a sphere; x, distance along the drum axis; r, distance from particle to drum axis; φ, angle between vertical axis and current radius-vector $\overline{r}$; $\overline{r}^0$, unit radius-vector in the $\overline{r}$ direction; $\overline{p}^0$, transverse direction; D_d, drum diameter; v_x, projection of particle velocity in x direction; v_r, radial velocity component; v_φ, angular velocity of particle; t, time; ω, angular velocity of drum.

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PRESSURE DISTRIBUTION IN GAS FLOW IN THE PRESENCE OF A FIBROUS FILTER IN THE CHANNEL

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The characteristics of gas flow through a fibrous filter in the presence of supercritical pressure drops are investigated.

Modern aerosol filters present porous systems of very long cylindrical fibers arranged in parallel planes randomly [1]. Their hydrodynamics, in particular of FP filters [2], has been well studied for relatively small velocities of the gas flows and small pressure drops at the filter [3-6]. For supercritical pressure drops when the ratio of static pressure behind the filter P_2 to the total pressure in front of the filter P_1 becomes smaller than 0.528 and the linear rates of filtration reach tens of meters per second, the gas flow in fibrous filters has not been investigated.

Isentropic gas flow in cylindrical channel [7] is known, which is a limiting case of gas flow through a filter whose resistance is equal to zero. The results of a computation of pressure distributions from the equation $P_1 = f(P_2, G)$ for different relative flow rates are given in Fig. 1 for the condition that the diameter of the channel is much larger than the mean free path of the gas molecules. Two characteristic zones can be separated out. In zone A, lying between straight lines I and II corresponding to equations $P_2 = 0.528P_1$ and $P_2 = P_1$, a decrease of P_2 for G = const results in a decrease of P_1. In zone B, lying between the straight line I and the ordinate, a change of P_2 for constant G does not effect P_1.

We introduce a quantity χ that is equal to the ratio of P_1 at any point on the curve $P_1 = f(P_2, G = \text{const})$ to the critical pressure P_{1*} at the intersection of this curve with line 1. Then zone A would be characterized by the values $\chi > 1$ while in zone B, $\chi = 1$.

Gas flow in multipath channels, i.e., labyrinths which are used, for example, in tube-machine construction [8], is also known. If the number of stages in the labyrinth is large, then in spite of the supercritical pressure drop between the input and the output of the labyrinth, the critical pressure drop at the last stage may not be reached. As seen from Fig. 1, the flow in the labyrinth differs substantially from the flow in a cylindrical channel discussed above; in zone B, χ is smaller than one. Thus, in spite of the supercritical pressure drop in the labyrinth as a whole, the decrease for P_2 for G = const leads to a decrease of P_1 everywhere.

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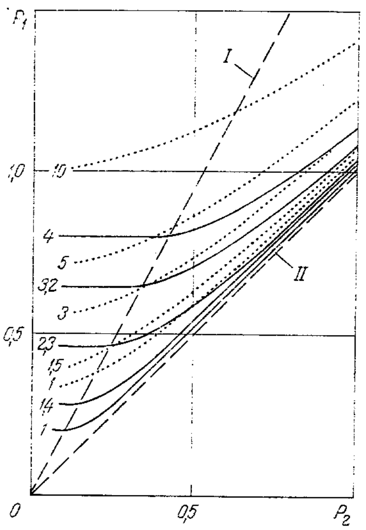

Fig. 1

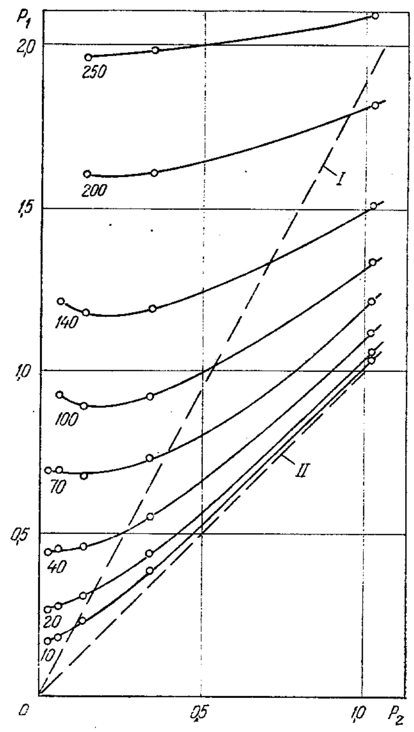

Fig. 2

Fig. 1. Pressure distribution in a channel (P_1, abs. atm) and at the end (P_2, abs. atm) of a cylindrical channel (continuous curves) and labyrinth (dashes) for isentropic flow of air. The numbers on the curves are relative flow rates of air G.

Fig. 2. Pressure distribution in front of (P_1, abs. atm) and behind (P_2, abs. atm) a fibrous filter FPP-70 during flow of different amount of air through it. Numbers on the curves are the specific flow rate of air Q, metric tons/m^2h.

We shall compare the flow in a cylindrical channel and the labyrinth with the flow in a real fibrous filter.

The filter FPP-70, chosen for the experiments, was prepared from perchlorvinyl fibers with mean hydrodynamic radius equal to $1.76 \cdot 10^{-4}$ cm. The thickness of the filter was 0.032 cm and the packing density, i.e., the fraction of the volume of the filter occupied by the fibers, was 0.057. For normal conditions and the velocity of the air flow equal to 1 cm/sec, the filter had a resistance of 0.42-mm water column.

The investigated sample was installed in a cylindrical channel of 8.5-cm diameter perpendicular to the direction of the air flow in a special filter holder ensuring continous air flow to the filter with diameter 1.5 cm. In order to prevent sag and break of the filter, it was supported on a grid made of wire of 0.025-cm diameter and with the transit cross section of the apertures equal to 0.0027 cm^2. The resistance of the grid was much smaller than that of the filter for all regimes and, therefore, it was disregarded. The flow rate of air cleaned by a special filter was determined by measuring washers. The retardation temperature measured by thermocouples was in the range 298 ± 10°K in all experiments. The static and total pressures required for computing the flow rate of air and the pressure drop at the filter were measured by group recording manometers.

The experimental results obtained for specific flow rates of air Q lying in the range $1 \cdot 10^4$ to $2.5 \cdot 10^5$ $kg \cdot m^{-2} \cdot h^{-1}$ and for pressures behind the filter in the range 1.02 to 0.027 abs. atm are shown in Fig. 2.

For small values of Q and relatively small rarefaction behind the filter, the pressure distribution curves are similar to those for labyrinth condensation (see Fig. 1). For $P_2 < 0.7$ abs. atm, a noticeable slippage of the gas flow begins at fibers of the given filter, since the mean free path of the gas molecule becomes comparable with the radius of the fibers. This leads to a decrease of the filter resistance. The air ostensibly passes through it more easily than through an equivalent labyrinth.

On increasing the specific flow rates of air and for pressure drops larger than 0.2-0.3 abs. atm, the turbulization of the flow at the fibers begins to affect the nature of the pressure distribution and a noticeable undercompression of the filter occurs. This leads to the result that in zone B the values of χ, computed, for example, for the point of intersection of a curve for $Q = 7 \cdot 10^4$ $kg \cdot m^{-2} \cdot h^{-1}$ with lines P_2/P_1 = const will be smaller than for points of intersection of the same lines with curves for smaller specific flow rates. For $P_2 < 0.2$ abs. atm, at the terminal segment of the curve for $Q = 7 \cdot 10^4$ $kg \cdot m^{-2} \cdot h^{-1}$ a small rectilinear segment is also observed which corresponds to χ = const, i.e., as if in the filter a flow appears similar to that occurring in a cylindrical channel at supercritical pressure drops.

For the flow of air with still larger specific flow rates, i.e., for example, $Q = 1 \cdot 10^5$ and $1.4 \cdot 10^5$ $kg \cdot m^{-2} \cdot h^{-1}$, the compression of the filter at pressure drops higher than 0.7 abs. atm leads to the result that the value of χ for $P_2 < 0.15$ abs. atm increases as the pressure behind the filter decreases.

For the maximum values of the investigated specific flow rates of about $2\text{-}2.5 \cdot 10^5$ $kg \cdot m^{-2} \cdot h^{-1}$ when $Re > 10$ the pressure drops were around 1 abs. atm even for small rarefactions behind the filter. Such loading resulted in an appreciable compression of the filter which ostensibly acquired a rigid structure. The air flow through the filter in the entire range of investigated pressures again becomes similar to the flow in a labyrinth.

It follows from these experiments that although the filter represents a very loose porous structure, unlike a cylindrical channel, the critical flow in the filter does not appear even for supercritical pressure drops. In these experiments the minimum attained ratio $P_2/P_1 = 0.04$. In certain regimes a flow similar to the critical flow was observed in the filter when for Q = const the decrease of P_2 had practically no effect on P_1. However, this was related to a compacting of the filter at large pressure drops.

The pressure distribution in the filter to a large extent coincides with the pressure distribution in the labyrinth. However, unlike the labyrinth, the filter can be compressed, which leads to a change in its structure and an increase in its resistance. Under these conditions during the air flow through the filter a qualitatively new phenomenon is observed, which is unknown for labyrinth or rigid porous structures: with the decrease of pressure behind the filter, the pressure in front of the filter must be increased in order to ensure constant specific flow rate.

The nature of pressure distribution in the filter for high velocities of gas flow and supercritical pressure drops is determined by a combination of a number of factors: turbulization of the flow at the fibers for $Re > 0.5$, development of slip at large rarefactions, and change of thickness and structure of the filter for large pressure drops.

All these factors must be taken into consideration in selecting and constructing filters. The filter in which the value of χ is the least has the best hydrodynamical qualities for supercritical pressure drops.

NOTATION

P_1, total pressure at the entrance to the cylindrical channel, labyrinth, or fibrous filter; P_2, static pressure at the end of the cylindrical channel, labyrinth, or fibrous filter; P_{1*}, total pressure at the beginning of the cylindrical channel, labyrinth, or fibrous filter at the point of intersection of the curve or pressure distribution with line $P_2/P_1 = 0.528$; Q, specific flow rate of gas; G, relative flow rate of gas; $\chi = P_1/P_{1*}$ for Q = const; Re, Reynolds number for mean hydrodynamic diameter of the wires.

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