)$$

From relation (2) based on experimental data, was calculated the friction factor:

$$f_f = \frac{\Delta p}{\rho \cdot w_f^2} \cdot \frac{d_p \cdot \psi}{l} \cdot \frac{\varepsilon^3}{1-\varepsilon} \qquad (3)$$

* email: mariapopa2007@gmail.com

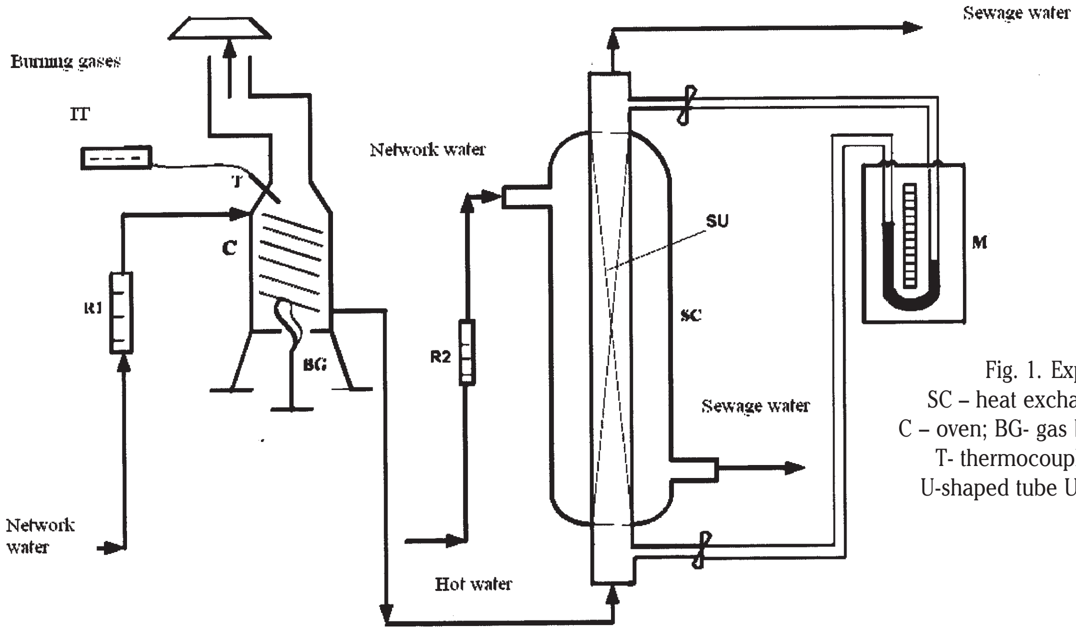

Fig. 1. Experimental scheme
SC – heat exchanger; R1, R2 – rotameter;
C – oven; BG- gas bulb; IT- temperature meter;
T- thermocouple; M – manometer with
U-shaped tube U; SU – bed of ring packing

Table 1
GEOMETRICAL CHARACTERISTICS OF THE RING PARTICLES [9]

Geometric characteristic	Symbol and calculation relation	Value	
Height of the particle, mm	H_p	10.3	5.4
External diameter, mm	D_e	9.2	4
Internal diameter, mm	d_i	5.8	1.6
Surface of the particle $\cdot 10^6$, m^2	$A = a_p$	565.5	141.3
Volume of the particle $\cdot 10^8$, m^3	v_p	41.2	5.7
The specific surface of the particles, m^2/m^3	$a = \frac{a_p}{v_p}$	1371	2478
Volume equivalent diameter $\cdot 10^3$, m	$d_0 = 1.24 \cdot v_p^{1/3}$	9.23	4.77
Sphericity of the particle	$\psi = 4.84 \cdot \frac{v_p^{2/3}}{a_p}$	0.4740	0.5074
Equivalent diameter of the bed$\cdot 10^3$, m	$d_{ech} = \frac{2}{3} \cdot \frac{\varepsilon \cdot \psi \cdot d_0}{1-\varepsilon}$	1.48	1.97
Porosity of the bed	ε	0.337	0.55
Specific surface of the bed, m^2/m^3	$\sigma = a \cdot (1-\varepsilon)$	909	1115

Theoretically, the friction factor is calculated taking into account the Re criterion, using Ergun's relation:

$$f_f = \frac{150}{\mathrm{Re}} + 1.75 \quad (4)$$

The Reynolds number is calculated by following relation:

$$\mathrm{Re} = \frac{d_{ech} \cdot w_f \cdot \rho}{\mu} \quad (5)$$

All these relations were applied to the beds of ring particles for which the heat transfer was studied [5] and the calculations were made for the hot flow too, flow which passed the fixed bed of ring particles.

Results and discussions

The measurements and the processing of the experimental data, following the calculation algorithm, led to the results shown in tables 2 and 3.

The processed data from in tables 2 and 3 permitted to graphically represent the variation of the friction factor and Re number for the hot water circulating through the packing bed. Figures 2 and 3 show the variation of the friction factor with Re number, for the annular packing, having various diameters. Figure 4 represents the variation of pressure drop with the actual speed of hot water.

It can be noticed that, for low Re numbers, the experimental friction factor is much higher than the theoretical one for a small ring packing (H_p/D_e = 5.4 / 4 mm). The highest value of the experimental friction factor (f_f = 5.3) was obtained at a hot water flow of 50 l/h. Also,

Table 2
RESULTS OBTAINED FOR THE FRICTION FACTOR FOR THE RING PACKING
WITH THE RATIO H_p/D_e = 10.3 / 9.2 mm

No. det.	V_c, l/h	$d_{ech}\cdot10^3$, m	ε	w_0, m/s	w_f, m/s	ρ_{tc}, kg/m³	$\mu_{tc}\cdot10^6$, kg/ms	Re	Δp, mm Hg	f_f exp.	f_f theoretical
1	90	1.483	0.337	0.047	0.139	990	587	349	4	0.06	2.18
2	86	1.483	0.337	0.045	0.134	989	564	347	4	0.07	2.18
3	80	1.483	0.337	0.042	0.125	988	540	336	2	0.04	2.20
4	69	1.483	0.337	0.036	0.107	987	525	299	1	0.03	2.30
5	50	1.483	0.337	0.026	0.077	985	510	222	1	0.05	2.40
6	75	1.483	0.337	0.039	0.116	986	517	329	1	0.02	2.20
7	41	1.483	0.337	0.021	0.060	979	499	185	4	0.31	2.60

Table 3
RESULTS OBTAINED FOR THE FRICTION FACTOR FOR THE RING PACKING
WITH THE RATIO H_p/D_e = 5.4 / 4 mm

No. det.	V_c, l/h	$d_{ech}\cdot10^3$, m	ε	w_0, m/s	w, m/s	ρ_{tc}, kg/m³	$\mu_{tc}\cdot10^6$, kg/ms	Re	Δp, mm Hg	f_f exp.	f_f theoretical
8	90	1.973	0.55	0.047	0.085	988	544	307	70	3.8	2.18
9	79	1.973	0.55	0.041	0.075	986	519	281	58	4.2	2.18
10	75	1.973	0.55	0.039	0.071	984	501	277	49	3.9	2.20
11	74.5	1.973	0.55	0.039	0.071	982	496	277	51	4.1	2.25
12	61	1.973	0.55	0.032	0.058	983	498	226	39	4.6	2.43
13	47	1.973	0.55	0.025	0.045	992	631	139	22	4.2	2.21
14	50	1.973	0.55	0.026	0.047	994	736	127	30	5.3	2.56

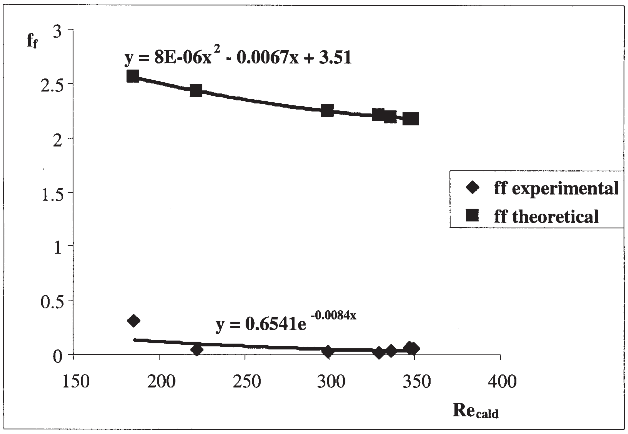

Fig. 2. Variation of the friction factor with Re number for the ring packing with H_p/D_e = 10.3/9.2 mm

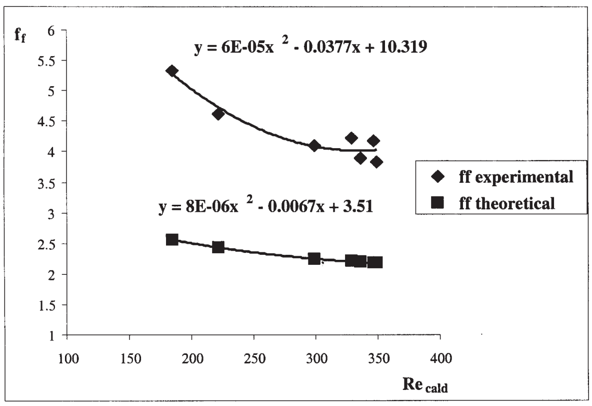

Fig. 3. Variation of the friction factor with Re number for the ring packing with H_p/D_e = 5.4/4 mm

for the calculated (theoretical) friction factor, the highest obtained value (f_f = 2.6) was the lowest hot water flow (41 L/h). At the same flow of hot water (for example at 50 l/h), the experimental friction factor is higher (f_f = 5.3) in the case of particles with equivalent lower volume diameter (d_0 = 4.77 mm) than in the case of particles with d_0 = 9.23 mm - (f_f = 0.05).

In figure 4 is represented the variation of the pressure drop with the hot water velocity, water crossing the packing bed, one can notice the close values of the experimental points for the two types of ring particles, both for low velocities and pressure drops, and their remote values at a higher rate of the water flow.

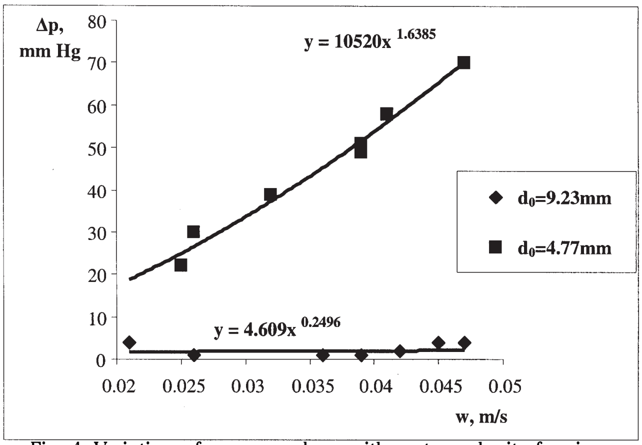

Fig. 4. Variation of pressure drop with water velocity for ring packing

Conclusions

As Re number increases, the friction factor decreases both at its experimental determinations, and theoretical ones, the values tending to get close for the ring particles with a smaller diameter, while for ring particles with bigger diameters, the differences are almost constant.

The variation of the pressure drop with the hot water velocity is almost linear and constant for the big ring packing, having a value of the volume equivalent diameter d_0 = 9.23 mm.

It is noted that the experimental friction factor values have an inverse variation with the volume equivalent diameter of ring particles used (d_0).

Notations

Δp – pressure drop, N/m^2;

f_f - friction factor which takes into consideration the pressure drop due to the frictions fluid- surface of filling parts, and the change of velocity and flow direction of the fluids through the channels formed between the elements of the packing;

l – length of the bed, m;

d_{ech} – equivalent diameter of the packing, m;

w_f – real velocity of the fluid, m/s;

ρ – density of the fluid flowing though the packing bed, at average temperature, kg/m^3;

μ – dynamic viscosity of the fluid flowing though the packing bed, at average temperature, kg/m·s;

w_0– linear velocity of the fluid if the tube were without packing, fictive velocity, m/s;

d_p – diameter of the particle, m;

Ψ – sphericity factor (Ψ = 1 for spherical particles);

ε – porosity of the bed of particles.

References

1. ETTEHADIEH, B., GIDASPOW, D., LYCZOWSKI, R.W., Hydrodinamics of Fluidization in a Semicircular Bed with a Jet AlChE Journal, **30**, nr.4, 1984, p.529

2. IONIŢĂ, L., NAGY, I., MUNTEAN, O, Rev. Chim. (Bucuresti), **42**, no.8-9, 1991, p. 424

3.JINESCU, G., VASILESCU, P., PÂRVULESCU, C., Rev. Chim. (Bucuresti),.**55**, no.8, 2004

4. PANAITESCU, GH., IONESCU, R, Rev. Chim. (Bucuresti), **31**, no.6, 1980, p.568

5. POPA, M., ONUŢU, I.., Rev. Chim. (Bucuresti), **60**, no.11,2009, p.1185

6. POPA, M, Studiul căderii de presiune la curgerea unui gaz prin straturi de particule sferice, Buletinul Universităţii Petrol-Gaze din Ploieşti, **LVII**, Seria Tehnică Nr.2/2005, ISSN 1221-9371

7. POPA, M., ONUŢU, I. , Contribution to heat transfer study in reactors with fixed particles bed, Buletinul Universităţii Petrol-Gaze din Ploieşti, Volum LX, Seria Tehnică Nr.4B/2008, ISSN 1224-8495, p.113

8. POPA, M., ONUŢU, I., Studiul transferului de căldură într-un schimbător de căldură de tip tub în tub, Editura Universităţii din Piteşti, 2009, ISSN 1453-1151, p.44

9. JINESCU, G., Procese hidrodinamice şi utilaje specifice în industria chimică, Editura Didactică şi Pedagogică, Bucureşti, 1983

Manuscript received: 9.12.2009