Section: Environmental protection

Hydrodynamics of Packing Beds Made of Differently Structured Material for Thermal Utilization and Mass-Exchanged Processes in Columns of Environment Protection

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Abstract

The submitted concept is a new perspective design of regular packing of PFF type (fluctuating packing "flag") made of thin, elastic, wetted cloth materials. One end of packing bed elements is fixed on rigid framework, and another enables to make free vibrational motions under the influence of incoming gas stream. Using of the proposed packing bed of PFF type allows, to develop a contact surface up to 400 m^2/m^3, having increased thereby the efficiency of heat-and-mass transfer process performance in environment protection units.

Keywords: environment protection; regular packing bed; heat-and-mass transfer processes; hydrodynamics.

Nomenclature

W_0	the velocity of gas stream per full cross-section of empty apparatus, m/s
d1	reference length of stream-lined body, m
Re	Reynolds' number
Eu	Euler number
ΔP	head losses, Pa
d2	hole size, m
D	diameter of tested column, m
F	free cross section of wire lattices
Greek symbols	
υ	kinematic viscosity, m^2/s
ζ	hydraulic resistance coefficient
ρ	gas density, kg/m^3

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1. Introduction

Sulfur and nitrogen oxides can be related to the main harmful gaseous emissions, for example, at the coal-fired power stations (see Table 1). According to data [1, 2], the quantity of sulfur dioxide emissions in the atmosphere of Earth in 2008 was more than 4 million tons. It accounts for about 23% of total emissions from all industrial sources in Russia.

Unlike the European Community countries, where the total quantity of coal fuel from the fuel stock ranges from 40 to 50%, in Russia it amounts to 30% and as to natural gas – 60%. For this reason the experience of implementing the wet-type purification (filtration) technologies of sulfur oxide combustion gases in the power industry of Russia is now limited. However, research works in this area are carried out quite actively [1, 3–12].

The most regular packing of falling film type used at present in the power industry are made of the structured corrugated plates vertically installed in the unit of equipment [4, 7, 11–15]. The metal or plastic is usually used as a material for manufacturing these corrugated plates. It is possible, to illustrate the structured packing bed as an example of a similar packing of Montz Pak B1-250M type, which allows to develop geometrical surface of contact up to the size a= 250 m^2/m^3. The specified packing bed is arranged inside the column in tiers, the height of which is 0.2 m [13–15]. For this purpose the

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adjoining tiers are performed with 90-degree turn relative to each other, that provides permanent disruption of liquid film so intensifying to some extent the heat-and-mass transfer by using "end" effects [16].

Table 1. Atmospheric pollutant emissions from stationary sources in the Northwestern Federal District of Russia [2]

Emissions	Thousands of tons per year
Sulphur dioxide	554,2
Carbon oxide	705,7
Nitrogen oxides	168,5
Solid particles	273,9
Total	2243,9

If the regular corrugated packing bed is used, the main tool enabling to provide rather high specific surface is a manipulating corrugated plates in height. The less the height of corrugated plate is, the greater is the figure of the developed geometrical specific surface. The tilt angle of corrugated packing beds to the horizontal of packing beds in question usually makes 45–60° [8–9]. The plate thickness is from 0,1 to 0,5 mm depending on the used material. The specific surface, which for instance differently manufactured packing FLEXIPAC HC of KOCH-GLITSCH firm has is from 225 m^2/m^3 (type 2Y) up to 725 m^2/m^3 (type 700Y) [14]. At the same time it is noted, that when being used [10] even at the smaller size of the specific surface equal to 500 m^2/m^3, packing bed elements during their operation inside process units are often plugged. Other major fault of regular packing beds are their high cost and big specific gravity, as well as.

In many research works has been pointed out the critically high sensitivity of regular packing beds to the initial uniform distribution of liquid at the packing bed input [9, 12, 16].

In the research work [19] are quoted results of experiences on using of sanitary absorbing packed columns with the diameter of 0,63 m and height of packing bed between 3,2 m and 5,2 m, respectively. The specified units allow, to perform the absorption purification of ammonia and chloride hydrogen waste (offluent) gases by using the solution of chloride ammonium. However, 8×10 mm in-size Rashing rings [19] rings used in work don't provide the required reduction of energy consumption costs, because of big hydraulic resistance of a small and inefficient packing, the internal element surface of which isn't practically washed by interacting streams [16].

Using the elements of PFF packing type in contact apparatuses allows, to solve a problem of sanitary purification of waste gases in more compact space due to bigger development of specific surface, where hydraulic (fluid) resistance at the same time is lower.

While considering the presented analysis, urgent problem is a development of the new regular packing beds, which have got highly extended surface, but are manufactured from materials commercially obtainable according to the cost and are to certain extent free of the above mentioned faults.

In this report are presented concept notes of regular packing bed of new type made of cloth elements, as well as results of preliminary trials to research the hydrodynamics of cloth packing beds from various materials (silk, nylon, polyethylene, organza OSG-153).

2. The concept of a regular packing made of cloth elements

It has been suggested that the regular packing bed will be made in form of cloth "flag" system making free vibrational motions under the influence of incoming gas stream [18]. The tier of PFF type (fluctuating packing "flag") packing proposed for the column with 150 mm in diameter is presented in Figure 1.

The use of such packing involves the existing gas stream vortex-like flow in the volume of apparatus provided with the packing (please see Fig. 2). The specified vortex currents, for example, Karman's vortex street are intended to provide vibrational motions of cloth "flags" and so intensify heat-and-mass transfer processes in the contact apparatus.
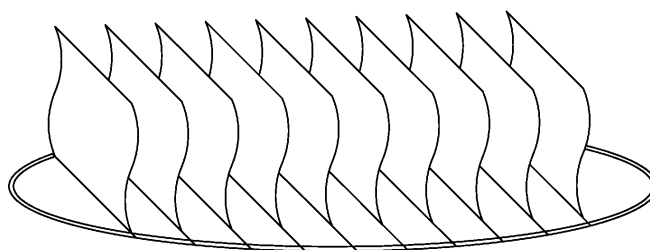

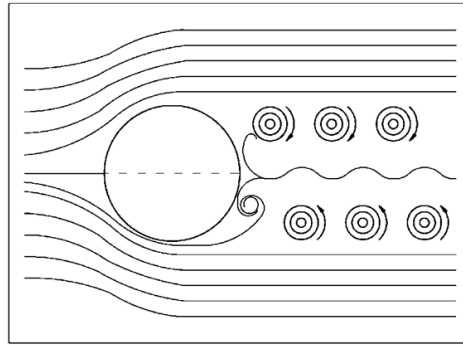Fig. 1. General view of PFF packing bed tier

Fig. 2. Karman's vortex street scheme

Let's take a good look within outer problem of hydrodynamics at the diagram of flow around the elementary cylindrical body with the diameter **d** by stationary stream of gas with W_0 velocity. May the velocity of gas stream vary within the limits of Reynolds' numbers Re: $10^0 < Re < 10^7$

Here: $Re = (W_0 * d1)/\upsilon$ (1)

The characteristic curve of horizontal cylinder drag coefficient dependency ζ on Reynolds's number is shown in Fig. 3. The flow pattern corresponding to the segment AC on dependency diagram $\zeta = f(Re)$ is of special interest for practical use, when implementing of heat-and-mass transfer processes (please see Fig. 3). As it seen from the diagram, with increase of Reynold's number the gas stream behind the stream-lined cylinder becomes asymmetric (please see Fig. 4). After the point **B** there is an area of the slowed-down stream, which starts making vibrational motions here and there. With further increase of Reynold's number on the segment **BC**, Karman's vortex street appears (please see Fig. 4).
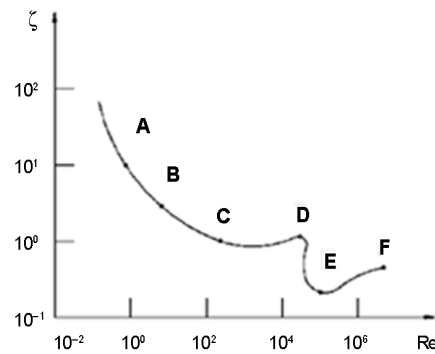
Fig. 3. Dependence of hydraulic resistance coefficient ζ from the specific value
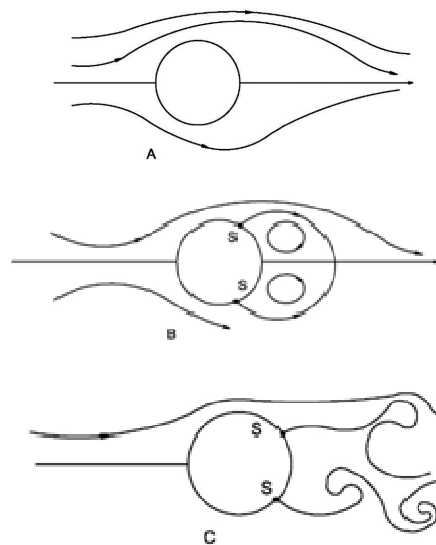of Reynold's criterion in case of the stream-lined single cylinder

Fig. 4. Diagram of flow around the cylinder by cross stream of gas at various values of Reynold's criterion
(notation of points **A, B** and **C** please see in Fig. 3): **S** – breakaway points, in which there is a breakaway
of boundary layer from the stream-lined body surface

The value of hydraulic resistance coefficient can be assessed according to the following equation [19]:

$$(\zeta/2) = (\Delta P)/(\rho * W_0^2) = Eu. \tag{2}$$

3. Hydrodynamic tests of PFF type packing bed

Experiments were performed at the test stand which schematically shown in Figure 5. The column in diameter is 150 mm.

Using of wire lattices as a generator of vortex currents is for PFF packing bed at packing one input of special interest. In this regard, previously were carried out hydrodynamic tests of the specified lattices with different free cross section **F = d2/D**. Characteristics of the tested lattices are shown in Table 2.

Table 2. Characteristics of tested wire lattices

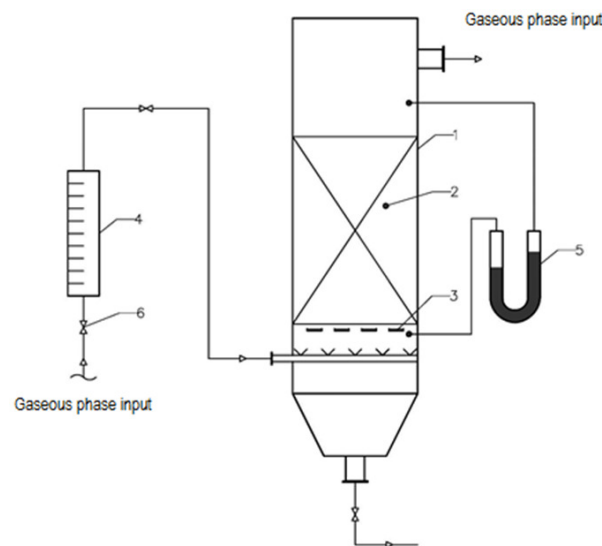| № п/п	1	2	3	4	5	6
F, %	20	30	40	50	60	70

Fig. 5. Scheme of test facility: 1 – column housing; 2 – packing bed; 3 – gas-distributing lattices;
4 – variable area flowmeter (rotameter); 5 – differential pressure manometer; 6 – valve

The dependence of hydraulic resistance coefficients of tested lattices on the air stream velocity calculated per the full cross section of W_0 in the range of W_0 from 0,5 m/s to 3,0 m/s is presented in Figure 6. The influence of free cross section of lattice F on the size of hydraulic resistance coefficient ζ at various velocities of air stream W_0 is shown in Figure 7. As it seen from presented diagrams, with increase of free cross section of wire lattices F from 20% to 70 % the value of hydraulic resistance coefficients ζ at air stream velocity, for example, W0=1,0 m/s is will be reduce from 16,5 to 1,05, i.e. by 15,7 times.
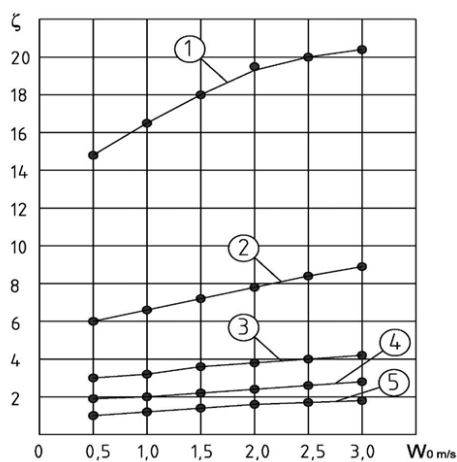

Fig. 6. Dependence of hydraulic resistance coefficient ζ of wire lattices with different free cross section F on the air stream velocity W0:1 – F=20% 2 – F=30%; 3 – F=40%; 4 – F=50%; 5 – F=60%
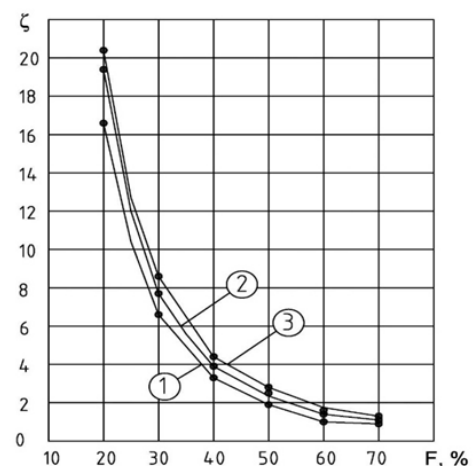
Fig. 7. Dependence of hydraulic resistance coefficient ζ of wire lattices on the size of their free cross section F at different velocities of air stream W0: 1 – W0=1,0 м/с; 2 – W0=2,0 м/с; 3 – W0=3,0 м/с

Hydrodynamic tests of PFF packing bed tier were carried out in the same column with a diameter of 150 mm. The preciously tested lattice with the free cross section F=50% was used in the course of this set of experiments as a generator of gas stream vortex at the working volume input. The height of investigated cloth materials during those experiments varied between 50 mm, 100 mm and 140 mm.

In the course of experiments while purging samples of packing beds in the column the gas stream velocity was W0=1,0÷2,0 m/s. Visual observation (please see a photo in Fig. 8) showed that in specified range of velocities the tested types of packing bed elements made free vibrational motions with an amplitude A=2±1 mm. It was noted, that in doing so the greatest amplitude of packing bed cloth fluctuations created a polyethylene film from samples.

Fig. 8. Tests of PFF packing tier

4. Conclusions

1. It was conceptualized a regular PFF type packing bed made of cloth elements making free vibrational motions under the influence of ascending vortex-like gas flow.

2. Preliminary results of hydrodynamic tests of the suggested PFF packing bed tier made of different materials are presented. It is shown that the most promising from all tested materials is the polyethylene *cloth*.

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