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Abstract. A series of experiments by air purification on fibrous filtering nozzles was made. It is experimentally shown that the fibrous filter can operate in a wide rate range. The degree of trapping of fine aerosols of glass was 99 *%* at a linear rate of 0.01 *m/s*. the degree of capture decreased to 85 *%* at the increasing of filtration rate up to 0.06 *m/s*. Dustiness of the air ranged from 3 to 5 *g/m*^{3} at the course of the experiment. Hydraulic resistance changed from 5 to 25 *mm* of water column. The calculated data of resistance and falling of pressure on fibrous filters are given; these data were received on the equations from various sources in comparison with experimentally obtained data. According to the results of series of experiments the amendment of the well-known Fuchsian equation is calculated for calculation of the resistance of fibrous air filter. This amendment considers a form and defects of surface of the fibers received by centrifugal-spinneret method.

1. Introduction

Currently the polymeric fibrous materials are widely used in the industry as filters for air purification from dust and aerosols, for capture of hydrocarbons. Compared with the fibers from vegetable raw materials the polymeric fibrous materials have greater chemical resistance and can work in wide range of temperatures and pH environment [1]. Besides, these materials have a low moisture capacity, high resistance to ionizing radiation and to bacterial influence.

Possibility of gas purification in devices of the filtering type considerably extends on the basis of the fibrous polymeric filtering materials. In the USSR for thin purification of ventilating emissions of the enterprises (including the nuclear industry) the cell filters with the volume nonwoven filtering fabric (for example, the *FVNR* or *FPP* type) were used. The filtering materials of *FPP* type (Petryanov's filters) were manufactured from perchlorvinyl fibers with diameter from 1.5 to 2.5 microns by *TU* 16-16-2813-84, these materials are used in filters of thin purification and for production of means of individual protection of respiratory organs (*MIPRO*) of "Petal" type. *FVNR* fibrous material is a nonwoven material of polyethylene or polypropylene fibers with diameter of 25

40 μm. The production of these materials was left outside of Russia, and therefore it was necessary to find competitive alternative to these materials.

The following advantages are characteristics of the fibrous polymer of nozzles:

•   a higher degree of gas purification from suspended particles compared to gas purification devices of other types;

•   versatility (the ability to capture solid particles in dry form and liquid particles of the fog);

•   ability of filters to work at any pressure gases;

•   good degree of purification at low concentrations of suspended particles in the purified gas (portions of *mg* per 1 m^3 of cleaned gases);

•   stability of purification and less dependence from the physical and chemical properties of entrained particles, expense of gases than, for example, at the electrical purification;

•   possibility of using of chemically resistant materials;

•   easy operation.

2. Experimental

Accordingly we developed a centrifugal-aerodynamic method and installation for receiving fiber on its basis. As a result the layers of fibers are parallel to surface of form-building mandrel. Also the interlacings of threads are on depth of sample of fibrous material. According to the standard opinion this structure is considered nondirectional. Thus elementary fibers are characterized by tortuosity and thickness with different values. The material has pores of complex geometry; dimensions of pores are defined by many technological, physicochemical and other factors. Material differs in high mechanical durability due to interaction between fibers.

The essence of the method is the formation of film of melt of thermoplastic inside of the rotating reactor and the formation of the fibers on the edge of this reactor. The difference of this method from known is that the heating of melt of thermoplastics until the desired viscosity is ensured by film mode of flow inside of rotating reactor with linear rate more than 10 m/s on the edge by heating of reactor walls. The molten fiber at the outlet from the reactor is cooled by air flow [2]. Control of temperature and flow rate of the melt in the installation, the rate of rotation of reactor and some other parameters allowed us to produce fibers with originally specified diameter and other physical and mechanical properties. These fibers have high sorption properties with respect to hydrocarbons and other air pollutants.

The filtration characteristics of the materials obtained from the wastes of polyethylene and polypropylene are significantly higher than those fibers obtained from commodity polymers by standard techniques. This is due to the influence of high-temperature method of producing fibers in air, which leads to structural changes of the polymer at the molecular level. In turn, it leads to an increase of specific surface area and surface energy of the resulting polymeric fibers and also to the appearance of carbonyl and hydroxyl functional groups on the surfaces, which give the properties of ion exchangers to the fibers. The obtained fibrous materials advantageously differ in their physical and chemical characteristics from the traditionally used the Petryanov's fabric and can be recommended for systems of submicron purification of air from pollutants of natural and anthropogenic origin.

The installation for testing of fibrous filters is shown in figure 1.

The generator of dustiness was used for the formation of contaminated dust-gas mixture supplied to the volume of the filter; the researched filtering partition from a mixture of polypropylene fibers was installed in this filter. Particles of glass with particle sizes from 0.1 to 3.0 μm were used as the pollutant of air. Air was supplied to the lower part of the generator of dustiness by blower through the receiver and the valve.

Due to this, the suspended particles of glass were carried away from the generator of dustiness; particles were moved into the studied filter and then into the sampler. The sampler with porous partition with pore size of 0.001 μm (porous metal ceramics) is intended for catching of the dispersed particles in dusty air, passing through the studied filtering partition in the filter. Controlling of air consumption and, therefore, the rate of filtration was carried out by indicators of rotameter, and this

process regulated by the valve. The particles of glass were moved from the hopper by auger into the generator of dustiness. The dust content in air was regulated by the number of turns of the auger. The exemplary manometer was used for measuring of the aerodynamic resistance of the filter.
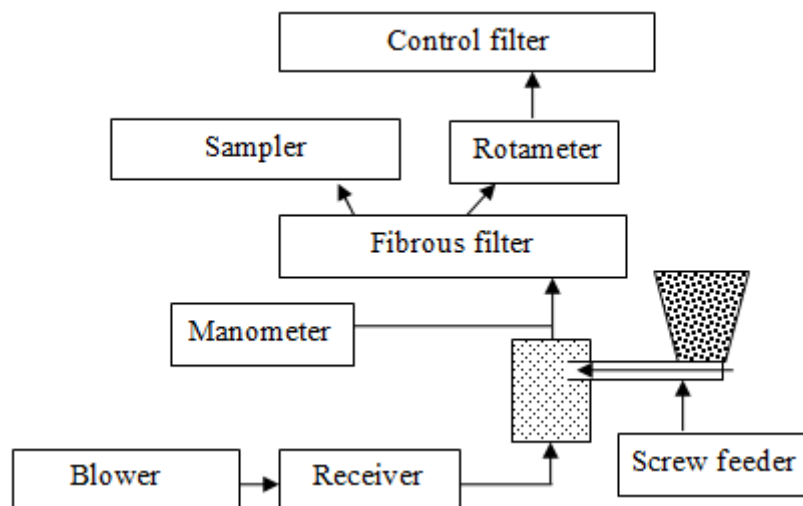
Figure 1. Scheme of experimental installation for testing of fibrous filters on efficiency of air purification from dust.

A control filter was used for additional control catching of dust particles; in the case of work with toxic substances it was used for preventing of hitting of those particles into the atmosphere of the laboratory space. Determination of the efficiency of work of the filter was carried out by the gravimetric method by weighing the filter and sampler on an analytical balance. The technique allows sufficiently accurately determining the efficacy of the filter. Particles of glass with particle sizes from 0.01 to 1.0 μm were used in experiment.

As a result of the conducted research it was found that the fibrous filter can operate in a wide rate range. The degree of catching of fine aerosols of glass was 99% at a linear rate of 0.01 m/s. At increasing rate of filtration up to 0.06 m/s the degree of catching decreased to 85 %. Dustiness of the air ranged from 3 to 5 g/m^3 in the course of the experiment. Hydraulic resistance changed from 5 to 25 mm of water column. The possibility of using of designed fibrous filter material at rates of 0.06 m/s is the undoubted advantage, as fibrous filters from fiberglass, cermet, ceramic and granular filters operate at the rate range from 0.01 to 0.02 m/s; the Petryanov's filters (*FPP*-15-1.7) can operate only at the rates smaller than 0.01 m/s.

The special catching device was used to carry out the experiments for catching of dust on the fibrous filters from recycled materials with the parallel use of standard filters *AFA*. It consists of the filter holder, filter from hydrophobic material of *FP* type with a working area of 20 cm^2 (*AFA-CPS*-20), aspirator, allowing the passage of air through the filter with volume rate of 20 l/min, and the above-described non-standard device.

Multi-stage air cleaning system used for cleaning and conditioning of atmospheric air with an initial dust content of up to 1.0 mg/m^3 (at the possible short-term content of dust up to 10 mg/m^3) moved into "clean" industrial premises.

On first stage the air filters of third class were used and intended for catching of dust particles with size from 5 to 50 μm; those filters were located before the electric air heaters. The filter consists of casing, the fixed zigzag lattice of rods strengthened in casing. The filter material is manually placed on a lattice and fixed by the clamping brackets on bends. Thus corrugations are formed; the filtering surface develops by four times in comparison with the entrance section of the filter. Dusty material removed from the filter and replaced on new at reaching the maximum of allowable resistance.

3. Results and considerations

In our opinion an approximate processing of the obtained results by the method of Davis the most accurately describes the process of purification of gases. A more precise definition of the geometric structure of fibers of the investigated filter has shown that mechanism of touch and diffusive mechanism are the main mechanisms of catching of aerosol particles. These can explain the insignificant hydraulic resistance and ability to regeneration of fibrous filters. In addition, according to the basic provisions of the theory of filtration the most effective filters are made from compositions of fibers from different materials and diameters. The developed production technology of fibers from secondary raw materials allows receiving the filtering material with such structure.

Table 1 shows the calculated data of the resistance and pressure drop in fibrous filters obtained from equations of various sources compared to experimental data.

Table 1. The results of calculations of the resistance coefficient and pressure drop in fibrous filter with diameter of fiber 100 μm.

H_f, m	α	u, m/s	K_f				ΔP_l, Pa
			1		2	3	
0.16	0.19	0.0885	$K = 4\alpha\,/\,-1.15 \cdot ln\alpha - 0.75$ (1)		[3]	0.666	943
0.16	0.19	0.0885	$K = 2B\alpha\,/\,-0.5 \cdot ln\alpha + \alpha - \alpha^2/4 - 0.75$ (2)		[5]	$B = 2.0$ $K = 4.72$	6684
						$B = 1.5$ $K = 3.5$	5013
0.16	0.19	0.0885	$K = 4\alpha\,/\,-1.15 \cdot ln\alpha - 0.5$ (3)		[6]	0.539	763
0.16	0.19	0.0885	$K = 4\alpha\,/\,-1.15\,ln\alpha - 0.5$ (4)		[6]	0.539	763
0.46	0.222	0.0461	$K = 4\alpha\,/\,-1.15 \cdot ln\alpha - 0.75$ (5)		[3]	0.88	1870
0.46	0.222	0.0461	$K = 2B\alpha\,/\,-0.5 \cdot ln\alpha + \alpha - \alpha^2/4 - 0.75$ (6)		[5]	$B = 2.0$ $K = 8.3$	17681
						$B = 1.5$ $K = 6.2$	3262
0.46	0.222	0.0461	$K = 4\alpha\,/\,-1.15\,ln\alpha - 0.5$ (7)		[6]	0.722	1531

The calculations are performed for model filter with a filtration area of $19.625 \cdot 10^{-4}\ m^2$. The following symbols are shown in the columns of the table 1: 1 - the equation, 2 - source of information, 3 - result of the calculation, H_f - height of the filter (m), A - relative packing density (numerically equal to the volume of fibers in volume of the filter), u – the rate of filtration, B - the coefficient of heterogeneity of the packing fibers (at b = 2 all fibers parallel to each other and perpendicular to the flow), K_f - resistance coefficient of filter, ΔP_l - head loss on the filter, defined by the equation (8) [4]

$$K_f = \Delta P_l \cdot r^2 \,/\, u\mu H \,. \qquad (8)$$

Calculations by Fuchsian equation (1) in [3] show the closest to the experimental results of pressure drop and resistance coefficient of the fibrous filter. The experimental data obtained on the installation according to figure 1.

Figure 2 shows the results of calculations of the resistance coefficient by equation (1) [3] and results experimentally obtained on the filters with fiber with average nominal diameter 2.2, 30, 50 and 100 mkm with porosity 80.56, 82.2, 82.6 and 83.6%, respectively.

As can be seen from figure 2 the experimentally obtained coefficient of resistance increases in comparison with the calculated coefficient with the increase in fiber diameter; it is due to one factor. The number of defects on the surface of the fibers and shape of section of the fibers increase with increase of diameter of the fiber. It increases the turbulence of the air flow in the filter and, as a consequence, the coefficient of resistance.

These defects of fiber form almost did not influence on the results of experiments at the filtering purification of water with higher density and viscosity, but these defects became apparent in experiment with purification of air.

However, the experimental results are described quite accurately by the linear equation (9)

$$K_e = -0.0016D + 0.6955,$$ (9)

where D is the diameter of the fiber, which can be used as a correction factor to equation (1) [3], and then:

$$K = (4\alpha / -1.15 \cdot ln\,\alpha + 0.75) + K_e = 4\alpha / -1.15 \cdot ln\,\alpha + 0.016D - 0.0545,$$ (10)

K_e is actually a measure of difference of the resistance coefficient of the fibers (obtained by centrifugal-spunbond method) from the typical fibers with section in the form of a circle.
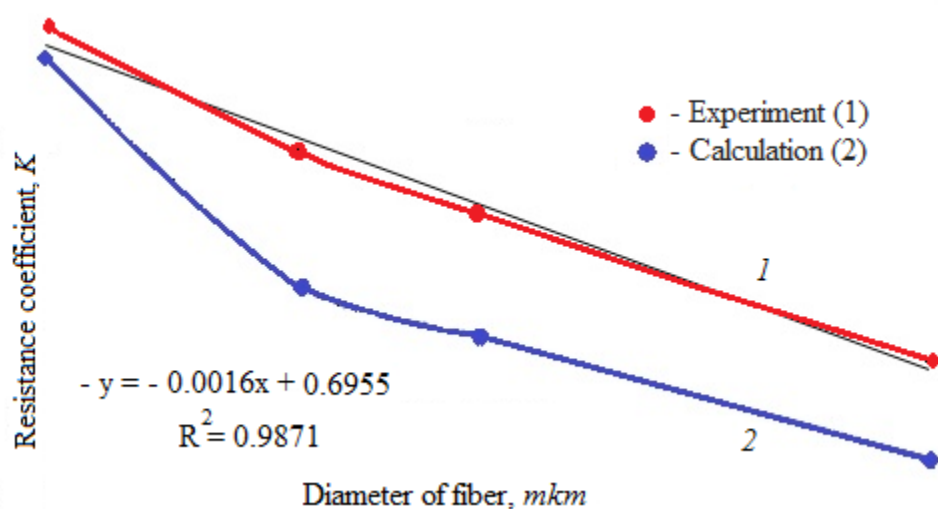
Figure 2. Dependence of the resistance coefficient on the diameter of the fiber.

4. Summary
According to the results of series of experiments the amendment of the well-known Fuchsian equation is calculated for calculation of the resistance of fibrous air filter with regard to form and surface defects of the fibers.

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