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Aerodynamics of Ceramic Regular Packing for Heat-Massexchenge Processes

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1. Introduction

The chemical, petroleum and other industries in implementing the removal processes, distillation and purification of gases from the emissions are widely used structured, as well as structural attachment mesh configuration [1-2]. Both of these belong to the regular batch nozzles, forming a three-dimensional spatial multi-channel structure.
Structured packing is usually implemented as a set of individual corrugated sheets assembled in packets (blocks). Themselves with sheets can be made of polymer, ceramic and other materials. Formed in this channel have a complex spatial configuration. The most common structured nozzle of this type in the industry are packing company Sulzer Chemtech (Switzerland).
To clear the air of various pollutants also find application developed at the Vilnius Gediminas Technical University biological plants, the main element of which is a filter with bio-fill [3, 4]. As a sorbent in the biofilter used cheap and available material - pieces of fir bark of various fractions, eg, 35, 25 and 12,5 mm [4, 5]. Performance and prospects of biofilters for air cleaning from harmful impurities doubt. However, the use of apparatus thin layer pieces sorbent indicated linear sizes and fractions makes it difficult to organize an optimal homogeneous structure of the granular layer throughout the cross section of the apparatus described in [4]. At the same time of contact of microorganisms with pollution in different parts of the biofilter, it seems, can vary significantly.
Unlike the bulk of irregular attachments regular structured [1] as the structural attachment [2] have a greater specific surface and at the same time have significantly lower hydraulic resistance. In addition, the structured packing sheet avoid contacting bypass flows due to inherent in bulk irregular layers (eg, rings and saddles Rashig Burley) phenomena wall anisotropy [6, 7, 16, 17].
However, the known sheet structured packing does not have the properties of isotropy. They are due to the peculiarities of its design will organize a system of parallel isolated from each other channels and therefore do not provide a satisfactory cross-mixing of contacting streams. This affects the effectiveness of a column of contact devices of chemical technology, as well as in power (cooling towers) processes.
One possible way to improve a class of structured nozzles is to create three-dimensional isotropic structure on the basis of highly porous cellular materials (HPCM) [8], which in the European Community referred to the term "foam".

Given the emergence of new highly porous cellular materials can offer the following tips for a new classification of heat and mass transfer processes (see Fig. 1).

Recently, a number of publications devoted to studying the possibilities of using HPCM as industrial attachments for the implementation of the processes of heat and mass transfer in the chemical industry.

So in [10] L. Padeste, A. Baiker, J.P. Gabathuler point to prospects of using ceramic foam packaging of cordierite as carriers for catalysts. In their experiments the authors of [10] based on the known method of determining the dwell time distribution of fluid flow in a layer of packing for writing marking substance (label). Moreover, for the greater persuasiveness of their results, the authors [10] conducted experiments for two cases: the sand layer of spheres of diameter 1, 2, 3 and 5 mm, as well as ceramic foam packaging. However, as shown by O. Levenspiel, J.C.R. Turner [11] using the principle of measuring the distribution of time spent using the tags must be complete confidence in the presence of a flat profile of velocity. Contrary to the authors of [10] with reference to the work of [12] for bulk layers of balls, this condition is just not satisfied. On the contrary, as follows from a series of special studies in the timing characteristics of devices with bulk layers of balls and other grains form in a wide range of Reynolds numbers in a layer have the balls characteristic velocity profile with an extreme surge near the walls of the apparatus of the greater looseness of packing of spheres in this area [6, 17]. Incidentally, this is also evidenced by the results of [12]. This circumstance gives rise to a certain degree of doubt and in other results [10] on ceramic foam packaging.

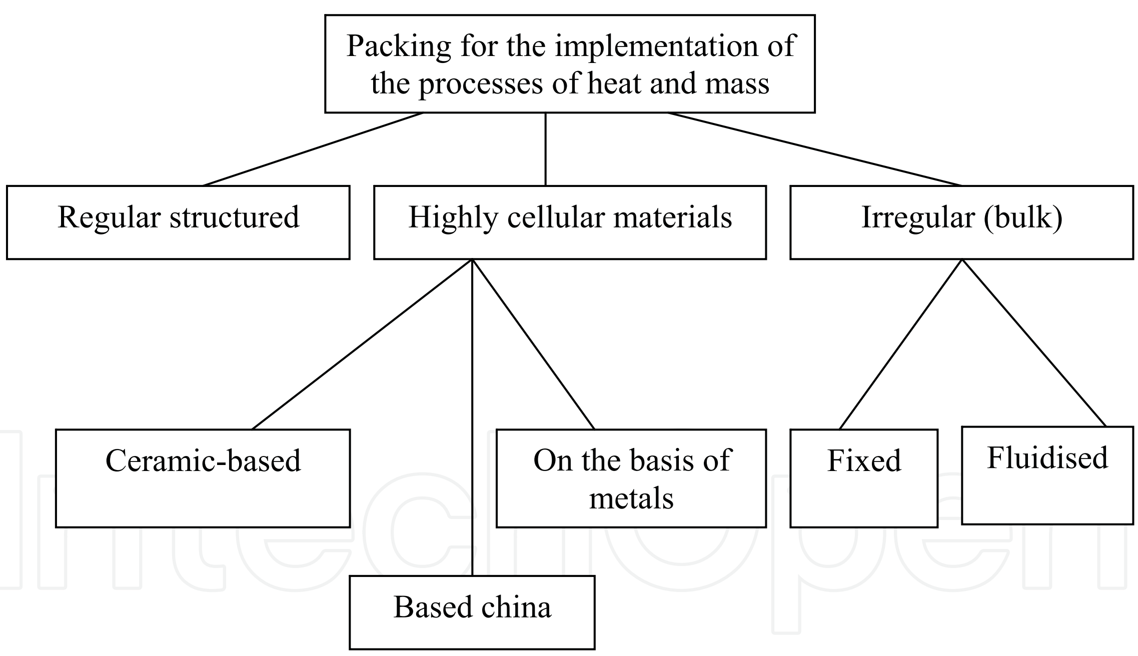

Fig. 1. Classification of packing for the processes of heat and mass transfer

Thus, the problem of studying the aerodynamics of packing on the basis of ceramic HPCM remains relevant.

In another study [13] presented the results of experiments on samples of porous blocks of metallic foam.

However, experimental data on the basic geometric characteristics of porous packing of ceramic materials technology HPCM in the literature is largely absent. Hydrodynamics of ceramic packing HPCM also is not yet sufficiently studied.

This paper presents the results of a study of the aerodynamic and geometric characteristics of the regular porous bits of ceramic materials - namely, pressure loss and the degree of turbulence in a wide range of loads on gas.

2. The structure of highly porous cellular materials

Highly cellular materials represent a new type of porous material. These materials, generally speaking, can be manufactured as a metal and nonmetal on the basis of having the maximum possible porosity and permeability of the reticulated cellular structure of the pore space.
The geometrical structure of these HPCM`s really almost entirely consistent with the definition of isotropy and it could be used to produce a new generation of ceramic packing by powder metallurgy. Since the porous structure of the framework HPCM`s for the manufacture of packing largely determines the appropriate level of physical and chemical properties of the future heads, with its development were considered different options. It was preferred porous polymer materials, namely - widely used in polyurethane foam industry. That this material is completely open, transparent, thin, isotropic, spatial, three-dimensional structure with virtually no local defect closed macropores that may violate isotropy of any fragment of the future attachments.
Another important advantage of polyurethane foam as a basis for the manufacture of a new nozzle is easy to cut the material into separate pieces of any predetermined arbitrary shape (see fig. 2).
It is also important to note a small volume fraction of foam in the total amount of future attachments. According to [8] itself polymeric material occupies no more than 2,5%. Thus, the initial proportion of free volume (separately) a fragment of the foundations of attachment of this polymer could reach 97.5%.
From the viewpoint of the properties of the full isotropic element attachment is particularly important to high initial homogeneity of the structure of polyurethane foam, as well as linear geometric dimensions themselves local micropores, forming the frame of the future attachments. It is important and the lack of closed pore canals.
Samples from the nozzle HPCM produced by slip casting [20]. After heat treatment formed delicate arch-labyrinthine structure (see Fig. 3). Geometric model of the unit cell packing of the space pore HPCM is pentagondodecahedron, whose structure is shown in Fig. 4.

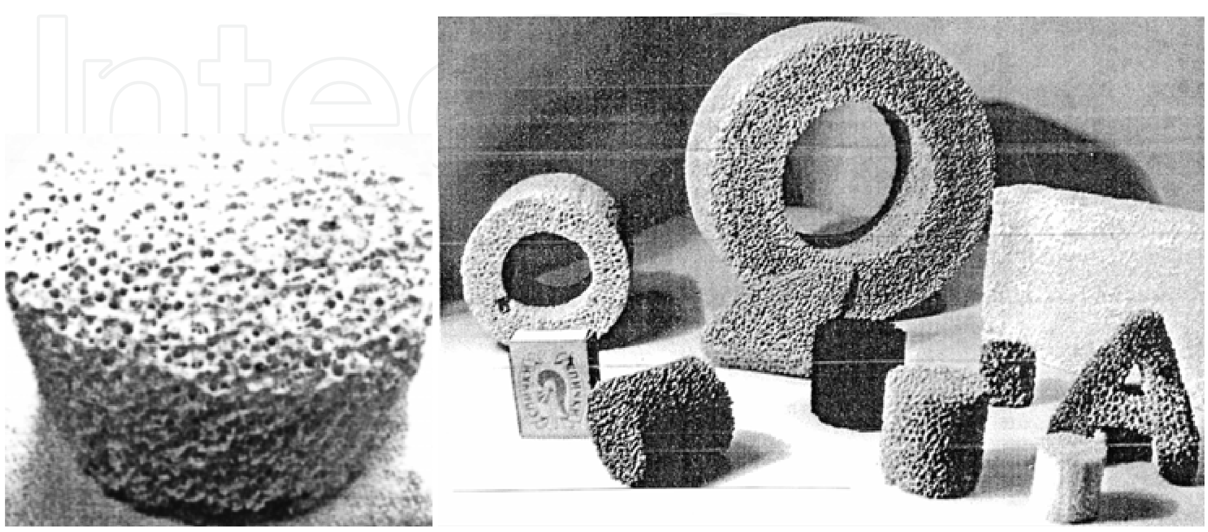

Fig. 2. Photo samples from the packing HPCM

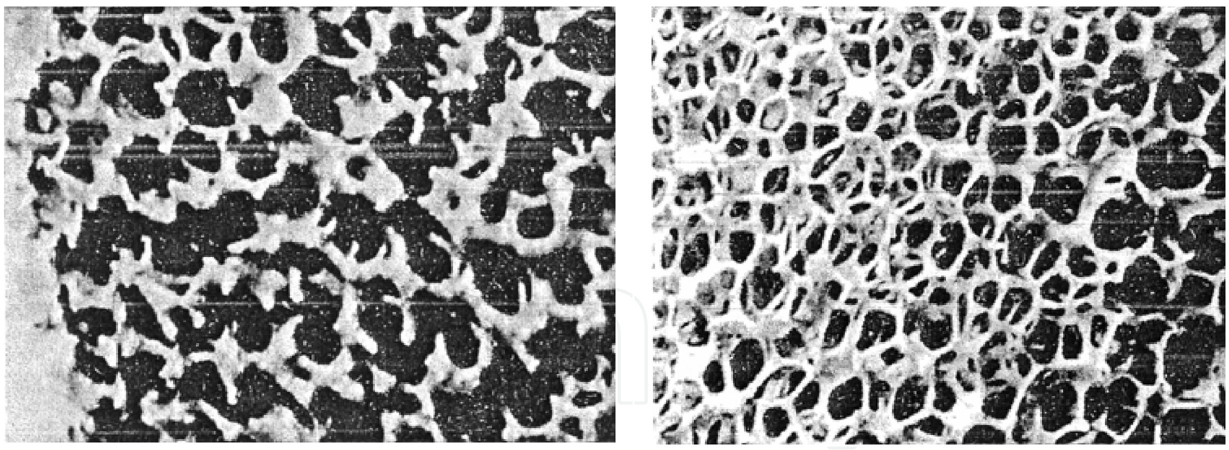

Fig. 3. Arch-labyrinthine structure of highly porous cellular material

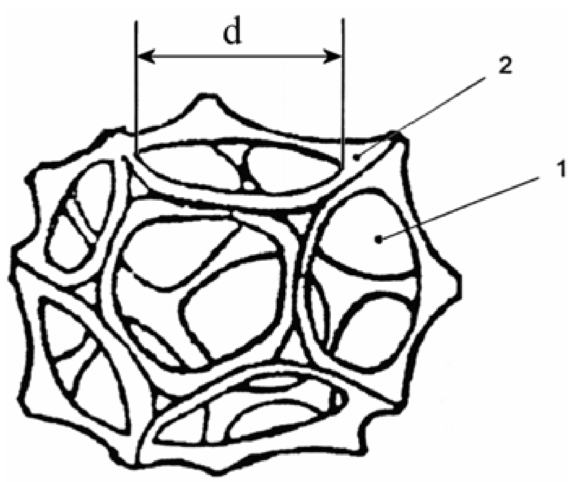

Fig. 4. Structure pentagondodecahedron cell material from the packing HPCM, 1 - pore channel; 2 - wall

3. Geometric characteristics of layer packing

3.1 General

The main geometric characteristics, determining the structure and parameters of heat and mass transfer in a packed column apparatuses include:

- • the proportion of free volume of the layer packing - **ε** (porosity), m^3/m^3;
- • specific surface layer of regular or bulk packing in a unit volume - **a**, m^2/m^3.

The magnitude of the porosity of the layer packing is numerically equal to the value of "live" section of the layer, determines the value of the characteristic velocity of the gas flow in the layer.

Generally speaking, during the gas flow in the layer of bulk (irregular) packing is a "hybrid" hydrodynamic problem. On the one hand, the gas stream flows around the elements of the packing layer. On the other hand, the flow proceeds in the pores between adjacent elements of the packing.

In the case of the packing, made of highly porous cellular material there is reason to consider the flow in a layer of a packing as an internal problem - that is, the flow in the pore channels (see Fig. 4). Gas flows through the layer HPCM through the complicated cross-section, defines the surface of **a** layer of packing per unit volume and the proportion **ε** of free volume (porosity).

3.2 Equivalent diameter packing

In the English literature to refer to the equivalent diameter of the channel often use the term *hydraulic radius*. Here, the term *equivalent diameter of the channel*.

In [22] suggested as the defining geometric size of the channels of complex cross section using the equivalent hydraulic diameter - $\mathbf{d_e}$, equal to:

$$d_e = 4 \cdot F / P \tag{1}$$

where: **F** - cross sectional area of the channel, m^2, **P** - wetted perimeter of the channel, m.

Looking for a gas flow in the packing layer Zhavoronkov and Aerov [23, 24] introduced the concept of equivalent diameter of pore channels is equal to four times the hydraulic radius:

$$d_e = 4 \cdot \varepsilon / a \tag{2}$$

In [22] that the concept of equivalent diameter "is not in general is universal and allows only a few cases to calculate the pressure loss in the channels of different geometry formulas for tubes of circular section. On the other hand, made in [25-27] treatment of the results of experiments to measure the pressure loss in granular layers of various geometric shapes and sizes showed that these results can be generalized single dual-term criterial equation of the form [25]:

$$Eu_m = A + B / \mathrm{Re}_{d_e} \tag{3}$$

In equation (3): **A** = 0,9, **B** = 100; $\mathbf{Eu_m}$ - modified Euler number equal to:

$$Eu_m = \left(\Delta P \cdot \varepsilon^2\right) / \left(H \cdot a \cdot \rho \cdot W_0^2\right) \tag{4}$$

ρ - gas density, kg • s^2/m^4; **H** - height of the layer packing, m; **ΔP** - pressure loss, kg/m^2; $\mathbf{W_0}$ -velocity gas in the expectation of full cross-section of an empty vehicle, m / sec.

Re_{d_e} - Reynolds number, relative to the equivalent diameter of the channel in a layer of packing equal to:

$$\mathrm{Re}_{d_e} = \left(W_0 \cdot d_e\right) / \left(\varepsilon \cdot \nu\right) \tag{5}$$

Here, **v** - kinematic viscosity of gas, m^2 / s; $\mathbf{W_0}$ - gas flow velocity in the calculation of the total cross section of empty vehicle, m / s.

Thus, the use of equation (3) as the defining geometric parameters of the layer packing equivalent diameter of the channel - d_e with respect to the granular layers and packed columns allows the apparatus with sufficient accuracy to calculate the pressure loss in them. Consequently, we can assume that in packed columns vehicles use the equivalent diameter of the channel is fully justified in carrying out hydraulic and other technological calculations of these devices.

3.3 Methods for determining the basic geometric characteristics of the packing HPCM

With respect to the packing of HPCM most accurate method for determination of the porosity should be considered as a method of weighing fragment packing of known volume. Another widely known method - fill the porous packing water can in this case to make significant errors due to air bubbles remaining in the pore volume packing at filling it with water. For a known specific weight of material value of porosity packing can be determined by the ratio:

$$\varepsilon = 1 - \frac{\gamma_{pack}}{\gamma_m} \tag{6}$$

where - γ_{pack} - weight fragment of the packing, kg/m³;
γ_m - the proportion of the monolith (packing material), kg/m³.
The specific surface of the packing HPCM because of the complexity of the geometry of its forms appropriate to define terms of the known hydraulic resistance element of the packing from the equation Gelperin I.I., Kagan A.M. [14]:

$$a = \left(324 \cdot 10^{-6} \cdot \frac{W_0^2}{\nu^2} + \frac{0{,}04 \cdot \varepsilon^2 \cdot \Delta P}{\nu \cdot H \cdot \rho \cdot W_0}\right)^{0{,}5} + 18 \cdot 10^{-3} \cdot \frac{W_0}{\nu} \tag{7}$$

where:
W_0 - the rate of gas flow per total cross section of an empty vehicle, m / s;
v - kinematic viscosity of gas, m^2 / s;
ρ - density of gas, kg • s^2/m^4;
ΔP - hydraulic resistance of the layer packing, kg / m^2;
H - height of a packed layer, m.
Determination **ΔP** for subsequent calculation of specific surface attachment technique [14] should be made as a result of blowing a fragment of the test packing at a rate of gas flow corresponding to the laminar flow regime dominated by viscous forces. This condition is explained by the fact that the measured resistance should be caused only by friction on the surface of the packing.
According to [14] laminar flow in the granular layer correspond to the values of Reynolds numbers:

$$\mathrm{Re}_e << 40 \tag{8}$$

The Reynolds number is assigned to an equivalent diameter of grain - **d_e**:

$$\mathrm{Re}_e = \frac{W_0 \cdot d_e}{\varepsilon \cdot \nu} \tag{9}$$

$$d_e = \frac{4 \cdot \varepsilon}{a} \tag{10}$$

Geometrical characteristics of some ceramic and metal bits of HPCM presented in Table.

Number	Name	**ε**, m^3/m^3	**a**, m^2/m^3	d_e, m
1	Fine-pored	0,85	2700	0,00126
2	Coarse-pored	0,92	1500	0,00245

Table 1. Characteristics of regular ceramic industrial attachments of HPCM according to [21]

Num ber	Material and shape of the packing	The average cell size, d, mm	Specific surface, **a**, m^2/m^3	Fenes tration, ε, m^3/m^3	Bulk density, ρ, kg/m^3	**$d_e \cdot 10^3$**, m	Link
1	Nickel, pentagon-dodecahedron	-	570	0,935	512	6,56	[13]
2	Nickel, pentagon-dodecahedron	-	700	0,96	310	5,49	[13]
3	Ceramics, pentagon-dodecahedron	1,5	-	0,8648	540	-	[34]
4	Ceramics, pentagon-dodecahedron	1,5	-	0,875	500	-	[34]
5	Ceramics, pentagon-dodecahedron	1,5	-	0,8306	680	-	[43]
6	Ceramics, pentagon-dodecahedron	1,5	-	0,7929	830	-	[34]
7	Ceramics, pentagon-dodecahedron	3,0	-	0,905	400	-	[34]
8	Ceramics, pentagon-dodecahedron	3,0	-	0,905	390	-	[34]
9	Ceramics	1,0	-	0,97	-	-	[35]
10	Ceramics	-	2373	0,89	605,7	1,5	

Table 2. Geometrical characteristics of packed HPCM

3.4 Dependence of specific surface attachment on the value of equivalent diameter

Below are the results of generalization of experimental data on the basic geometric characteristics of HPCM accessories, as well as various bulk and regular tips for heat and mass transfer processes as they relate to the hydraulic radius (equivalent to the diameter of the channel) packed column apparatus. Our results generalize the results of [1, 21, 28-33] in the form of dependence of specific surface of the packing - **a** the value of equivalent diameter - $\mathbf{d_e}$ represented on the graph (see fig. 5).

Presented on Fig. 5 results shows that an increase equivalent to the diameter of the packing from the $\mathbf{d_e} = 2 \bullet 10^{-3}$ m to $\mathbf{d_e} = 10^{-2}$ m (five times) leads to a decrease in the specific surface area from 1700 m^2/m^3 to 350 m^2/m^3, there are also about 5 times.

Presented in Fig. 5 dependence of the surface - **a** from the equivalent diameter - $\mathbf{d_e}$ for packing of different shapes, bulk materials and regular, from ceramics and metals was universal. Dependence $a = f(d_e)$ for all industrial attachments with a deviation not exceeding ± 10%, described by the equation:

$$d_e = A \cdot (a)^n \tag{11}$$

Here: A = 57319; n = -1,3985.
As seen from the graph shown in Fig. 5, the proposed equation (11) satisfactorily correlates well the experimental data of Kozlov [21] on ceramic head of HPCM.

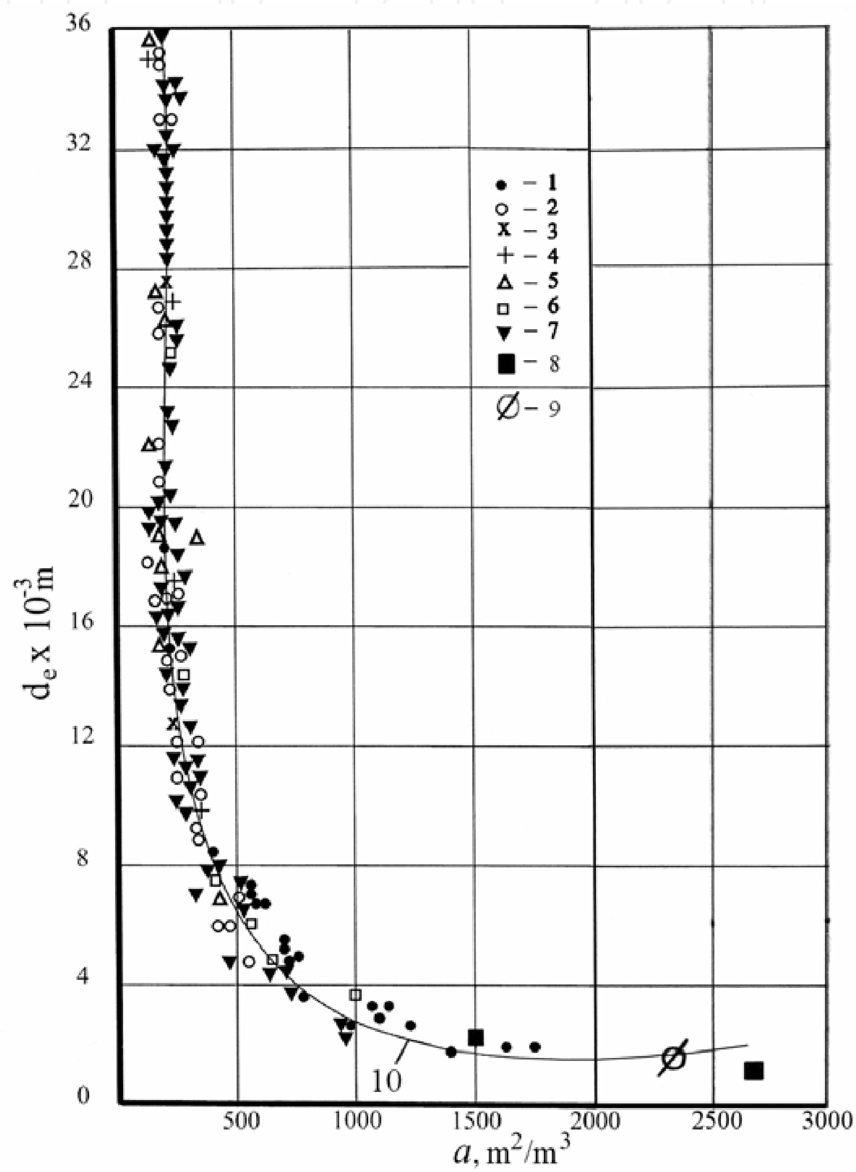

Fig. 5. Dependence of specific surface bulk and regular tips - **a** the value of equivalent diameter - $\mathbf{d_e}$**;** 1 - various bulk packing according to the Polevoy [28]; 2 - bulk packing according Vedernikov et al [29]; 3 - bulk packing according Kolev et al [30]; 4 - bulk packing "Inzhehim - 2000" according to the Laptev and Farahov [31]; 5 - regular packing according to [1, 29]; 6 - bulk packing according to [32]; 7 - bulk packing according to [33]; 8 - ceramic packing of HPCM according to [21]; 9 - ceramic packing of HPCM on the results of our experiments; 10 - calculated according to our equation

4. Experienced stands and methodology for conducting experiments

The study of aerodynamics HPCM samples were carried out on a laboratory setup in the apparatus with a diameter of 100 mm. Height experienced packing layer was 40 mm. The support grid for the packing was carried out in a grid of stainless steel 1 mm thick with a cell size of 7x7 mm. The experimental setup is shown in Fig. 6.

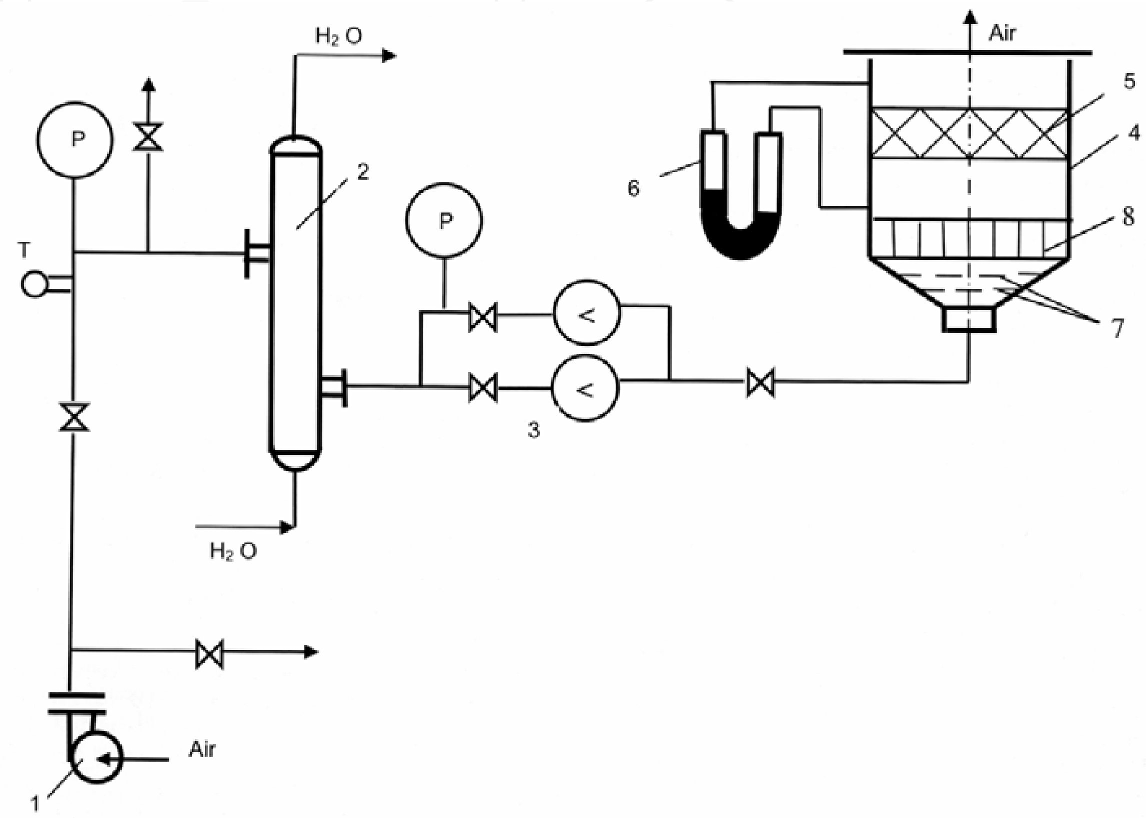

Fig. 6. Scheme of experimental equipment: 1 - air tank; 2 - heater; 3 - diaphragms; 4 - cylinder mechanism ∅ 100 mm; 5 - block of high porosity material sedimentation; 6 – differential pressure gauge, 7 –graded lattice; 8 - honeycomb

During the experiments, controlled the flow of the gas phase and the pressure loss in the layer of the packing. Gas flow in the test apparatus 4 with a packing 5, measured apertures 3, and pressure loss - a standard pressure switch 6 designs TCXA with the price scale division of 1 mm water column.

The experiments were conducted in a range of load variation on the gas, the corresponding average linear velocities in the calculation of the total cross section of empty vehicle from 0,3 to 1,2 m/sec. The set of gas distribution grids honeykomb 7 and 8 in the experimental apparatus 4 in accordance with the recommendations of [7] aligns the velocity field of gas flow at the entrance to the subject block attachments. The velocity profile was monitored during the preliminary experiments in the empty apparatus without attachment with the Pito tube.

Investigation of velocity field and the degree of turbulence on the air outlet of the experimental ceramic samples HPCM performed on a specially designed stand to test the individual elements of the nozzle [15] LEI (r Kaunas, Lithuania) using a precision hot-wire system equipment «DISA 55M».

Use of the equipment and experimental plot of the stand shown in Fig. 7.

Besides the above mentioned hot-wire apparatus used a tape recorder company Lipeks and Fourier analyzer firm Gevlet-Pakkard. Static pressure was measured by sensors and analog device company Gëttingen Baldvin Messtehnik. Pilot plant itself is an open aerodynamic contour. As in the first series of experiments, experimental plot device included a leveling device in the form of gas distribution grids and perforated honeykomb that ensures uniform velocity fields and turbulence intensity at the location of the studied sample packing.
Measurements of the velocity profile and the degree of turbulence performed directly on the output stream from the test element packing at a distance of 10, 30 and 60 mm from the packing exit (see fig. 7).

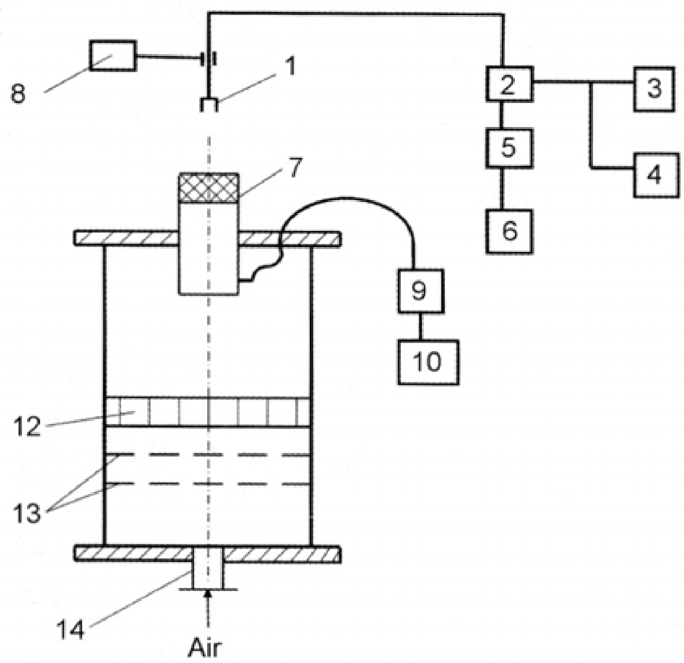

Fig. 7. Experimental section of bench and measuring block-scheme: 1 - velocity gauge; 2 - anemometer; 3 -voltmeter; 4 - quadratic voltmeter; 5 - tape recorder; 6 -analyzer of Furje; 7 - block high porosity material of sedimentation; 8 - mechanism of moving velocity gauge by X-Y axes; 9 - static pressure gauge; 10 - second pressure gauge; 11 - experimental apparatus; 12 - honeycomb; 13 -grid of gas distribution; 14 - entering branch

The diameter of the test sample nozzle was 50 mm, thickness - 20 mm, and pore size in different samples varied in the range from 0,4 to 1,8 mm. In addition to the hydraulic resistance in these experiments were carried out special experiments to measure the dependence of the degree of turbulence of the gas flow from the **Tu** Reynolds number $\mathbf{Re_D}$ samples packing with equivalent pore diameter $\mathbf{d_e}$ = 0.4 mm and 0.9 mm and 1.8 mm.
Here $\mathbf{Re_D}$ - Reynolds number, relative to the diameter of the column **D**:

$$\mathrm{Re}_D = \frac{W_0 \cdot D}{\nu} \tag{12}$$

In this series of experiments, Reynolds numbers were: $\mathbf{Re_D}$ = 6800, 15600, 27700.
The degree of turbulence of the gas flow **Tu** was estimated by the relation:

$$Tu = \sqrt{W_0^{'2}} \,/\, W_0, \% \tag{13}$$

Here $W_0^{'2}$ - standard deviation from the mean flow velocity, m / sec.

Fig. 8 shows the basic scheme of the experimental setup RXTU them. Mendeleev [34], designed to measure the hydraulic resistance in the flow of the fluid flow through the samples HPCM.

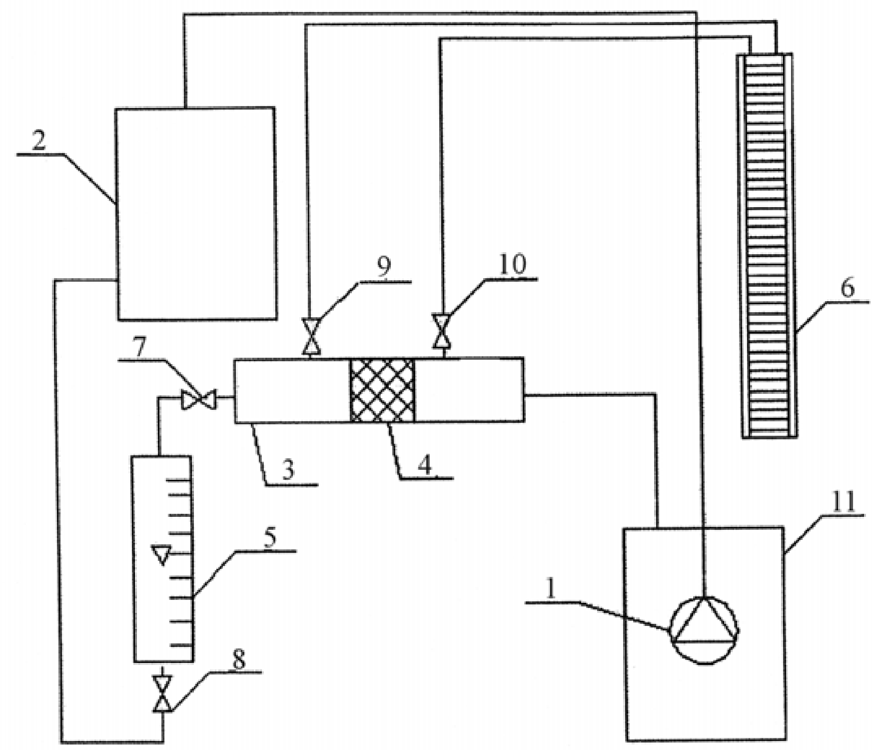

Fig. 8. Experimental setup for determining the hydraulic resistance in the flow of fluid flow through the ceramic samples HPCM produced by slip technology [34]: 1 - drain pump, 2 - pressure tank, 3 - working chamber, 4 - sample of a ceramic carrier based on HPCM, 5 - rotameter, 6 - U-shaped differential manometer, 7 ¸ 8, 9, 10 – valves; 11 - reception tank

5. Hydraulic resistance of the ceramic head HPCM

5.1 Filtration of the gas flow

Fig. 9 presents the results of our experiments to measure the pressure loss **ΔP/H** airflow through the sample HPCM with the following geometrical characteristics: the linear dimensions of time - from 1,0 to 2,0 mm; $\mathbf{d_e}$ = 1,5 mm, weight of 1 m^3 - 605.7 kg / m^3; porosity - 0,89 m^3/m^3. As can be seen, the experimental data fit satisfactorily on a single curve.

Fig. 10 in the semi-logarithmic coordinates shows the dependence of **ΔP/H** on the Reynolds number $\mathbf{Re_D}$ on the results of our experiments [18] with a ceramic packing of HPCM with equivalent pore diameter $\mathbf{d_e}$ = 1,8 mm.

Comparison of hydraulic resistance of the tested samples of ceramic packing HPCM with other types of industrial attachments and dry granular materials is presented in Fig. 11 in logarithmic coordinates in the form of dependence $\mathbf{\Delta P/H = f(W_0)}$. From the Fig. 11 graphs can be seen that the linear velocity of air flow $\mathbf{W_0} \approx 0{,}5$ m/s occurs characteristic kink curves, which indicates a change in flow regime of gas flow in a layer of packing. From the Fig. 11 experimental data that the samples from the packing HPCM have an order of magnitude lower hydraulic resistance as compared to granular materials at similar values of $\mathbf{d_e}$.

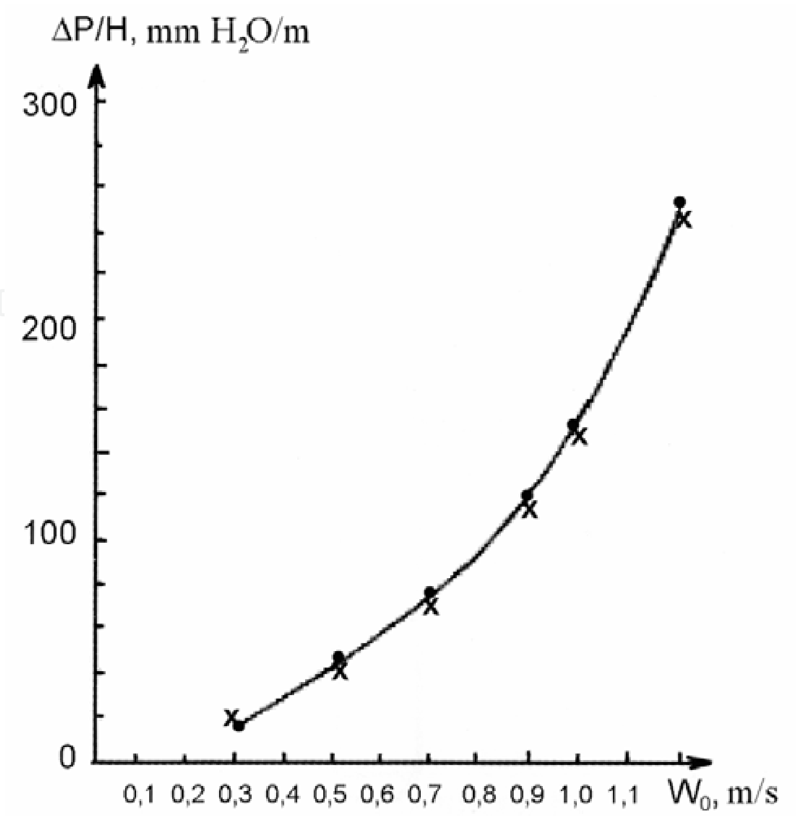

Fig. 9. Dependence of pressure loss **ΔP/H** of the air velocity **W_0** dry ceramic head of HPCM; ● - first experiments; x - repeated measurements

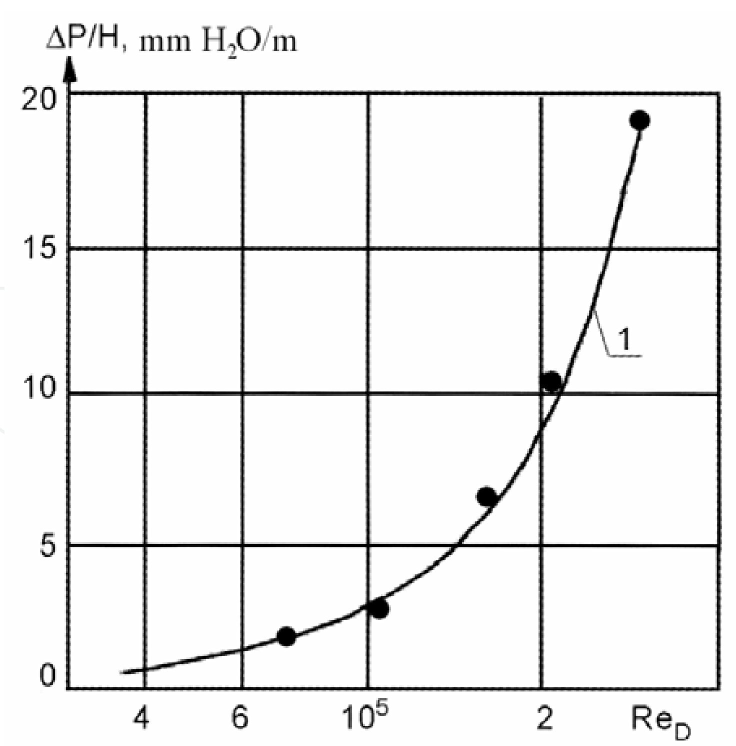

Fig. 10. Dependence $\Delta P / H = f\left(\mathrm{Re}_D\right)$ for dry sedimentation from ceramic high porosity material with equivalent diameter of pore **d_e**= 1.8 mm

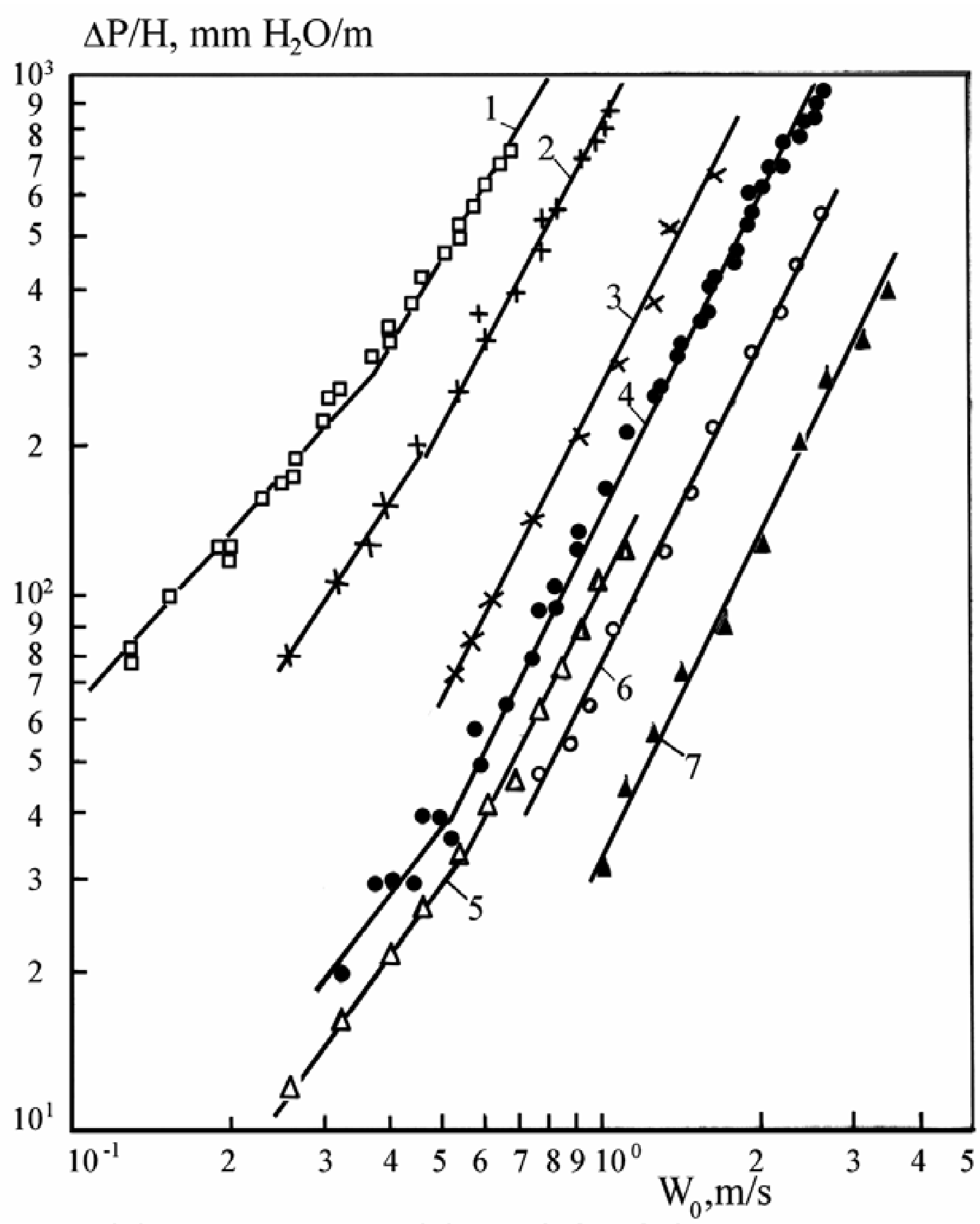

Fig. 11. Dependence $\Delta P / H = f(W_0)$ for various attachments: 1 - coal "SKT-2, cylinders ∅ 1,5 x5 mm; 2 - catalyst tablets ∅ 6x6 mm; 3 - HPCM, $\mathbf{d_e}$ = 0,9 mm; 4 - Block catalyst, **ε** = 0,5, $\mathbf{d_{hol.}}$ = 4,7 mm; 5 - Ring Rashig, ceramics, 10x10x2 mm; 6 - ring Rashig, metal, 10x10x1 mm; 7 - HPCM, $\mathbf{d_e}$ = 2,75 mm

5.2 Fluid filtration

The study of fluid flow through the samples from HPCM conducted Grunsky and others [34] and Kozlov et al [21]. In this paper Beklemeshev et al [35] in their experiments observed that the values of the pressure drop obtained with the same flow rate of the samples HPCM compiled in module, higher than those for the whole sample, with values exceeding **ΔP** greater, the higher the number blocks in the module. Similar situation was observed in [36] when laying block Honeycomb Catalysts "overlap" when overlapping channels in the blocks reached 10%. It can be assumed that the cause of such phenomena is a violation of the

homogeneity of the structure of storage material in the plane of the junction of the samples, since the ends of the jumper of one sample does not coincide with the terminal jumpers another, forming a cross-section with an area smaller than the average cross-sectional sample.
We have completed processing of experimental data [35] to study the pressure drop in the samples HPCM in logarithmic coordinates in the form of dependence **$\Delta P = f(W_0)$**. This dependence is shown in Fig. 12. As seen from the data shown in this figure, the experimental data [35] describes a system of direct, regularly increase with the velocity - **W_0** and height of blocks attachments - **h**. This data **ΔP** for **d_e** = 1,26 mm are higher than for **d_e** = 2,45 mm.

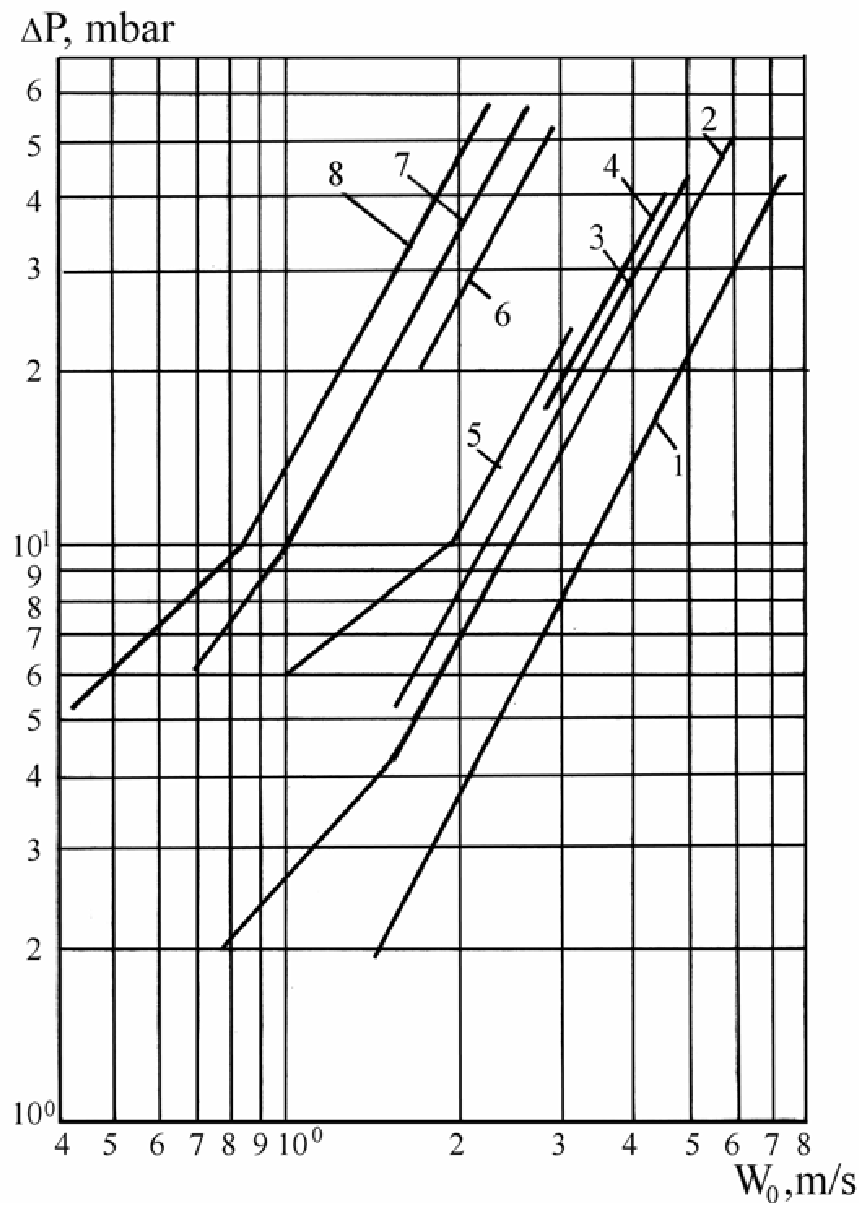

Fig. 12. The dependence of the differential pressure on the rate of filtration of fluid samples of ceramic packing HPCM with different diameter of the cell and at different height blocks attachments: curves 1 ÷ 4 - d_e = 2,45 mm: 1-h = 70mm, 2-h = 140mm, 3-h = 210mm, 4-h = 280mm; curves 5 ÷ 8 - d_e = 1,26 mm: 5-h = 70mm, 6-h = 140mm, 7-h = 210mm, 8-h = 280 mm

In the literature, very little information about the hydraulic characteristics of the packing HPCM filtering liquid at low speeds, which can be explained by the complexity of measuring small pressure drop. Fig. 13 shows the dependence **ΔP = f(W_0)** to filter water through a packing HPCM with **d_e** = 1,26 mm at a flow rate 0,01-0,025 m/s, we have constructed according to the Grunsky and others [34] in logarithmic coordinates. The height of the experiments, as is evident (see fig. 13), was different. It may be noted that the data at a block height **h** = 15mm a few fall out of the picture. However, curves 1-3 in this figure show the regular increase **ΔP** with increasing altitude blocks attachments.

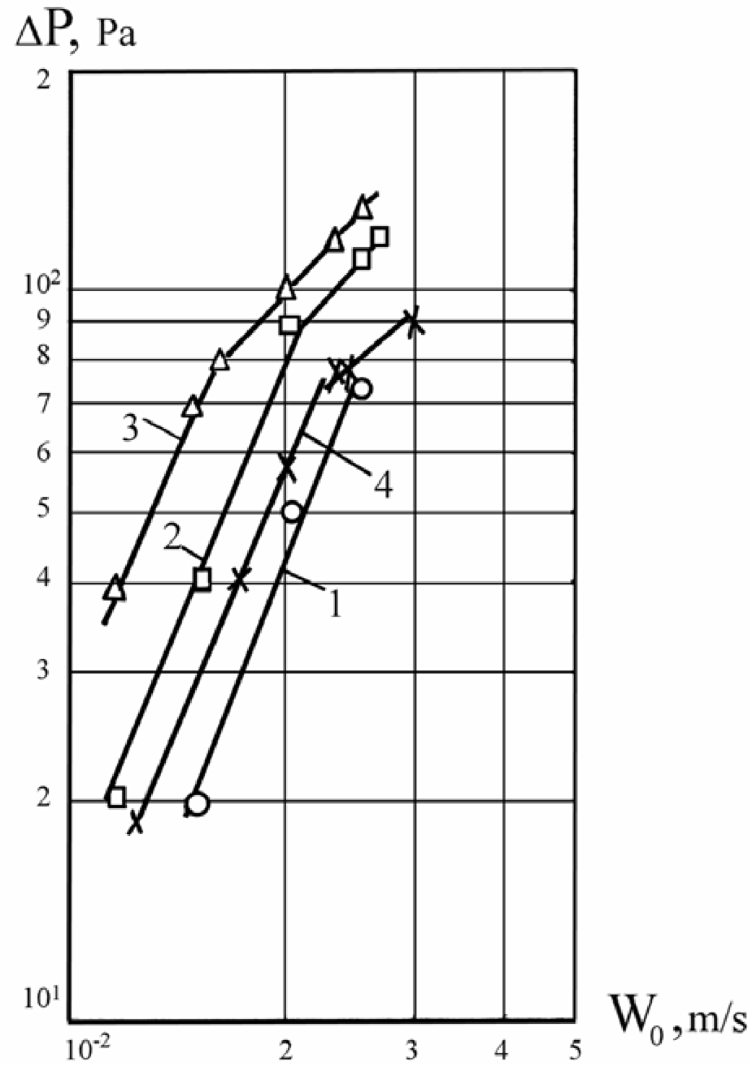

Fig. 13. Dependence of hydraulic resistance **ΔP** of the fluid velocity according to the Grunsky and others [34] for fine-meshed blocks (**d_e** = 1,26 mm) packing HPCM varying height **h**: 1-h = 20mm, 2-h = 40mm, 3-h = 60mm, 4-h = 15mm

6. The velocity field and turbulence of the gas flow in the samples from HPCM

Results of preliminary test experiments on the velocity field of airflow in the empty apparatus without attachment shown in Fig. 14.

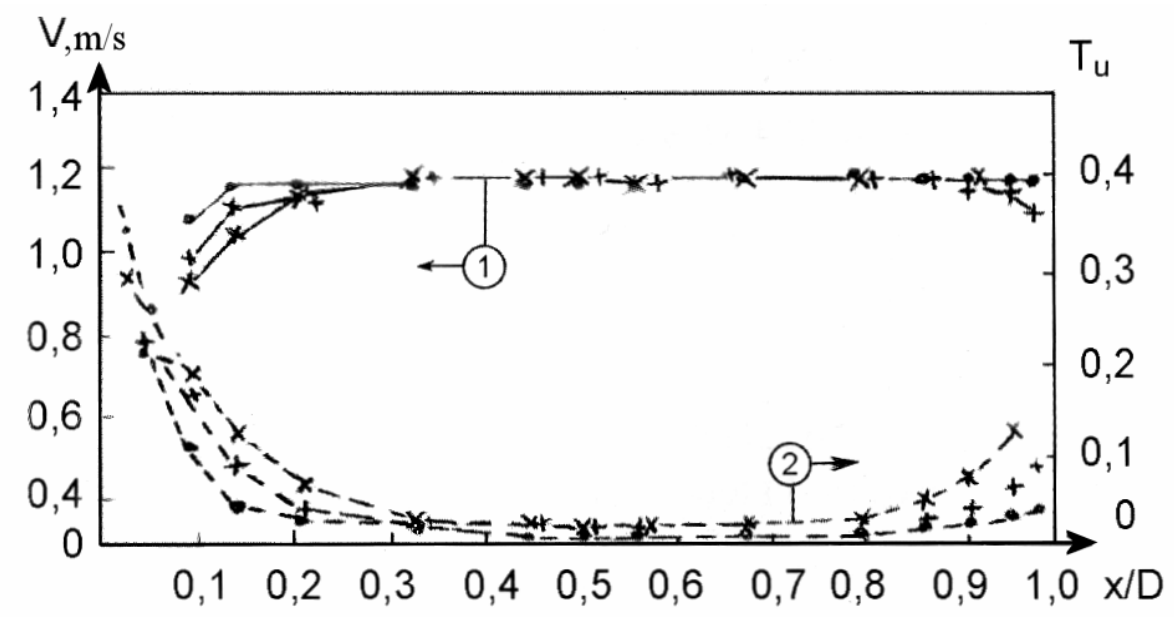

Fig. 14. Profile of creasing longitudinal velocity of stream - **V** and degrees of turbulence - **Tu** in identical sections of empty experimental apparatus without sedimentation at the charge corresponding number $\mathbf{Re_D}$ = 24400 at various distances from a cut tip: ● - distance from the packing exit $\boldsymbol{l}$ =10 mm; + - distance from the packing exit $\boldsymbol{l}$ = 30 mm; x — distance from the packing exit $\boldsymbol{l}$ = 60 mm

Fig. 15 shows the profile of the longitudinal air flow - **V** and the degree of turbulence - **Tu** in the wind tunnel layer for a block of ceramic nozzles HPCM Reynolds numbers $\mathbf{Re_D}$ = 6800 and $\mathbf{Re_D}$ = 15600.

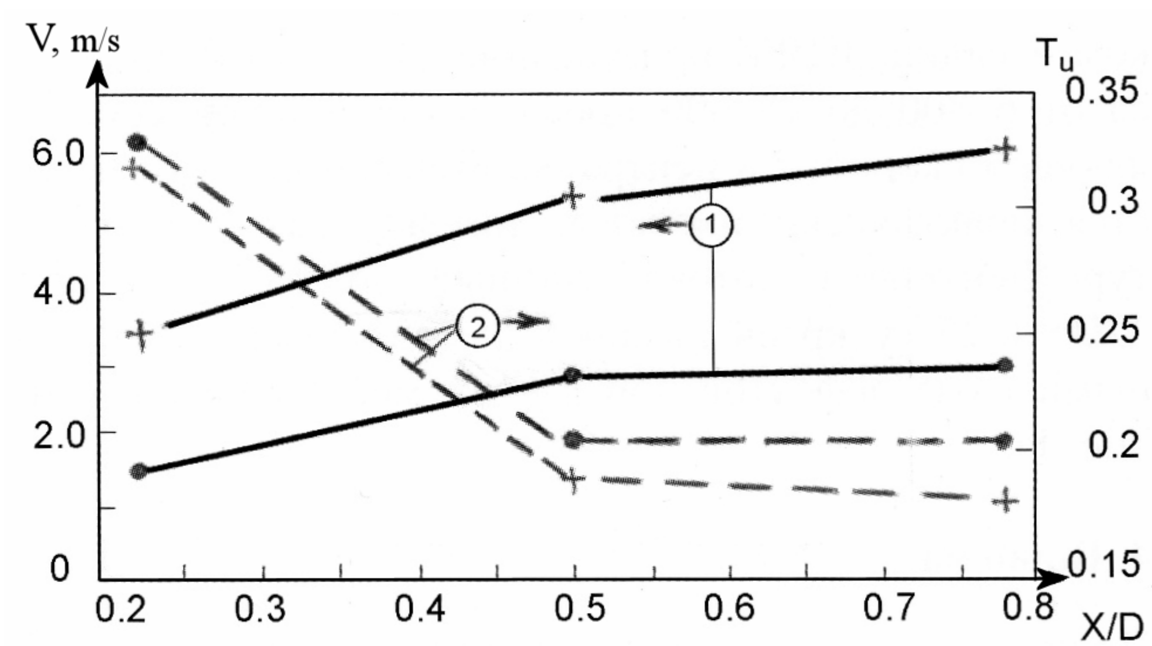

Fig. 15. Longitudinal component of velocity of stream **V** and degrees of turbulence of stream in aerodynamic environment behind the block of sedimentation high porosity material at different numbers $\mathbf{Re_D}$: ● - $\mathbf{Re_D}$ = 6 800; + - $\mathbf{Re_D}$ = 15600

As can be seen from the graph presented in Fig. 15, the longitudinal component of velocity - **V** in the aerodynamic wake behind the block of packing HPCM with increasing Reynolds numbers from 15600 to 6800 profile of the longitudinal velocity in the central part of the packing remains essentially flat, as well as the degree of turbulence. Data on **V** and **Tu** at **X/D** <0,25 (at the edges of the packing) are not typical because of defects since at this point the packing (see picture in Fig. 2).
A comparison of data on the value of the degree of turbulence packing HPCM and immobile granular layer. The comparison showed that the magnitude **Tu** in all samples tested packing HPCM in 3 ÷ 10 times lower than the parameter **Tu** of the layer of grains, where he was, according to [6], 30-50%. At the packing HPCM samples tested value **Tu** is in the range from 4,6 to 16% in all-tried a range of Reynolds numbers (see Fig. 16).
In [19] based on the well-known Navie-Stokes equations using the finite element method is considered the hydrodynamic flow structure in the cell, isolated in a layer HPCM. The model is described in detail in [19].

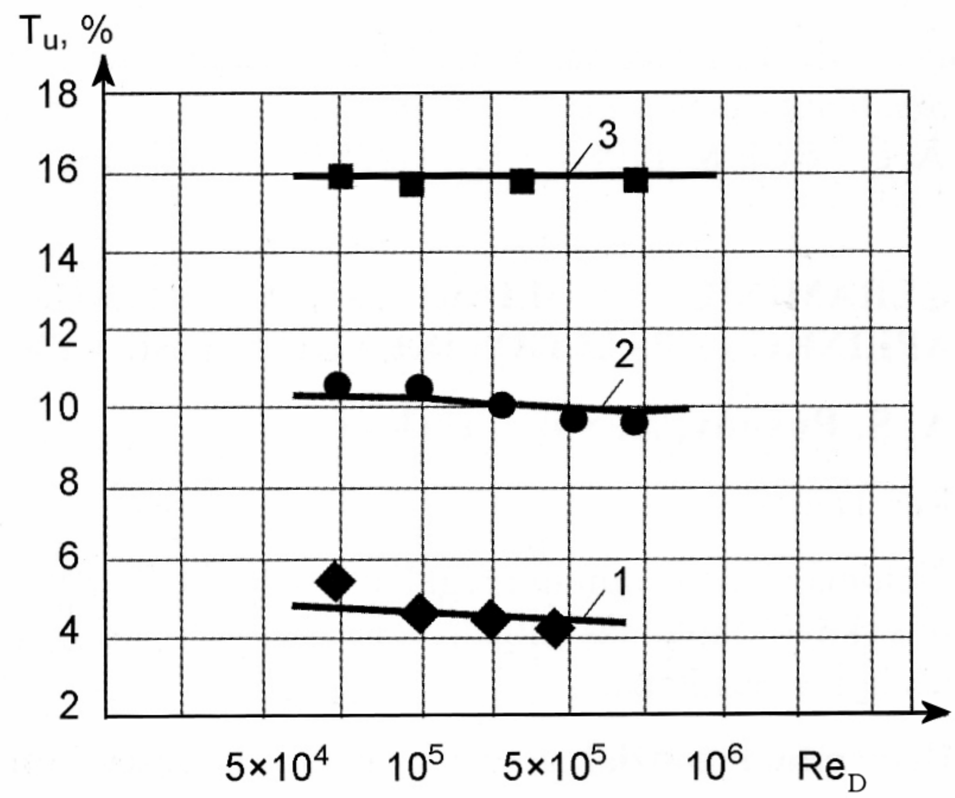

Fig. 16. Dependence of turbulence degree of stream **Tu** on Reynolds number $\mathbf{Re_D}$ for sedimentation from ceramic high porosity material with different size of equivalent diameter of pours: 1 - d_e = 0,4 mm; 2 - d_e = 0,9 mm; 3 - d_e = 1,8 mm

7. Findings

The results of aerodynamics testing of new ceramic packing of highly porous cellular materials have shown promising ceramic materials for the manufacture of packing HPCM for a wide range of chemical technology processes, including those for hardware design methods for cleaning absorption of harmful gases to protect the ambient air.

It is shown that the profiles of longitudinal velocity and the degree of turbulence of the gas flow in the aerodynamic wake behind a block of ceramic packing HPCM at Reynolds numbers $\mathbf{Re_D}$ = 6800 ÷ 15600 remain virtually flat, which proves the isotropy of the structure of the packing.

Found that the magnitude of hydraulic resistance in samples from the packing HPCM significantly lower compared with a layer of grains of other industrial attachments.

For the first time measured the degree of turbulence in a wind layer for the elements of the ceramic head HPCM. It was found that all samples tested the degree of turbulence is in the range from 4,6% to 16%, which is 3 ÷ 10 times lower compared to conventional granular materials as a layer of cylinders.

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