SEDIMENTATION OF PARTICLES FROM A CONCENTRATED DISPERSED FLOW

G. I. Kelbaliev, A. G. Rzaev, A. F. Guseinov, and A. A. Kasymov

UDC 536.6

It is pointed out that the existing equations for the rate of sedimentation of an aggregate of particles from a flow give values that are lower than the experimentally measured values. A new equation is derived theoretically for the rate of sedimentation of an aggregate of drops. The results are in good agreement with experiment.

The technological processes of separating concentrated heterogeneous systems are widely employed in petrochemical, petroleum refining, and oil production industries. Calculations of such processes are based on adequate determination of the average rate of sedimentation of an ensemble of particles. A quite accurate theory of sedimentation of a single solid spherical particle in a gravitational field and an approximate semiempirical theory of sedimentation of an ensemble of particles, which takes into account the crowding of the particles, have now been developed. Among the equations describing the rate of sedimentation, it is important to note Tem's equation [1]

$$U = U_{st}\frac{4 + 3\varphi + 3\sqrt{8\varphi - 3\varphi^2}}{(2 - 3\varphi)^2}, \tag{1}$$

and the Mod–Whitmer equation

$$U = U_{st}(1 - \varphi)^{4,8}, \tag{2}$$

which satisfy the conditions $\varphi > 0.05$ and $r < \sqrt{\sigma/(g\Delta\rho)}$, as well as Hankel's equation for a liquid–liquid system [2]

$$U = U_{st}\frac{3\mu_\varphi(1 - \varphi^{1/3})(1 - \varphi^{5/3}) + \mu_c\left(3 - \frac{9}{2}\varphi^{1/3} + \frac{9}{2}\varphi^{5/3} - 3\varphi^2\right)}{2\mu_\varphi(1 - \varphi^{5/3}) + \mu_c(3 + 2\varphi^{5/3})}, \tag{3}$$

where $U_{st} = (2/9)(\Delta\rho q r^2/\mu_c)$ is Stokes equation for the rate of sedimentation of a single spherical particle. The latter equation is also used to calculate the rate of sedimentation of many particles under the conditions $\varphi \leq 0.05$ and $r < \sqrt{\sigma/(g\Delta\rho)}$.

Calculations using Eqs. (1) and (2) for $\varphi > 0.05$ showed that the values obtained for the rates of sedimentation are lower than the experimental values. In particles, Eq. (3) gives a rate of sedimentation that is two to three times lower than the experimental value (Fig. 1).

The aim of this investigation is to see if it is possible to describe adequately the rate of sedimentation of many drops in a liquid–liquid system for the case when their hydrodynamic fields interact.

It should be noted that any spherical particle in a dispersed flow is surrounded by a symmetric layer of close-lying particles. If the radius of such a spherical cloud is equal to l (Fig. 2), then it can be assumed that all parameters of this field reach extrema in a sphere of radius $l/2$. This makes it possible to construct spherical cellular models with a free surface of the extremal conditions.

Institute of Theoretical Problems of Chemical Engineering, Academy of Sciences of the Azerbaidzhan SSR, Baku. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 61, No. 3, pp. 365-368, September, 1991. Original article submitted November 12, 1990.

 0022-0841/91/6103-1064$12.50

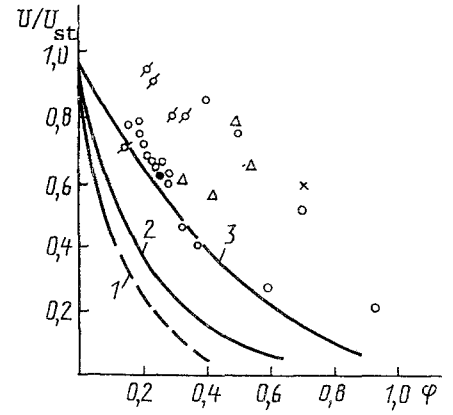

Fig. 1. The rate of sedimentation as a function of the volume fraction of dispersed particles and comparison with experimental data: 1) calculation using Eq. (2); 2) calculation using Eq. (3); 3) calculation using Eq. (12).

In the theoretical analysis of the motion of drops in a flow we make the following assumptions:

a) The flow around the particles is viscous, which follows from the condition that the Reynolds number is small $\mathrm{Re} = |U_d|(a/\nu) \ll 1$, and is described, to a first approximation, by the linear Stokes law ($F_s = 3\pi\mu_\varphi a \cdot U_d$, where $U_d = U - U_f$ and U_f is the flow velocity);

b) the drops are strictly spherical; in the case when the drops can become deformed it is necessary to introduce a shape factor and in the case when the drops are polydispersed each fraction must be studied separately;

c) the average distance between the particles, determined according to the equation in [3]

$$l \simeq a \sqrt[3]{6{,}2/8\varphi}, \tag{4}$$

is large compared with the sizes of the particle, so that the particles do not collide with one another and they do not coagulate, though the hydrodynamic fields around the drops can interact with one another; and,

d) the motion of a drop is not affected by forces arising owing to transfer of drops as a result of turbulent and buoyant migration, as well as by electric, thermophoretic, diffusophoretic, and other forces of a nonhydrodynamic nature, with the exception of the force of gravity, under whose influence the sedimentation of the particles occurs.

The motion of the drops in the flow is described by the Navier–Stokes equation, which characterizes both the external and internal steady flows in the drop

$$\operatorname{div} P = \mu_c \Delta v_c, \tag{5}$$

as well as by the equations of continuity

$$\operatorname{div} v_c = 0, \quad \operatorname{div} v_\varphi = 0. \tag{6}$$

Transforming to spherical coordinates in Eqs. (5) and (6) and omitting the simple but laborious calculations, by analogy to [4] we obtain analytic expressions for the velocity distribution in the continuous and discrete phases. For the final solution we formulate the boundary conditions for Eqs. (5) and (6).

Under the conditions of steady motion, spherical drops having the same size a, and moving in the horizontal plane I–I drop over an infinitesimal time $d\tau$ over a distance dz, i.e., to the plane II–II (Fig. 2). As the drops move they free up a space, equal to $n(\pi a^2/4) - dz$, which is filled by a continuous liquid which flows into this space with an average velocity v_t in the transverse section I–I of the sedimentation tank. Therefore we can write

$$nf\,dz = -v_t(F - nf)\,d\tau, \tag{7}$$

where $f = \pi a^2/4$ is the transverse cross-sectional area of the drop and F is the free cross section of the working zone of the tank.

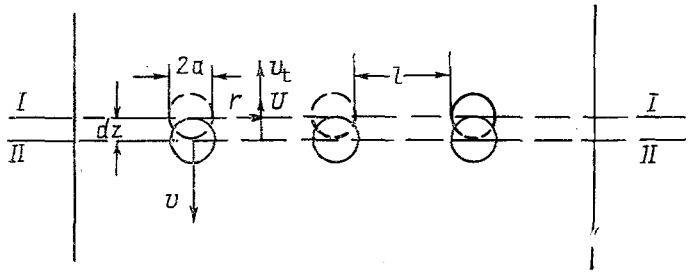

Fig. 2. Diagram illustrating the arrangement of drops in the flow.

We note that $dz/d\tau$ is the absolute velocity U of the drops. Thus expression (7) can be put into the following form:

$$\frac{dz}{d\tau} = U = -v_t\left(\frac{F}{nf} - 1\right), \tag{8}$$

hence we obtain

$$v_t = U\Big/\left(1 - \frac{F}{nf}\right). \tag{9}$$

Setting $\varphi = nfa/Fa$, we obtain from Eq. (9)

$$v_t = \frac{U}{1-\varphi}. \tag{10}$$

Thus at a distance $r \to a + l/2$ the velocity distribution in the liquid medium satisfies the condition

$$v_r = U\left(\frac{1}{1-\varphi}\right)\cos\theta,\ v_\varphi = -U\left(\frac{1}{1-\varphi}\right)\sin\theta, \tag{11}$$

where θ is the spherical angle, and v_r and v_φ are the normal and tangential components of the velocity. Aside from the conditions (11), we also employ the condition that on the surface of the drop $r = a$ the normal and tangential stresses are equal, and the normal components of the velocity of the exterior and interior liquids vanish on the surface of the drop. Without analyzing the solution to (5) and (6), given in [4], but using the new condition (11), we obtain finally an expression for the velocity of crowded sedimentation:

$$U = 1{,}5U_{st}(1-\varphi)\,\frac{\mu_\varphi - (3\mu_\varphi + 2\mu_c)(1+k)^2 + 2(\mu_\varphi + \mu_c)(1+k)^3}{(3\mu_\varphi + 2\mu_c)(1+k)^3}, \tag{12}$$

where $k = \sqrt[3]{6.2/8\varphi}$. As follows from Fig. 1, the rate of crowded sedimentation (12) describes better the experimental data of [5] than do Eqs. (2) and (3).

In the particular case when $\varphi \to 0$ and $k \to \infty$ the relation (12) transforms into the formula of Hadamard–Rybchinskii:

$$\lim_{\varphi\to 0} U = 3U_{st}\,\frac{\mu_c + \mu_\varphi}{2\mu_c + 3\mu_\varphi}.$$

If $\mu_\varphi \gg \mu_c$, the average rate of sedimentation of concentrated systems of solid particles is determined in the form

$$U = \frac{1}{2}U_{st}(1-\varphi)\,\frac{1 - 3(1+k)^2 + 2(1+k)^3}{(1+k)^3}. \tag{13}$$

If $\varphi \to 0$ and $k \to \infty$, then Eq. (13) transforms into Stokes equation $\lim_{\varphi\to 0} U = U_{st}$ and in the limit $\varphi \to 1$ and $U \to 0$ sedimentation of the particles does not occur.

For polydispersed particles the size distribution of the particles $P(a)$ must be taken into account when determining the average rate of sedimentation. If it is assumed that the average drop size satisfies the expression

$$a_s = \int_0^\infty aP(a)\,da,$$

then Eq. (12) can be used to calculate the average rate of sedimentation.

NOTATION

Here a is the diameter of the drops; r is the radius of drops or the coordinate; P is the pressure; U is the rate of sedimentation of the drops; v_c is the velocity of the drops; σ is the surface tension at the interface of the phases; μ is the dynamic viscosity; ρ is the density; $\Delta\rho$ is the difference of the densities of the dispersed particle and the medium; φ is the volume fraction of particles. The index φ designates a dispersed plane and the index c designates a continuous phase.

LITERATURE CITED

1. V. I. Loginov, Dehydration and Desalination of Petroleum [in Russian], Moscow (1979).
2. V. V. Kafarov and I. N. Dorokhov, Systems Analysis of Processes in Chemical Technology [in Russian], Moscow (1976).
3. E. P. Mednikov, Turbulent Transfer and Sedimentation of Aerosols [in Russian], Moscow (1981).
4. V. G. Levich, Physicochemical Hydrodynamics [in Russian], Moscow (1959).
5. S. N. Bulatov, "Statics, hydrodynamics, and kinetics of extraction in plate-type column apparatus," Doctoral Disseration in Technical Sciences, Moscow (1971).

INFLUENCE OF ADSORBED LAYERS ON THE ELECTRICAL CONDUCTIVITY OF DISPERSED SYSTEMS

D. É. Gutso and V. M. Kiseev

UDC 537.311:542.937

We present the results of an experimental investigation of the effects of adsorbed layers on the conductivity of a charge of finely divided nickel particles.

The use in technology and industry of an increasing number of dispersed working media requires a satisfactory theoretical description of the physical and physicochemical processes which occur in them. The transport of heat, mass, and electrical charge in dispersed media are of considerable interest. There is a broad literature devoted to a description of transport phenomena in dispersed media, some examples of which are found in [1-3]. In turn, the shortage of experimental material prevents a realistic description of the physical processes.

The goal of the present work is to clarify the effect of adsorbed layers on the transport of electrical charge in dispersed media.

Different physical mechanisms contribute to the electrical conductivity of a dispersed medium. One is metallic conductivity along individual particles and across the metallic contacts between them. Another is activation conductivity, resulting from gaps between particles, with adsorbed gases oxidized on the particle surfaces. In contrast to metallic conductivity, activation conductivity is characterized by a negative temperature coefficient of resistivity. The dynamics of the dependence of the electrical resistivity of a dispersed medium upon temperature will be investigated in the experiments described below.

A. M. Gor'kii Ural State University, Sverdlovsk.

Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 61, No. 3, pp. 369-372, September, 1991. Original article submitted September 28, 1990.

0022-0841/91/6103-1067$12.50