Journal of Engineering Physics and Thermophysics, Vol. 70, No. 3, 1997

A PROCESS FOR PRODUCTION OF POROUS ELEMENTS WITH AN ASYMMETRIC STRUCTURE FOR TANGENTIAL MICROFILTRATION OF LIQUID MEDIA.

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UDC 66.096.5

A process for production of asymmetric porous structures of filtering elements by the method of vibration molding of a mixture of powders with different granulometric compositions is described. Theoretical and experimental curves of segregation modes versus vibration parameters are given.

Decontamination of liquids or separation of suspensions from liquids by filtering is the main stage that determines the quality and purity of the final product of modern chemical, oil-refining, food-producing, pharmaceutical, and other productions, and processes of purifying drinking and process water. In recent years rapid R&D in the field of filtration necessitates better quality of the product achieved by increasing the purification fineness and efficiency of industrial filters, their service life, and by decreasing the cost per production unit.

Various production operations are used to ensure a continuous filtration process. They are aimed at the periodic or continuous removal of sediments from the surface of the filtering element, which can be realized, for example, by countinuous washing-off with the suspension flow itself directed along this surface or by applying centrifugal forces [1]. This type of filtration is called tangential filtration. In tangential filtration the suspension flow is parallel to the surface of the filtering element. This gives rise to shear and buoyancy forces exerted on the settling particles and these forces prevent sediment formation. The filtrate flow is perpendicular to the flow direction through the filtering element [2-5].

While for tangential ultrafiltration, a broad class of polymer and mineral materials for filtering elements has been developed and is produced in series by some firms in the CIS and foreign countries, for microfiltration (separation of particles with the size varying from 0.5 to 10 μm), such materials have not been developed or they are in the research stage [2].

In what follows we describe the process of production of porous elements for tangential microfiltration with a better set of operation properties.

Analysis of publications [1-8] has shown that tangential ultrafilters with permeable plane filtering elements are used more and more extensively because they have the largest filtration surface per unit volume for an installation with elements of this type. This trend is also characteristic of microfilters. For this reason we consider the production process of plane, porous elements for tangential microfilters.

In some recent publications, in particular, in [9, 10], it is shown that to minimize the hydrodynamic resistance and, consequently, to increase the specific efficiency of an element and the filter as a whole with equal purification fineness, an asymmetric porous structure is most suitable, which consists, as a rule, of two layers, one of which is selective with a minimal thickness and the other supportive layer is thicker and has an average pore size that exceeds substantially the average pore size of the selective layer [9]. The pressure drops for filtering elements with symmetric and asymmetric porous structures [9] illustrate the effect to be achieved (Fig. 1).

The authors of [10] have shown that it is possible in principle to produce filtering elements with an asymmetric porous structure by methods of powder metallurgy but did not present the process parameters.

A number of production processes of powder metallurgy such as extrusion [11], cold forging of sintered blanks, bending over a cylindrical and spherical surface, and deposition of fine particles into a presintered blank

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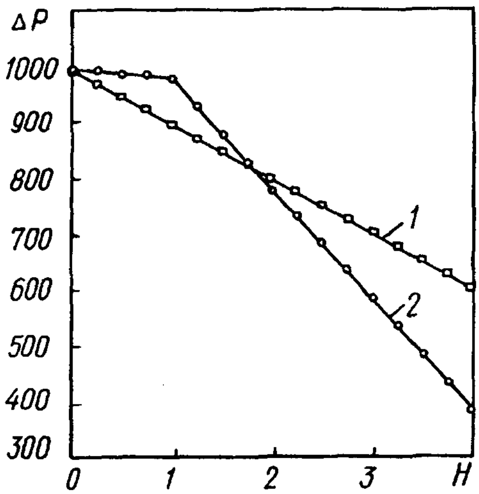
Research Institute of Powder Metallurgy, Minsk, Belarus. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 70, No. 3, pp. 362-367, May-June, 1997. Original article submitted December 9, 1994.



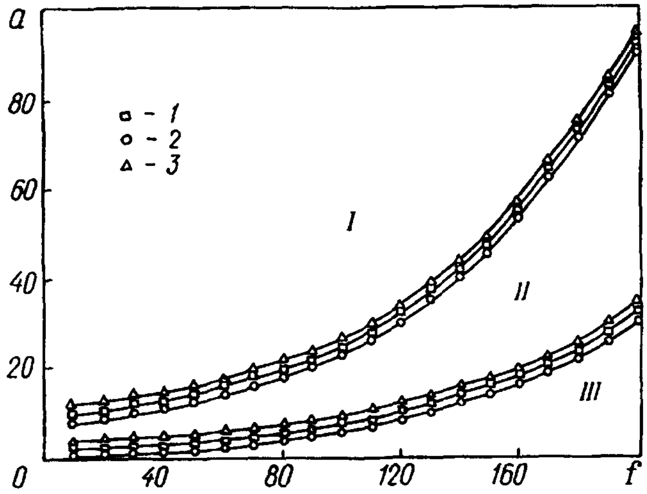


Fig. 1. Plot of pressure drop ΔP (Pa) versus thickness H (mm) of filtering element with symmetric (1) and asymmmetric (2) pore structure and equal fineness of cleaning.

Fig. 2. State of mixture of powders with different granulometric composition as a function of acceleration a (m/sec^2) and vibration frequency f (Hz) for fractions: 1) 0.4–0.63, 2) 0.315–0.4, 3) 0.16–0.2 mm

followed by resintering [12] give asymmetric porous structures. A common disadvantage of all these methods is the low permiability of produced elements, since purification fineness is increased due to decreasing the porosity. Vibration molding methods based on size segregation of powder particles by application of vibrations with preset parameters to the mixture to be molded are the most effective, simple, and economical [13]. They are easily automated and give materials with a preset pore distribution.

In [14] it is shown that the apparatus of random functions, which is consistent with the physical essence of the phenomena, is the most suitable for description of segregation of elements of a disperse medium subjected to vibration.

Application of the theory of random functions to segregation of particles of the various disperse media into fractions is considered most completely and consistently in [15], which gives the equation of motion for a particle in a vibrating layer

$$M_2 V_M = M\left(1 - \frac{\rho_c}{\rho}\right) g - \mu V_{M_1} + \xi(t). \qquad (1)$$

Apart from gravity and hydrodynamic resistance forces it also includes interparticle interaction forces that depend on the positions of real particles that randomly change with time and the choatic structure of the pore space.

The suggested stochastic approach to the mathematical description of segregation and mixing of loose materials appeared rather universal and suitable for a wide range of production operations. In this connection, it may be effective in solving problems of vibration-induced segregation of particles.

Segregation takes place at strictly specified vibrational accelerations which depend on the particle density and size; however, there is no information about segregation mechanisms in disperse media of coarse and fine particles [16-18]. Because of the lack of this information, in particular, on molding of an asymmetric pore structure from powders of different granulometric compositions, it is necessary to carry out experimental studies to investigate the mechanisms of size segregation of powder particles.

In this study powdered bronze Br OF 10-1 TU 48-42-3-85, which is most frequently used for production of filtering elements for various purposes, was used as a material of study. The powder was sieved into fractions with a device of 029 version with a set of sieves from 0.04 to 1.0 mm.

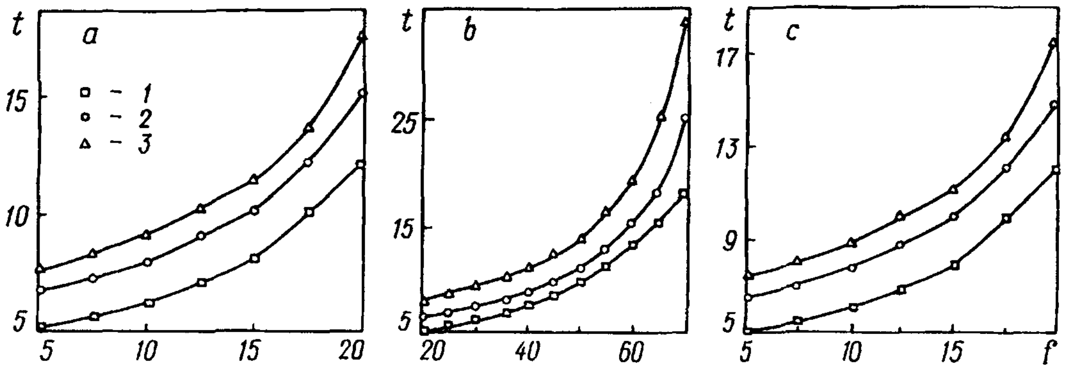


Fig. 3. Segregation time t (sec) of coarse partial fraction (1-3 in Fig. 2) passing through layer of fine particles with thickness 5 mm and particle size 0.04–0.063 mm versus vibration frequency f (Hz) at accelerations: a) 5, b) 10, c) 20 m/sec.

The particle size segregation and modes of vibration molding were studied with a VÉDS-10A electrodynamic vibration stand that consisted of an amplifier and a control board located in the same cabinet and a VÉD-10A electrodynamic vibrator.

The study of vibration-effected size segregation of metal particles consisted of experiments on migration of coarse particles that pass through a layer of fine particles at various parameters of vibration. For this purpose coarse particles were placed on the bottom of an optically transparent cylindrical container that was attached to the vibrator table. A layer of fine particles was spread over the coarse particles and the container with the powder was subjected to vibration with a preset frequency and acceleration. The segregation parameter (the time required for large particles to rise to the surface) was determined by observing the positions of coarse particles in the container and measuring the time of motion of the coarse particles to the surface. It was also assumed that the larger the parameter, the less the tendency of the particles in the powder mixture with a given granulometric composition to segregation.

The phenomenon of segregation was studied with powders of the following fractions: 0.04–0.063, 0.063–0.1, 0.1–0.16, 0.16–0.2, 0.2–0.315, 0.315–0.4, and 0.4–0.63 mm. Before the experiments, the powders of the first two fractions were dried in a drying cabinet at 100°C for 1 h, and the powders of the other fractions, at 450°C. Under these conditions the powders of large fractions were oxidized and became dark, because of which they could be distinguished in the experiments. The following factors that affect the segregation process were studied: the initial position of the large particles in the container; parameters of vibration (frequencies and accelerations); the thickness of the layer of fine particles; the size of coarse and fine particles; the direction of vibration.

Experimental determination of the dependence of the segregation process on the vibration parameters has shown that size segregation of the particles was observed in a certain range of these parameters and their combinations. Experimental results are presented in Fig. 2, where three sections of the curve of the state of the powder mixture versus the parameters of vibration can be seen: I, the powders are only compacted; II, the particles are size-segregated with the length of the section independent of the ratio of the coarse to fine particle size; III, the powder mixture "boils" under vibration. Mathematical processing of the data presented in Fig. 2 gives regression relations for the range of vibration parameters that provide size segregation of the particles:

$$3.96 \exp(0.0103f) < a < 8.78 \exp(0.012f)\,. \tag{2}$$

In Fig. 3 one can see curves of the time of the size segregation of the particles versus the vibration parameters. It follows from these plots that at any preset frequency the segregation time decreases with an increase in acceleration, and at fixed acceleration it increases with frequency.

Figure 4 shows a plot of the segregation time versus the size of coarse particles and the thickness of the layer of fine particles. It can be seen from the curves that the thicker the layer of fine particles, the longer the

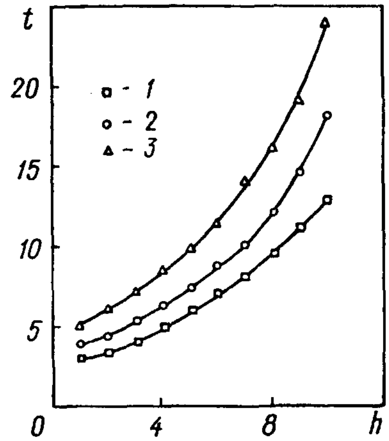


Fig. 4. Segregation time t (sec) of coarse particles (1-3 in Fig. 2) versus thickness h (mm) of layer of fine particles with size 0.04–0.063 mm.

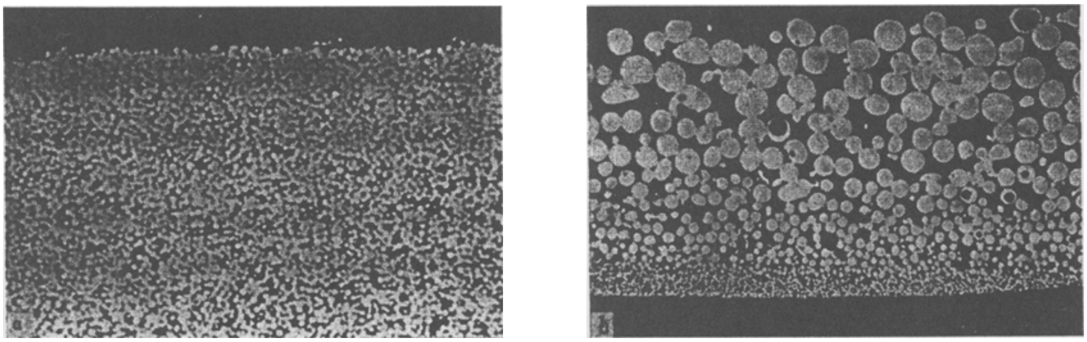


Fig. 5. Microstructure of specimens of filtering elements with symmetric (a) and asymmetric (b) pore structure.

segregation time. Moreover, the time of segregation decreases as the ratio of the coarse to fine particle size increases under the same conditions of vibration.

Experiments on the effect of the initial position of the coarse particles in the container have revealed that because of the wall effects the segregation time of a coarse particle is shorter in the center of the container than it is near its edges.

From the present experiments it can be concluded that segregation of powders occurs within a strictly specified range of the vibration parameters defined by inequality (2). It should be noted that it is unnecessary to use high vibration frequencies to provide a maximum rate of the process but it is necessary to use acceleration that provides the highest rate of size segregation of the particles at the lowest possible frequency (10–50 Hz). The segregation time depends on the ratio of coarse to fine particle sizes: it decreases as the ratio increases. Since the segregation time depends on the positions of particles in the container (and, consequently, on its shape and size), it should be specified experimentally for every particular case.

Experimental specimens of porous elements for tangential microfilters with an asymmetric pore structure were produced following the described procedure in the form of disks with a diameter of 185 mm, a thickness of 2.8–3.0 mm, and an average pore size of 10 μm in the selective layer. Comparison of the operation parameters was made with specimens of the same size, made of powder of only one (fine) fraction, and with the same average pore size. Photographs of the microstructure of both types of specimens are presented in Fig. 5.

Figure 6 shows the pore size distribution functions obtained with the method of mercury porosimetry [19] for specimens with symmetric and asymmetric pore structures and Fig. 7 shows a plot of the hydrodynamic resistance versus the amount of filtered liquid. As can be seen from Figs. 5-7, the specimens with an asymmetric pore structure have a better set of properties than the homogeneous specimens. It should be noted that with the

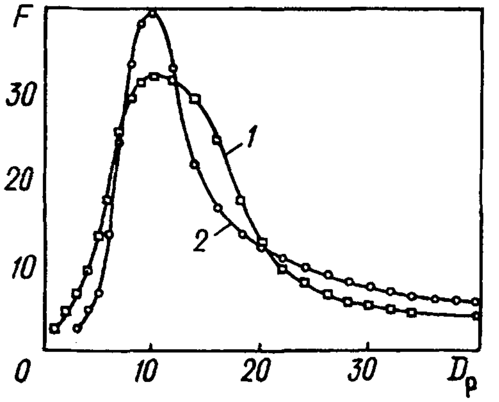


Fig. 6. Pore size distribution function F (%) for specimens with symmetric (1) and asymmetric (2) pore structure.

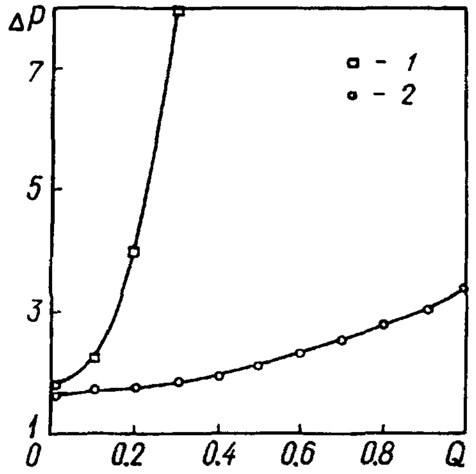


Fig. 7. Plot of hydrodynamic resistance ΔP (kPa) versus amount of filtered liquid for specimens with symmetric (1) and asymmetric (2) pore structure.

same purification fineness in the specimens with an asymmetric pore structure, permeabilities according to GOST (State Standard) 25283-82 are 4–5 times higher than the specimens with a symmetric structure.

Thus, it is theoretically proved and experimentally confirmed that with the method of vibration molding it is possible to produce filtering elements with an asymmetric pore structure and an improved set of operation properties.

The work was carried out within Project T9-303 under financial support from the Fundamental Research Fund of the Republic of Belarus.

NOTATION

M, mass of particle; M_0, associated mass due to unsteady motion in medium; M_1, mass of medium in volume equal to volume of particle; $M_2 = M + M_0$, effective mass; ρ, ρ_m, densities of considered particle and of particle of medium; μ, dynamic viscosity of medium; $\xi(t)$, random time function; V_M, particle velocity relative to medium; V_{M_1}, absolute velocity of medium at the point that coincides with the center of gravity of particle in the absence of the particle; g, gravitational acceleration, a, vibrational acceleration, m/sec^2; f, vibration frequency, Hz; P, pressure drop; H, thickness of filtering element; t, time; h, thickness of powder layer; n, the number of pores; D_p, diametr of pores; π, pore diameter; Q, amount of filtrate; F, pore size distribution function.

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