EVALUATING THE EFFECT OF SMALL-PARTICLE CAPTURE BY LARGE PARTICLES OR LIQUID DROPLETS AND EVALUATING THE EFFECT OF HYDROPHILIC PARTICLES ON THE COEFFICIENT OF CAPTURE

A. T. Litvinov

UDC 541.182.3/.4

We examine the influence exerted by the effect of capture on the inertial path of particles and the influence of the dust-content parameter on the free path of the particles; in addition we establish the effect of hydrophilic particles on the coefficient of capture. Equations are presented for the determination of the free path, the duration of motion, and the relative particle velocity.

We know that the decisive factor in the selection of a given dust-collecting apparatus is its fractional coefficient of purification or the limit (minimum particle size which can be trapped by this piece of equipment).

The efficiency of dust-particle collection in such equipment is usually calculated on the basis of the path covered by the particle.

If a particle of a specified size, under applied external forces, reaches the trapping zone, it is assumed that it will be trapped. In the solution of the differential equations of particle motion we use a coefficient of hydrodynamic resistance which provides partially for the inertial terms in the nonuniform motion of the particles, without any provision being made for the dust content of the medium [1, 2]. The calculated values of trapping efficiency therefore differs substantially from the experimental values [3, 4].

A dust particle or liquid droplet in a dust-collecting apparatus moves through a dust-filled medium and collides with smaller particles during its motion. This leads to a change in particle mass, as well as to a change in its velocity of motion and the path which it traverses.

The inertial path of the particles, without consideration of the capture effect involving a coefficient of hydrodynamic resistance which makes provision for the inertial terms applicable to the retarded motion of the particles has been studied in [5, 6].

Let us examine the inertial path of particles in a dust-filled medium, with consideration given to the effect of smaller particles being captured by larger particles.

The differential equation of particle motion is the following:

$$\frac{d}{dt}(m\overline{V}_{\mathrm{p}}) = 0.5\,\psi S \rho_1 (\overline{V}_{\mathrm{m}} - \overline{V}_{\mathrm{p}}) \,|\, \overline{V}_{\mathrm{m}} - \overline{V}_{\mathrm{p}} \,|\, + \overline{F}_{\mathrm{ex}}. \tag{1}$$

When a particle is in motion in the region Re < 1 and without consideration of the external force, the differential equation (1) is changed to the following form ($\overline{V}_{\mathrm{m}} = 0$):

$$m\frac{dV_{\mathrm{p}}}{dt} + V_{\mathrm{p}}\frac{dm}{dt} = KV_{\mathrm{p}}, \tag{2}$$

where $K = 6\pi\eta r$.

Institute of Industrial and Sanitary Gas Purification, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 16, No. 6, pp. 1052-1061, June, 1969. Original article submitted May 24, 1968.

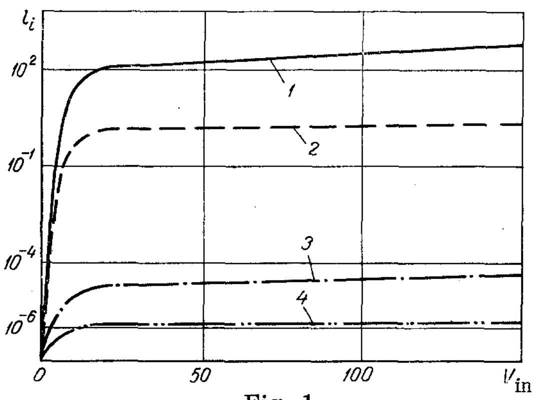

Fig. 1

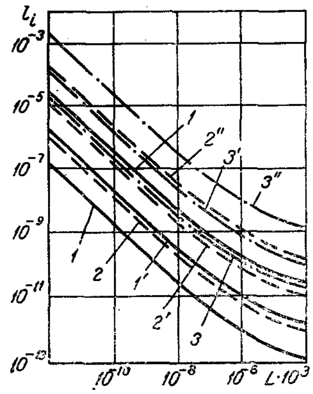

Fig. 2

Fig. 1. Inertial particle path l_i (m) as a function of the initial velocity V_{in} (m /sec): 1) calculation in accordance with the Stokes formula for a dust-free medium; 2) according to (9) for the region in which Re < 1; 3) according to the formula given in [5], with a coefficient of hydrodynamic resistance to provide for the inertial terms in the case of retarded particle motion; 4) the same, in a dust-containing medium.

Fig. 2. Inertial particle path (l_i, m) as a function of the dust-content parameter (L, g/nm^3): 1,1',1") calculated for particles whose diameters are, respectively, 10^{-7}, 10^{-6}, and $5 \cdot 10^{-6}$ m, from Eq. (14); 2,2',2") the same, from Eq. (19); 3,3',3") the same, with a coefficient of hydrodynamic resistance equal to 24/Re.

The increase in mass for the particle moving in the dust-filled medium is equal to the mass of the particles which it has captured in a hypothetical tube whose volume is $\pi r^2 dl$, i.e.,

$$d\left(\frac{4\pi r^3}{3}\rho_2\right) = \pi r^2 L dl, \tag{3}$$

where L is a parameter characterizing the extent to which the medium is filled with dust, equal in this case to $\alpha E z$.

From (3) we obtain

$$\frac{dr}{dl} = \frac{L}{4\rho_2}, \tag{4}$$

$$\frac{dm}{dt} = \pi r^2 L V_p \tag{5}$$

Having substituted the value of dm/dt from (5) into (2), after appropriate transformations, we obtain

$$dt = -\frac{dV_p}{V_p(\gamma V_p - \beta)}, \tag{6}$$

where

$$\beta = \frac{1}{\tau} = \frac{18\eta}{d^2\rho_2}; \quad \gamma = 1.5\frac{L}{d\rho_2}.$$

Integrating (6) in limits from $t_1 = 0$ to $t_2 = t$, and from $V_p = V_{in}$ to $V_p = V_i$, we obtain

$$t = -\int_{V_{in}}^{V_i} \frac{dV_p}{V_p(\gamma V_p - \beta)} = \tau \ln\left|\frac{V_i(V_{in} - \theta)}{V_{in}(V_i - \theta)}\right|, \tag{7}$$

where $\theta = 12\eta/dL$.

Multiplying both parts of (6) by dx, after appropriate transformation, we obtain

$$dx = -\frac{dV_p}{\gamma V_p - \beta}. \tag{8}$$

Integrating (8) in limits from $x_1 = 0$ (i.e., at the instant of entry into a nonmoving medium) to $x_2 = l_i$, and from $V_p = V_{in}$ to $V_p = V_i$, we obtain

$$l_{i,1} = -\int_{V_{in}}^{V_i} \frac{dV_p}{\gamma V_p - \beta} = \frac{d\rho_2}{1.5L} \ln \left| \frac{V_{in} - \theta}{V_i - \theta} \right|. \tag{9}$$

As we can see from (9), the inertial path of the particle in a dust-filled medium is proportional to the particle diameter, and to its density, being inversely proportional to the criterion L giving the extent to which the medium is filled with dust.

The relationship between the inertial path of the particle in a dust-filled medium and in one that is free of dust to the initial velocity of motion is shown in Fig. 1, while Fig. 2 shows this relationship with respect to the dust-content parameter L, in accordance with Eq. (9).

As we can see from Fig. 1, the inertial particle path in a dust-free medium, calculated in accordance with the Stokes formula $l_i = \tau V_{in}$ (curve 1) differs substantially from the path calculated with the coefficient of hydrodynamic resistance in which provision is made for the inertial terms in the case of retarded particle motion (curve 3). The inertial particle path in a dust-filled medium, calculated under the same conditions from (9) and (14), diminishes sharply in the region of low values for the initial velocity, and a further increase in the initial velocity increases the path only insignificantly (curves 2 and 4). We see from Fig. 2 that the increase in the dust content sharply reduces the particle path.

For particles moving in the region Re ≤ 300, the differential equation of motion is the following:

$$m\frac{dV_p}{dt} + V_p\frac{dm}{dt} = \left(A + \frac{B}{Re}\right)\frac{\pi d^2}{8}\rho_1 V_0^2, \tag{10}$$

where A and B are constants by means of which we account for the change in the coefficient of hydrodynamic resistance to motion in the case of retarded particle motion [5].

After appropriate transformations, we write (10) in the form

$$dt = \frac{dV_p}{V_p^2(\varphi_1 - \gamma) + \varphi_2 V_p}, \tag{11}$$

where

$$\varphi_1 = 0.75\frac{A\rho_1}{d\rho_2}; \quad \varphi_2 = 0{,}75\frac{B\eta}{d^2\rho_2}.$$

Having integrated (11) within the same limits as (6), we find

$$t = \int_{V_{in}}^{V_i} \frac{dV_p}{V_p^2(\varphi_1 - \gamma) + \varphi_2 V_p} = a\tau \ln \left| \frac{V_{in}(V_i + \varphi_3)}{V_i(V_{in} + \varphi_3)} \right|, \tag{12}$$

where

$$\varphi_3 = M/\varphi_2 = \frac{B\eta}{d(A\rho_1 - 2L)}; \quad M = 0.75\frac{A\rho_1 - 2L}{d\rho_2}; \quad a = 24/B$$

Having multiplied both parts of (11) by dx, after appropriate transformations, we obtain

$$dx = \frac{dV_p}{MV_p + \varphi_2}. \tag{13}$$

Integrating (13) within the same limits as (8), we find

$$l_{i,2} = \int_{V_{in}}^{V_i} \frac{dV_p}{MV_p + \varphi_2} = \frac{d\rho_2}{A\rho_1 - 2L} \ln \left| \frac{V_{in} + \varphi_3}{V_i + \varphi_3} \right|. \tag{14}$$

For equipment which uses centrifugal and inertial forces to remove particles from the flow, the capture effect will also affect the velocity of particle motion.

The following represents the differential equation of particle motion in a field of gravitational forces:

$$m\frac{dV_p}{dt}+V_p\frac{dm}{dt}=mg\pm 0.5\,\psi S\rho_1(\overline{V}_m-\overline{V}_p)\,|\,\overline{V}_m-\overline{V}_p\,|. \tag{15}$$

When the particles are moving in a region in which Re < 1, we transform Eq. (15) to

$$dt=\frac{dV_p}{\gamma V_p^2+\beta V_p\pm g}. \tag{16}$$

Integrating (16) within the same limits as (11), we find

$$t=\int_{V_{in}}^{V_i}\frac{dV_p}{\gamma V_p^2+\beta V_p\pm g}=\frac{1}{A_1}\ln\frac{P}{q}, \tag{17}$$

where

$$A_1=\sqrt{\beta^2\pm 4\gamma g};\quad P=(\beta+2\gamma V_{in}-A_1)(\beta+2\gamma V_i+A_1);$$
$$q=(\beta+2\gamma V_{in}+A_1)(\beta+2\gamma V_i-A_1).$$

Having multiplied both members of (16) by dx, after appropriate transformations, we obtain

$$dx=\frac{V_p dV_p}{\gamma V_p^2+\beta V_p\pm g}. \tag{18}$$

Integrating (18) within the same limits as (8), we find

$$l_{i,3}=\int_{V_{in}}^{V_i}\frac{V_p dV_p}{\gamma V_p^2+\beta V_p\pm g}=\frac{d\rho_2}{3L}\left[\ln\frac{q_1}{P_1}-\frac{\theta}{P_2-q_2}\ln\left|\frac{(V_{in}-P_2)(V_i-q_2)}{(V_{in}-q_2)(V_i-P_2)}\right|\right], \tag{19}$$

where

$$P_1=\gamma V_{in}^2+\beta V_{in}\pm g;\quad q_1=\gamma V_i^2+\beta V_i\pm g;$$
$$q_2,\ P_2=\frac{-\beta\pm\sqrt{\beta^2\pm 4\gamma g}}{2\gamma}.$$

Having substituted $(dV_p/dr)(dr/dt)$ into (15) for the value of dV_p/dt and having used (4) and (5), we bring (15) to the following form:

$$V_p\frac{dV_p}{dr}+\frac{1.5}{L}(2L+\psi\rho_1)\frac{V_p^2}{r}-\frac{4g\rho_2}{L}=0. \tag{20}$$

Integration of (20) yields

$$V_s^2=\left(V_{in}^2-\frac{q_3}{P_3+1}r_0\right)\left(\frac{r_0}{r}\right)^{P_3}+\frac{q_3}{P_3+1}r, \tag{21}$$

where

$$q_3=\frac{\gamma g\rho_2}{L};\quad P_3=\frac{3V_{in}}{L}(2L+\psi\rho_1).$$

Considering that $(r_0/r)^{P_3}$ is an insignificant quantity, we change (21) to the form

$$V_s=\sqrt{\frac{8g\rho_2 r}{7L+3\psi\rho_1}}. \tag{22}$$

As we can see from (22), the value for the rate of particle sedimentation diminishes in proportion to the increase in the criterion L. When L = 0, Eq. (22) changes into the Stokes equation for a dust-free medium.

For larger particles, velocity of motion begins in the region in which Re ≤ 300.

The differential equation of particle motion in the region in which Re ≤ 300 is the following:

$$m\frac{dV_p}{dt}+V_p\frac{dm}{dt}=mg-\left(A+\frac{B}{Re}\right)\frac{\pi d^2}{8}\rho_1 V_0^2. \tag{23}$$

After appropriate transformations of (23) we find

$$dt = \frac{dV_p}{V_p^2(\gamma + \varphi_1) + \varphi_2 V_p - g}. \tag{24}$$

Integrating (24) within the same limits as (7), we obtain

$$t = \int_{V_{in}}^{V_i} \frac{dV_p}{V^2(\gamma + \varphi_1) + \varphi_2 V_p - g} = \frac{1}{A_2} \ln \frac{P_4}{q_4}, \tag{25}$$

where

$$A_2 = \sqrt{4g(\gamma + \varphi_1) + \varphi_2^2};$$

$$P_4 = (\beta + 2\gamma V_{in} - A_2)(\beta + 2\gamma V_i + A_2);$$

$$q_4 = (\beta + 2\gamma V_i - A_2)(\beta + 2\gamma V_{in} + A_2).$$

Having multiplied both parts of (24) by dx, after appropriate transformations, we obtain

$$dx = \frac{V_p dV_p}{V_p^2(\gamma + \varphi_1) + \varphi_2 V_p - g}. \tag{26}$$

Integrating (26) within the same limits as (8), we obtain

$$l_{i,4} = \int_{V_{in}}^{V_i} \frac{V_p dV_p}{V_p^2(\gamma + \varphi_1) + \varphi_2 V_p - g} = \frac{d\rho_2}{1.5A\rho_1 + 3L}\left[\ln \frac{P_5}{q_5} - \frac{Q}{N_1 - N_2} \ln \left| \frac{(V_{in} - N_1)(V_i - N_2)}{(V_{in} - N_2)(V_i - N_1)} \right| \right], \tag{27}$$

where

$$N_{1,2} = \frac{-\varphi_2 \pm \sqrt{\varphi_2^2 + 4gQ}}{2Q}; \quad Q = \frac{18\eta}{d(0.75A\rho_1 + 1.5L)};$$

$$P_5 = (\gamma + \varphi_1)V_{in}^2 + \varphi_2 V_{in} - g; \quad q_5 = (\gamma + \varphi_1)V_i^2 + \varphi_2 V_i - g.$$

The derived equations (7), (9), (12), (14), (17), (19), (22), (25), and (27) thus makes it possible to calculate the time during which the particle is set into motion in a dust-containing medium, in addition to the inertial path, and the relative velocity of particle motion at any point from the instant at which it enters into this dust-containing medium. Thus, for example, having transformed (9), we find

$$V_i = V_{in} \exp\left(-\frac{1.5Ll_i}{d\rho_2}\right) + \theta\left[1 - \exp\left(-\frac{1.5Ll_i}{d\rho_2}\right)\right]. \tag{28}$$

Analysis of the derived equations shows that the dust-content parameter L significantly affects the particle path. Neglecting the capture effect in the theoretical basis for particle motion and in the derivation of the equations therefore results in substantial error.

We know that the capture coefficient E in the case of inertial deposition of particles on the liquid droplet is in a functional relationship to the Stokes criterion [7-10], i.e., E = f(Stc, Re, d/D_{av}).

The Stokes criterion, in turn, depends on the diameter of the particle, its density, its relative velocity, the force of hydrodynamic resistance to motion, and on the diameter of the droplet, i.e., Stc = $\varphi(m, V_0/F_l, D_{av})$.

For spherical particles in the region in which Re < 1 the Stc number is equal to

$$\mathrm{Stc} = d^2 V_0 \rho_2 (18\mu D_{av})^{-1}. \tag{29}$$

Empirical equations have been proposed in [7, 8, 12-21] to calculate the capture coefficient, but these equations are rather cumbersome and of a lower degree of approximation in the narrow interval of values for the Stc criterion, failing to make provision for the physicochemical properties of the particle (its hydrophilic or hydrophobic nature).

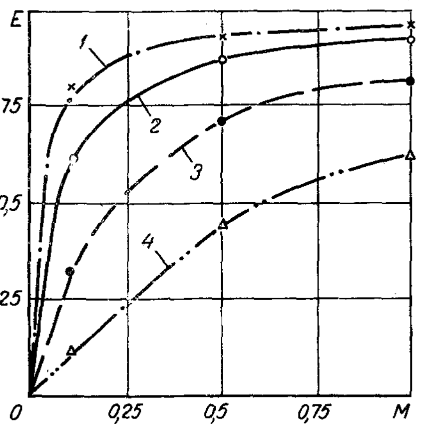

Fig. 3

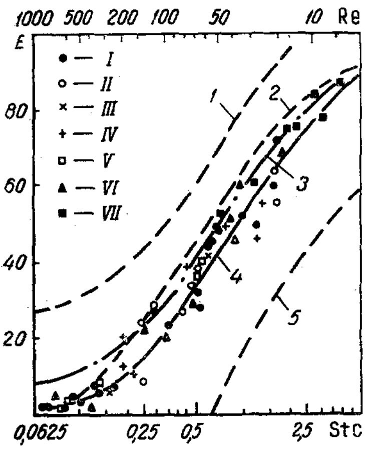

Fig. 4

Fig. 3. Capture coefficient E as a function of the hydrophilic parameter M: 1) Stc = 20; 2) 10; 3) 3; 4) 1.

Fig. 4. The capture coefficient E (%) as a function of the Stc criterion for various values of the Re number: 1, 2) theoretical curves in the case of potential streamlining for d/D_{av} = 0.1 (2) and 0 (1); 3) curve taken from the values calculated according to (35); 4) curve plotted from the experimental data of [22]; 5) theoretical curves for viscous streamlining when d/D_{av} = 0.1; I) Re = 65; II) 130-223; III) 223-266; IV) 445-520; V) 890; VI) experimental data from [14, 21]; VII) experimental data from [10, 18].

Analysis of a large quantity of experimental and theoretical material demonstrates that the wettability of the particle substantially increases the capture coefficient. Therefore, depending on the extent to which the particle is hydrophilic or hydrophobic, both the capture coefficient and the trapping efficiency, given identical conditions of dust-collector operation, change markedly.

We estimated the extent of the influence exerted by the wettability of the particle on the capture coefficient under the following conditions. For particles that are highly wettable (hydrophilic) the necessary condition for the capture of liquid droplets from such particles is the contact of the particle with the droplet (with displacement of the gas interlayer); for poorly wettable and nonwettable particles (hydrophobic) the necessary condition is the penetration of the particles into the droplet to a magnitude equal to the diameter of the particle.

The ratio of the Stc criterion or of the magnitude of the inertial path for a hydrophilic particle to the Stc criterion or to the inertial path of the hydrophobic particle, under respectively identical conditions, is referred to as the hydrophilic particle parameter M, i.e.,

$$M = \frac{\mathrm{Stc}_{\mathrm{phyl}}}{\mathrm{Stc}_{\mathrm{phob}}} \frac{l_{\mathrm{i,phob}}}{l_{\mathrm{i,phyl}}} \leqslant 1. \tag{30}$$

The quantity that is the reciprocal of the hydrophilic parameter is known as the hydrophogic parameter, i.e., L = 1/M.

To calculate the inertial particle path we will use the equations given in [5, 10].

The inertial particle path in the region in which Re < 1 is calculated from the equations:

a) for a hydrophilic particle [7]

$$l_{i,1} = V_0 \tau, \tag{31}$$

where τ is the relaxation time for the particle:

$$\tau = d^2 \rho_2 (18\,\mu)^{-1};$$

b) for a hydrophobic particle the inertial path (with consideration of the expenditure of kinetic energy on the immersion of the particle into a liquid droplet) is calculated from the equation [9]

$$l_{i,2} = V_0\tau - \varphi \ln\left|1 + \frac{V_0}{\psi}\right|, \quad (32)$$

where $\varphi = \sigma d^2\rho_2(81\ \mu^2)^{-1}$; $\psi = \sigma(4.5\ \mu)^{-1}$.

The inertial path of the particle in the region in which Re $\leq$ 300 is calculated from the equation:

a) for a hydrophilic particle [5]

$$l_{i,3} = \gamma \ln\left|\frac{\alpha V_0 + \beta}{\alpha V_x + \beta}\right|, \quad (33)$$

where

$$\alpha = 0.75\, A\rho_1 (d\rho_2)^{-1};\quad \beta = 0.75 B\mu (d^2\rho_2)^{-1};\quad \gamma = 1.33\, d\rho_2 (A\rho_1)^{-1};$$

b) for a hydrophobic particle [9]

$$l_{i,4} = \frac{1}{2\alpha} \ln\frac{\alpha V_0 + \beta V_0 + \zeta}{\zeta} - \frac{\beta}{\alpha\sqrt{2\alpha\zeta - \beta^2}} \operatorname{arctg}\frac{\sqrt{4\alpha\zeta - \beta^2}\,(\alpha V_0 + \beta)}{\alpha(2\zeta - \beta V_0) - \beta^2}, \quad (34)$$

where $\zeta = 4\sigma(d^2\rho_2)^{-1}$.

The capture coefficient as a function of the hydrophilic parameter M is shown in Fig. 3.

As we can see from Fig. 3, with small values for the Stc criterion the hydrophilic nature of the particle significantly affects the capture coefficient. In proportion to the increase in the Stc criterion and as $M \to 1$ the capture coefficient increases sharply.

In accordance with the processing of the experimental and theoretical data carried out by the author, the relationship between the capture coefficient and the Stc criterion – with consideration given to the wettability of the particles – can be expressed in approximate terms for the potential streamlining of the particles by the equation which yields satisfactory agreement between the theoretical values and the experimental data in the region in which Stc > 0.25 (Fig. 4):

$$E = \frac{\text{Stc}}{\text{Stc} + 0.59L} = \frac{l_i}{l_i + 0.59\, D_{av} L}. \quad (35)$$

In the case of viscous streamlining (Stc > 0.607) the capture coefficient is equal to

$$E_1 = \frac{\text{Stc}_1}{\text{Stc}_1 + 3L} = \frac{l_{i,1}}{l_{i,1} + 3D_{av} L}. \quad (36)$$

For the potential streamlining when d/D_{av} = 0.1 and in the interval 0.125 < Stc $\leq$ 2.5, the capture coefficient is equal to

$$E_2 = \frac{\text{Stc}_2}{\text{Stc}_2 + 0.23\, L} = \frac{l_{i,2}}{l_{i,2} + 0.23\, D_{av} L}. \quad (37)$$

As we can see from Fig. 4, curve 3 has been plotted from the calculated values of the capture coefficient when L = M = 1 from (35), and it provides a good approximation of the theoretical values calculated on a computer, as given in [12] (curve 2). The experimental data from [10, 21] are in good agreement with curves 2 and 3. Curve 4, plotted from the data of [22] without consideration of the hydrophilic nature of the particles yields substantial deviations.

Having calculated the hydrophilic parameter from (30), we used the nomogram in Fig. 3 to determine the anticipated capture coefficient E.

Bearing in mind that these conditions are critical, and also that each collision of a particle with a droplet will be effective (there will be no recombinations), from (35)-(37) we can calculate the effectiveness of particle trapping in the dust-collecting apparatus.

Satisfactory agreement between the values of trapping effectiveness calculated from (35) and the experimental data for active highly dispersed carbon [10] and for dibutylphthalate particles with d = 1 μm has been established experimentally [21]. The hydrophilic parameter for the particles of the highly dispersed active carbon is equal to M = 0.194. For the dibutylphthalate it is M = 0.03.

NOTATION

m	is the mass of the particle or of the liquid droplet, and equal to $\pi d^3 \rho_2/6$, kg;
ρ_1, ρ_2, ρ_3	are, respectively, the densities of the medium, of the particle, and of the liquid, kg/m^3;
ν, η	are the viscosities of the medium, $N \cdot sec/m^2$ and m^2/sec;
ψ	is the coefficient of hydrodynamic resistance for the medium, so that when $Re < 1$, $\psi = 24/Re$ and when $Re \leq 300$, $\psi = A + B/Re$, where A and B are constants respectively equal to 0.12 and 37;
S	is the area of the particle's midsection, equal to $\pi d^2/4$, m^2;
r, d	are, respectively, the radius and diameter of the particle, m;
$\bar{V}_m$, $\bar{V}_p$, $\bar{V}_{in}$, $\bar{V}_i$, $\bar{V}_x$, $\bar{V}_0$, $\bar{V}_s$	are, respectively, the velocity of the medium, of the particle, the absolute velocity, the initial velocity, the velocity of some distance from the point of entry, the relative velocity, and the sedimentation rate, m/sec;
$\bar{F}_{ex}$	is the vector of the external forces applied to the particle, N;
dl	is the elementary segment traversed by the particle, m;
τ	is the relaxation time for the particle, equal to $d^2\rho_2/18\eta$, sec^{-1};
Re	is the Reynolds number, equal to $V_0 d/\nu$;
g	is the acceleration force equal to 9.81 m/sec^2;
α	is the fraction of the particles in the aerosol, with the dimensions of the particles less than those of the particle being considered;
E	is the capture coefficient, characterizing the ratio of the trapped particles to the total number of particles contained in a hypothetical tube;
z	is the dust content of the medium, kg/m^3;
l_i and $l_{i,n}$	are the inertial paths, m;
Stc	is the Stokes criterion for the particles;
D_{av}	is the average value of the droplet size, m;
M, L	are the hydrophilic and hydrophobic parameters;
σ	is the surface tension of the liquid, N/m.

LITERATURE CITED

1. P. N. Smukhnin and P. A. Kouzov, Centrifugal Dust Separators [in Russian], ONTI (1935).
2. W. Muhlrad, Challeur Ind., No. 343 (1954).
3. A. I. Pirumov, Aerodynamic Fundamentals of Centrifugal Separation [in Russian], Gosstroyizdat (1961).
4. V. V. Baturin, Fundamentals of Industrial Ventilation [in Russian], Profizdat, Moscow (1951).
5. A. T. Litvinov, Inzh. Fiz. Zh., 10, No. 6, 776 (1966).
6. A T. Litvinov, Inzh. Fiz. Zh., 11, No. 5, 570 (1966).
7. N. A. Fuks, The Mechanics of Aerosols [in Russian], Izd-vo AN SSSR (1955).
8. L. M. Levin, Investigations into the Physics of Coarsely Dispersed Aerosols [in Russian], Izd-vo AN SSSR (1961).
9. A. T. Litvinov, Zh. Prikl. Khim., 38, No. 10, 2237 (1965).
10. A. T. Litvinov, Author's Abstract of Dissertation [in Russian], MIKhM (1965).
11. W. Sell, VDI Forschungsheft, No. 347 (1931).
12. H. Herne, Symposium of the Aerodynamic Capture of Particles, Pergamon Press (1960).
13. T. Pearcey and G. Hill, Quart. J. Roy. Met., 83, 77 (1957).
14. W. E. Ranz and G. B. Wong, Ind. Eng. Chemistry, 44, No. 6, 1371 (1952).
15. F. Albrecht, Physicalische Zeitshrift, 32, No. 18 (1931).
16. J. Langmuir and K. Bladgett, Army Air Force, Techn. Report, 5418 (1946).
17. J. Langmuir, J. Meteorol., 457, 175 (1948).
18. A. T. Litvinov, Khim. Prom., No. 8 (1964).
19. H. Landahl and K. Herman, J. Coll. Sci., 4, 103 (1949).
20. I. Khimich and N. Shishkin, Trudy GGO, No. 21 (93) (1949).
21. F. O. Ekman and H. F. Jonstone, Ind. Eng. Chemistry, 43, No. 6, 1358 (1951).
22. W. Walton and A. Woolcock, Symposium of the Aerodynamic Capture of Particles, Pergamon Press (1960).