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SOME LAWS FOR PRECIPITATION OF AEROSOLS ON A CHARGED COLLECTOR IN THE REYNOLDS NUMBER RANGE 10-100

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Experimental data are presented on the efficiency of electrostatic precipitation of aqueous aerosol particles on a strongly charged sphere in the medium Reynolds number range (Re = 10-100). The asymptotic solutions for the problem are presented, and typical errors allowable in interpreting this type of experiment are discussed.

Existing theoretical and experimental data [1-6] on the efficiency of the electrostatic precipitation of aerosol particles on charged bodies of very simple shape refer mainly to cases where there is either viscous (Reynolds number much less than 1) or uniform flow (the electric forces significantly predominate over the hydrodynamic) of air carrying aerosols over the collector.

In a number of cases associated with filtration and elution of aerosols by precipitation particles and artificial bodies [7-10] so-called medium or intermediate Reynolds numbers (Re = 5-100) are achieved. For this situation information on the laws of electrostatic precipitation of particles at an obstacle is practically nonexistent.

The present work analyzes the results of measurements of capture coefficients of neutral and charged particles of aqueous aerosols by a fixed, charged spherical collector. The Reynolds numbers values based on the sphere diameter fall in the range 10-100.

The experimental technique and some of the initial measurement data have been described in [7-8]. The essence of the technique is as follows.

A one-dimensional jet of droplets of a given size and charge is generated in a flow of moist air, washing a metal sphere of diameter 0.4 cm. The sphere potential is varied in the range 0 to ± 6000 V, and the droplet charge from 0 to ± 100e, the droplet diameter from 10 to 30 μ, and the flow speed from 4 to 40 cm/sec. From analysis of television photographs of the limiting trajectories for the droplet motion near the spherical collector we determined the capture coefficient, defined as the ratio of the area of the stream tube of precipitated particles to the projected area of the sphere.

The results of the tests of interaction of uncharged conducting droplets with a charged sphere, with an electric field intensity on its surface of 5, 10, and 20 kV/cm, are shown in Fig. 1; the capture coefficient K is shown as a function of the dimensionless coagulation parameter β, which characterizes the ratio of the mirror and aerodynamic forces acting on the particle

$$\beta = (2U^2d^2/3\pi\eta D^3u_\infty)\cdot(\varepsilon - 1)/(\varepsilon + 2), \quad (1)$$

where d and ε are the size and dielectric constant of the droplets; U and D are the potential and diameter of the sphere; η is the dynamic viscosity for air; and u_∞ is the flow velocity at infinity. We note that for U = 0 quite low values of K < 0.05 have been observed [8].

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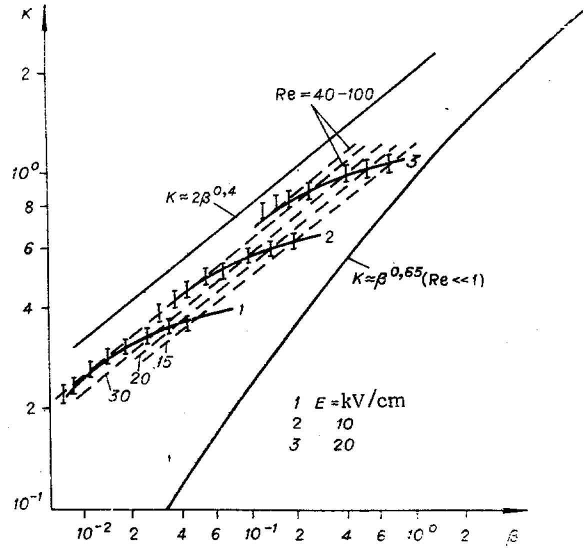

Fig. 1

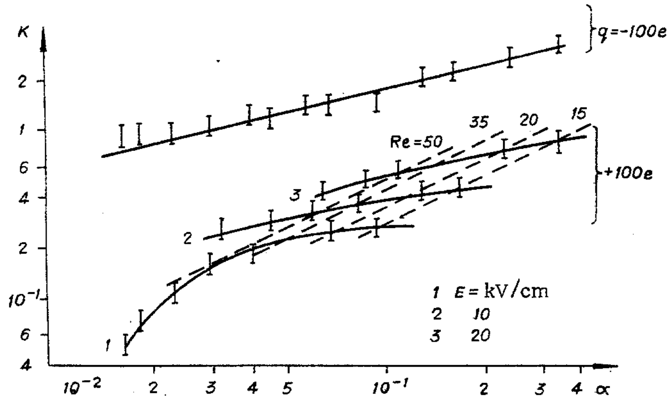

Fig. 2

For comparison Fig. 1 also shows calculated data using the Cauchy formula [1] for uniform flow over a sphere with $K=2\beta^{0.4}$ and the results of a numerical computation from [3] for viscous flow over a sphere (Re≪1). In the latter case for $\beta < 0.1$ one can use the approximation $K=\beta^{0.65}$.

It can be seen from Fig. 1 that approximations of the type $K=f(\beta)$ for uniform and viscous flow conditions give only limiting solutions to the problem for the Reynolds number range of interest; for the range Re = 10-100 there is no unique relation between the capture coefficient K and the parameters of the sphere and the aerosol particles, due evidently to the specific nature of the adjustment of the flow field around the sphere. Judging from Fig. 1, this adjustment is strongest in the region Re = 1-20, which corresponds to the theoretical conclusions [11]. It is known that, for Reynolds numbers from 1 to some tens, an axisymmetric recirculating wake appears and grows in the rear part of the flow over the sphere. The streamlines approach closer to the forward surface of the sphere, which causes an increase in K (for a fixed value of β), compared with the case of viscous flow. Expressions for the velocity fields, including vorticity, are not of explicit form [11], and therefore there is no unique method of solving the problem as a whole; i.e., this is a numerical analysis of a finite-difference approximation to the Navier–Stokes equations. However, this analysis has not been done, as far as we know, with the electrical forces included.

The situation is more favorable (from the viewpoint of determining the parameters of the experimental data) only for Re > 40 (see Fig. 1), when the process of flow adjustment around the sphere has practically finished. Therefore, quite simple approximations of the type $K=f(\beta)$ can be found for the region Re = 40-100.

It is considerably more difficult to interpret the results of tests with charged particles and a collector. On the one hand, it is known (see, e.g., [1]), that the laws for precipitation of particles on an obstacle due to Coulomb forces have a weak correlation with the type of flow; i.e., in the Reynolds number range R = 10-100 the simple formula

$$K = 4(\alpha) \tag{2}$$

can be used to estimate the capture coefficient of a spherical collector, where α is a parameter characterizing the ratio of the Coulomb and the aerodynamic forces acting on a small particle

$$\alpha = 16Uq/3\pi\eta d u_\infty D. \tag{2a}$$

On the other hand, one must bear in mind that in experiments with rather large collectors (on the order of 1 cm and more) it is difficult to estimate quantitatively effects associated with the Coulomb interaction mechanism, since in the real atmosphere the limiting radius for interaction of charged particles is bounded by the Debye screening radius r_d. If the actual concentration of aero-ions and other charged particles in the gas flow is close to $n_\pm \approx (1\text{-}5)\cdot 10^3\ \text{cm}^{-3}$, then $r_d = kT/4\pi n_\pm e^2 \approx 2\text{-}5$ cm.

Using Eq. (2) it can be estimated that for $q > 10^{-3}$ and a field intensity on the sphere surface close to 20 kV/cm, the characteristic scale for interaction (corresponding to the limiting distance of the limiting trajectory of a particle near the sphere) is on the order of 4-5 cm. This means that the Coulomb attraction forces are not fully apparent. In addition, in practice one often meets the situation where the aerosol particles have comparatively small charges, while the collector charge is the maximum value allowable in the atmospheric conditions. Then the specular and the Coulomb forces are of the same order of magnitude [7]. To find the total capture coefficient one can perform laborious numerical solution of the equation of relative motion of particles and collector, and this is done for specific problems only in the approximation of Stokes-type fields [4-10].

The results of the experiments shown in Fig. 2 are interesting in that, for the region Re = 10-100, one can obtain quantitative estimates of the combined action of specular and Coulomb forces and qualitative estimates of the effect of the velocity field. Thus, if the charge on the drop is 100e, and the charge sign is of opposite polarity to the sphere potential, then the nonunique dependence of the capture coefficient on the parameter Re typical for an induction interaction is noticeably weakened with the appearance of Coulomb forces. It seems possible to describe the experiment as a unique function of type $K = f(\alpha)$ over a wide range of Re values.

To compare the contribution of Coulomb collision forces and specular attraction forces, Fig. 2 also shows the results expressed in terms of α, for the case where the sign of the sphere charge is the same as the droplet charge. Here, because the induction forces predominate over the Coulomb forces, it can be seen, as in Fig. 1, that a role is played by factors responsible for adjustment of the flow field in the range of Re numbers considered.

Thus, the laws for electrostatic precipitation of aerosol particles on an obstacle, for Re = 10-100, are more complex than for viscous flow, and cannot be represented uniquely by the criteria of Eqs. (1) and (2a). It is difficult in most cases to single out the effects of Coulomb and induction interactions.

Taking account of what has been said, one must point out one typical error committed in interpreting this kind of experiment [5, 9]: the authors of [5] ascribed the effects of precipitation of charged aerosol particles on a charged cylinder for Re > 40 as being completely due to Coulomb forces, and this statement is by no means indisputable.

In analogy with the case of a spherical collector considered, we can postulate that the true values of induction capture coefficients for a cylinder, as for a sphere, lie between the limits [6]

$$K_{max} = [(3/2)\pi\beta_1]^{1/3} \text{ for } \beta_1 \gg 1; \qquad K_{min} = \pi\beta_1 \text{ for } \beta_1 \ll 1, \tag{3}$$

where

$$\beta_1 = U^2 d^2/3\pi\eta u_\infty D^3.$$

Then, by substituting typical experimental values into Eq. (3) [5], U = 1-6 kV, d = 4 μ, u_∞ = 60-600 cm/sec, D = 0.1 cm, we have K_{max} = 1.5-1.8, K_{min} = 0.045-0.41, which are on the same order as the values K = 2.4-0.24.

The agreement between experimental and calculated capture coefficients in [5], allowing only for Coulomb forces, should evidently be considered as accidental. The uncertainty can be explained by the fact that the values of electric field intensity on the cylinder surface during the experiment exceeded the allowable limits for atmospheric conditions (more than 25 kV/cm); this caused additional effects associated with corona discharge, and so on.

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