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MICROPARTICLE SEPARATION ON A PERFORATED ELECTRODE IN A NONUNIFORM ELECTRIC FIELD

S. I. Zhebelev

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We solve the problem of passage of microparticles through a perforated electrode under conditions of their electrodynamic fluidization (EDF) in a nonuniform electric field. It is shown that when the particle size is considerably smaller than the perforated hole size, microparticle sizing takes place in the region under the electrode. We report the experimental data.

Among the known technical applications of an EDF process is the use of electrodynamic fluidization for separation of microparticles with respect to their size. In [1, 2], for instance, the particles to be separated are supplied between capacitor plates, one of which is manufactured as a screen. Particles whose size is smaller than the perforated holes are screened under the conditions of the EDF process. Particles that do not pass through the screen are removed from the capacitor to form a coarse product. Some designs are known in which this process is realized in a nonuniform field of diverging electrodes [3]. In this case, besides the oscillatory motion of particles between the electrodes, the displacement of some particles toward the low-intensity field is also observed.

In the present work we solve the problem in which microparticles in an EDF process in a nonuniform field pass through a perforated electrode the size of whose holes is much larger than the particle size. We consider a system of diverging electrodes (Fig. 1), of which the lower electrode is uniformly perforated. The probability for a particle to pass through the electrode holes will be characterized as $0 < P < 1$ under the assumption that when the microparticle collides with the electrode, it passes through its holes with the probability P and recoils from the electrode with the probability $1-P$. Correspondingly, for n collisions the probability for the particle to continue motion, i.e., to be in the interelectrode gap, is $(1-P)^n$. We distinguish now a section with length $\Delta\rho$ along the electrode. Assuming that at the beginning of this section the number of EDF particles is $N(\rho)$, the change of this number over the section is

$$\Delta N = N(\rho + \Delta\rho) - N(\rho) = N(\rho)\,[(1 - P)^{\omega\Delta t} - 1]\,, \tag{1}$$

where ω is the frequency of collisions of a particle with the electrode; Δt is the time for which the particle is displaced by $\Delta\rho$ in the nonuniform field. Passing now to differentials, we obtain from (1)

$$\frac{dN}{N} = (1 - P)^{\omega dt} - 1\,. \tag{2}$$

Linearization of (2) yields

$$\ln\left(1 + \frac{dN}{N}\right) \simeq \frac{dN}{N} = \ln(1 - P)\,\omega dt\,. \tag{3}$$

The quantities ω and dt may be expressed as

$$\omega = \frac{V_{\parallel}}{2\varphi\rho}\,,\quad dt = \frac{d\rho}{V_{\perp}}\,, \tag{4}$$

Intrabranch Institute of Advanced Training at the Ural State Technical University, Ekaterinburg, Russia.
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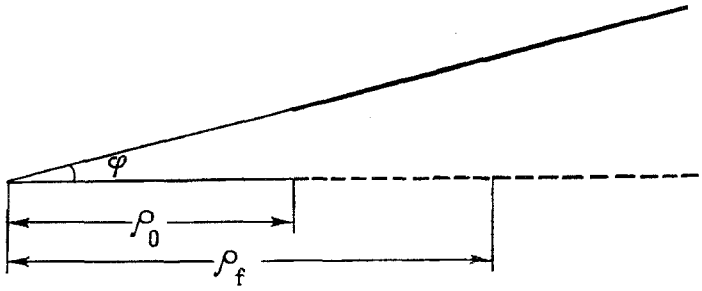

Fig. 1. System of diverging electrodes.

where $V_{\parallel}$, $V_{\perp}$ are the longitudinal and transverse velocities of the microparticles relative to the electrodes, respectively. According to [4], we may write, for a Stokes particle with radius r and small divergence angle φ of the electrodes,

$$V_{\parallel} = \frac{q_{\max} U}{\varphi \rho s}, \quad V_{\perp} = \frac{(q_{\max} U)^2 m}{\varphi^2 s^3 \rho^3}, \tag{5}$$

where $s = 6\pi\eta r$ is the resistance of the medium per velocity unit; $q_{\max} = 2\pi^2 \varepsilon\varepsilon_0 r^2 U / 3\varphi\rho$ is the maximum charge of particles dependent on the contact site in a nonuniform field. Therefore, assuming that $q_{\max} = q\ (\rho_0/\rho)$, where $q_{\max_0} = q_{\max}(\rho_0)$, substituting (5) into (4), and integrating (3), we obtain

$$\int_{N_0}^{N} \frac{dN}{N} = \frac{s^2 \ln (1 - P)}{2 q_{\max_0} \rho_0 m U} \int_{\rho_0}^{\rho} \rho^2 \, d\rho \tag{6}$$

or

$$N = N_0 \exp (A (\rho^3 - \rho_0^3)), \tag{7}$$

where

$$A = \frac{s^2 \ln (1 - P)}{6 q_{\max_0} \rho_0 m U}. \tag{8}$$

Since $\ln (1-P) < 0$, the number of particles in the interelectrode gap decreases along the electrode, i.e., the particles are screened through the holes. However, this decrease depends strongly on the particle size, $A \sim r^{-3}$. For instance, fine particles are screened closer to the beginning of the perforated section, and coarse particles, further from it.

Fixing $\rho = \rho_f$ so that fine particles at $\rho < \rho_f$ and coarse particles at $\rho > \rho_f$ gather beneath the electrode, we obtain from (7) the sizing curve for the coarse particles [5]

$$\Phi_c (r) = \exp (A (r) (\rho_f^3 - \rho_0^3)). \tag{9}$$

For this case, the Eder index [4] of the accuracy of separation with respect to size is

$$\kappa = \frac{r_{\Phi_c = 0.25}}{r_{\Phi_c = 0.75}} = \left(1 - \frac{\ln 3}{\ln 4}\right)^{1/3} \simeq 0.59. \tag{10}$$

Thus, the accuracy of sizing under the adopted conditions is independent of the parameters of the problem and amounts to ~60%. Expression (7) is obtained under the assumption that the probability P does not depend on the particle size. This holds for the case where the electrode hole size is much larger than the particle size. Then P may be assumed equal to the electrode transmission (the ratio of the hole area to the total electrode area).

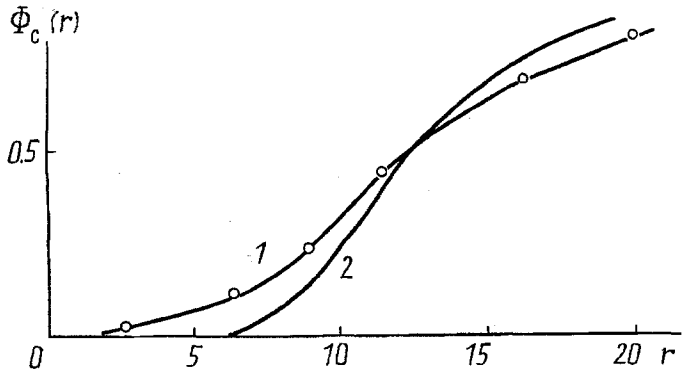

Fig. 2. Plot of fractional separation $\Phi_c(r)$, rel. units: 1) for iron powder; 2) theoretical curve (9). r, μm.

Figure 2 shows the sizing curve resulting from the photosedimentation analysis of the initial material and the separation products upon the electrodynamic fluidization of iron powder with particle sizes of 5 to 35 μm in the nonuniform fold of the capacitor at $\varphi = 5^\circ$; $u = 6$ kV, $\rho_f = 2 \cdot 10^{-2}$ m, $d_0 = \varphi\rho_0 = 1 \cdot 10^{-2}$ m. A screen with holes 40 μm and transmission factor 0.25 was used as the lower electrode. In this case, the separation boundary was $r_b = 12$ μm and $\kappa \simeq 0.5$. Figure 2 shows relation (9) with the same separation boundary. It is seen that the accuracy of separation is somewhat lower compared to (10) due, probably, to the focusing properties of the lower electrode [1]. To evaluate the effectiveness of this method, we must bear in mind that the microparticle concentration in the interelectrode gap is limited. Assuming it equal to $n \simeq n_{mp} = 1/\beta\varphi\rho_0$ [6], $\beta = 4\pi r_b^2$, provided $\Phi_c(\rho_b) = 0.5$, using (5) and (9), we evaluate the specific efficiency of separation per unit area of the perforated electrode with length $\rho_f - \rho_0$

$$W = \frac{1}{2} n_{mp} V_{||} \frac{\ln(1-P)}{\ln 0.5} m, \tag{11}$$

which depends on the particle size as $W \sim r_b^2$.

The separation of conducting powders with respect to size is useful for a number of reasons. For instance, the holes of a screen are not clogged by a material. Use of screens with relatively large holes leads to an increase in efficiency owing to the increase in electrode transmission. The required degree of separation may be achieved by the known methods of cascade sizing [4].

Conclusion. Upon the fludization of microparticles in the nonuniform electric field of a capacitor with a perforated electrode, sizing of the particles beneath the electrode takes place.

NOTATION

r, particle radius; η, medium viscosity; ε, ε_0, dielectric permittivity; m, particle mass; u, potential difference of electrodes; κ, index of accuracy of separation; n, particle concentration; subscripts: b, boundary; c, coarse; f, fraction; mp, microparticles.

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