EFFECT OF THE INTERACTION OF DROPS WITH SIMILAR DIMENSIONS ON THE GROWTH RATE AND LAG OF CONDENSATION PARTICLES IN POLYDISPERSE TWO-PHASE FLOWS

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New general dependences for the coagulation parameter Φ and the collisional splitting of a drop are obtained which take into account particles of similar dimensions. A numerical study of one-dimensional polydisperse flow in Laval nozzles is conducted. It is shown that the new dependence for Φ allows one to determine flow parameters more accurately.

An investigation of polydisperse two-phase flows has been considered in a number of studies (see [1]). Mathematical models have recently been obtained which take into account coagulation and lag of the particles upon collision, the polydisperse composition of the secondary particle fragments, etc. Additional experimental information on the transfer of mass and momentum during interactions of the drops is needed to make practical use of these models. The following equation was obtained in [2]:

$$\Phi_{ji} = 1 - 0.247\,\mathrm{Re}_{ji}^{0.434}\mathrm{Lp}_i^{-0.133}\Delta_{ji}^{-0.273} \quad (1)$$

for the ranges $35 < \mathrm{Re}_{ji} < 385$; $5 < \mathrm{Lp}_i < 600$; $2 < \Delta_{ji} < 12$. Here, $\mathrm{Re}_{ji} = |\mathbf{u}_j - \mathbf{u}_i|\delta_j\rho/\eta$ is the Reynolds number, $\mathrm{Lp}_i = \delta_i\sigma\rho/\eta^2$ is the Laplace number, $\Delta_{ji} = \delta_i/\delta_j(\delta_j < \delta_i)$; δ, **u** are the diameter and velocity of the particles, ρ, η, σ are the density, dynamic viscosity, and the coefficient of liquid surface tension, Φ_{ji} is the average ratio of the change in mass of particle i over some time interval to the total mass of the particles which collides with it.

Equation (1) is insufficient because it cannot be used for describing the interactions of particles with similar dimensions ($\Delta_{ji} < 2$). One should note that under real conditions particles with similar dimensions generally move with similar velocities, but in a series of cases the collision frequency (and, therefore, the contribution of these particles to the growth rate of large particles) can be significant. In correspondence with [1], the rate at which the dimension of particle i changes is equal to the following in the quasi-one-dimensional approximation

$$\frac{d\delta_i}{dx} = \frac{u_{\mathrm{gas}}\rho_{\mathrm{gas}}}{2\rho u_i\delta_i^2}\sum_{j=1}^{i-1}\frac{E_{ji}\Phi_{ji}(\delta_i+\delta_j)^2\mu_j|u_j-u_i|}{u_j}, \quad (2)$$

where x is the longitudinal coordinate, μ is the mass discharge density, and E is the precipitation coefficient; the quantities with the index g pertain to the gas, and the fractions are numbered in order of increasing particle dimension. It is evident from (2) that for a given t and an increase in δ_j the collisional cross section increases. In addition, the relative contribution from the different terms in the right-hand part of (2) is proportional to the concentration of fractions f. As was recently established in [1, 3], it is significant that in many cases particles from several large fractions take on very similar dimensions independent of their initial sizes.

The study in [4] presented experimental data on the transfer of mass during collisions of drops with similar dimensions ($\Delta_{ji} = 1, 1 \ldots 3$). For small Δ_{ji}, intense drop splitting is observed, where Eq. (1) overstates the value of Φ_{ji}. Processing of the experimental data in [2, 4] resulted in the following new general equation:

$$\Phi_{ji} = 0.893 - 1.979A_{ji} + 1.014A_{ji}^2,$$

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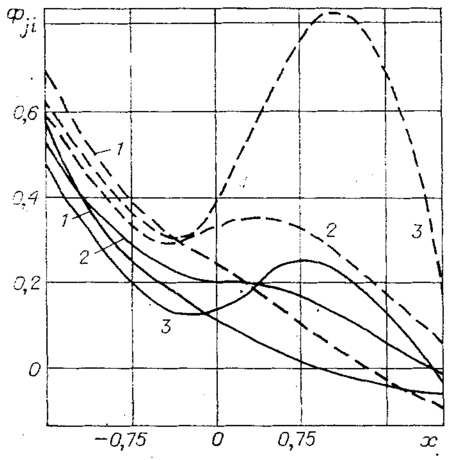

Fig. 1

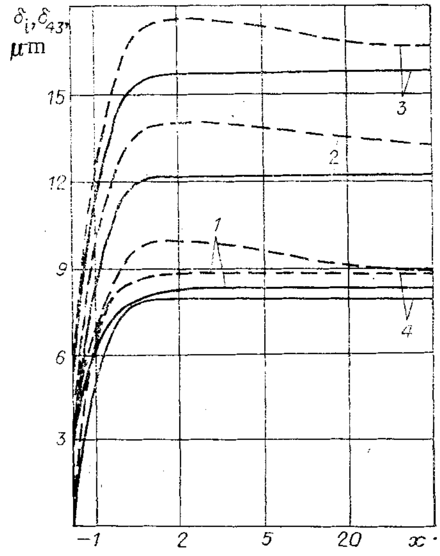

Fig. 2

$$A_{ji} \equiv (\mathrm{Re}_{ji}/383.6)^{0.572}(\mathrm{Lp}_i/370.4)^{-0.153}(\Delta_{ji}/2.73)^{-0.597}. \tag{3}$$

One should note that the applicability of Eq. (3) is limited by the condition $A_{ji} \leqslant 1$.

It is also more important to study high velocity flow of polydisperse two-phase mixtures with greater accuracy (compared to [1, 2]) taking into account the transfer of mass during interactions of particles with similar dimensions. This problem will be considered in connection with quasi-one-dimensional flow in Laval nozzles. Calculations were made using the technique in [2]. It was assumed that the fragments are polydisperse and have initial velocities corresponding to those in [1]. The parameters of dynamic and thermal interactions between the gas and the particles were determined according to [1] taking into account an increase in the coefficient of aerodynamic resistance which deforms the drop. The splitting of large particles by aerodynamic forces is not considered in this study. Calculations were conducted in connection with the Laval nozzle [1] for a wide range of values for μ, p_0, r^*, r_a/r^* (p is pressure, r is the cross-sectional radius of the nozzle, and the quantities with the indices 0, $_*$, and a are related to the initial, the minimum, and the final cross sections). Ten fractions of polydisperse condensation were considered; the average initial particle dimension was $\delta_{43}^0 = 1 \ldots 3$ μm. Every variant was calculated using Eqs. (3) and (1) (the solid and dashed curves in Figs. 1-5). The base variant corresponded to $r^* = 0.03$ m, $p_0 = 15$ MPa, $\mu = 7$ [$z = \mu/(1 + \mu) = 0.875$], $\delta_{43}^0 = 1.6$ μm, $r_a/r^* = 17$, and the initial particle dimensions for the factions δ_{i0} (μm) were: 0.8, 1.2, 1.6, 1.8, 2.0, 2.4, 2.8, 3.2, 4.4, and 6.0. Some of the results for the base variant are shown in Figs. 1 and 2.

Values of the coagulation and splitting parameters for intense particle interaction are shown in Fig. 1 (curves 1-3 correspond to j = 6; 6; and 8, and i = 8; 10; 10, and the value of x is related to r*). As one would expect, almost all the dashed curves lie above the corresponding solid curves. One should note that Fig. 1 gives values of Φ_{ji} calculated from Eqs. (1) and (3) for different δ_i, δ_j, u_i, u_j, etc. (also see Fig. 2). This explains the intersection of curves 1 for $x > 1.5$. The maxima on curves 2 and 3 for $x \sim 0 \ldots 1$ arise because the largest particles (i = 10) are deformed by aerodynamic forces, which leads to an increase in the force of interphase interaction and in the velocities of these particles such that $|u_j - u_i|$ and Re_{ji} decrease.

A change in the particle dimensions of the fractions along the length of the flow is illustrated in Fig. 2 (curves 1-3 correspond to $\delta_{i0} = 3.2$; 4.4; 6.0 μm, and curve 4 corresponds to the particle dimension δ_{43}). It is evident from this data that using Eq. (3), there is not rapid growth of the large particles. However, the selection of an equation for Φ has practically no effect on the particle dimensions of the small and moderately sized fractions. The fraction composition of the condensation noticeable changes when using Eq. (3) over Eq. (1) (especially for supersonic particles): The concentrations of small fractions increase, and the concentrations of large fractions significantly decrease. In addition, the difference between values for the average particle dimension corresponding to Eqs. (1) and (3) (curves 4) is greater than the difference between the particle diameters for individual fractions.

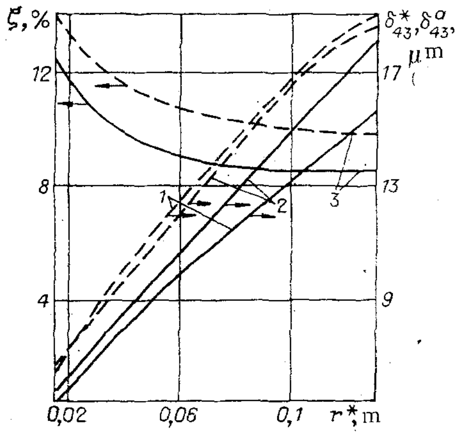

Fig. 3

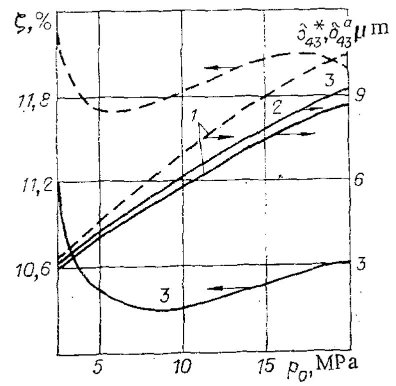

Fig. 4

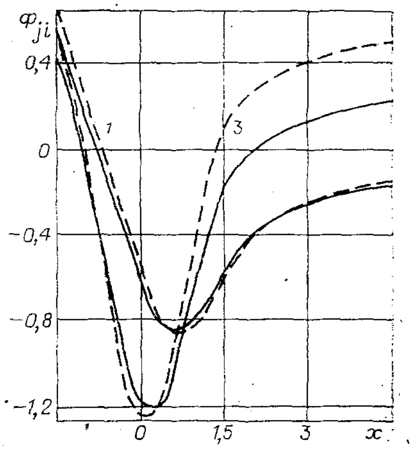

Fig. 5

TABLE 1

μ	3	7	10
Calculations using Eq(3), (4)	4,3/2,5	6,3/3,8	7,3/4,8
Calculations using Eqs. (1), (4)	4,8/2,8	7,0/4,2	8,1/5,3

Calculations show that the dynamic lag of all condensation fractions decreases somewhat when using Eq. (3). This is related to a decrease in the dimension of large particles (see Fig. 2) and to the more pronounced effect of the discrete phase on the gas, which leads to a decrease in the longitudinal gradients of the gas parameters.

The dependences of the average particle dimension for minimum 1 and final 2 cross sections are shown in Fig. 3 along with loss in momentum caused by particle lag 3. For an increase in r*, with other conditions being the same, the duration of the particle's existence in the flow increases, which leads to an increase in δ_{43}. However, the loss of momentum decreases, and the decrease in the rate of velocity increase for the gas becomes more important [1, 3]. One should note that using Eq. (3) for the supersonic part prolongs the growth of the particles, whereas Eq. (1) indicates a decrease in δ_{43} (compare with Fig. 2).

The dependences of δ_{43} and ζ on the initial pressure are given in Fig. 4 (the labeling is the same as that used in Fig. 3). For an increase in p_0 the volumetric particle concentration increases along with the collision frequency; therefore, the quantity δ_{43} monotonely increases. Dependence $\zeta(p_0)$ is more complicated with one (the solid curve) or two (the dashed curve) extrema. This is due to three factors: 1) the increase in the particle dimension (for an increase in p_0); 2) an increase in the force of aerodynamic resistance and the subsequent decrease in the dynamic lag; 3) the more significant effect of the particle on the gas, which leads to less dispersion of the gas. The second and third factors are related to the downward sloping parts of curves 3, and the first factor is related to the upward sloping parts.

For increase in the total concentration of condensation the intensity of interaction between the fractions increases, which leads to significant differences between the calculation results from Eqs. (1) and (3). Therefore, if for $\mu = 1$ the difference in the values for the loss of momentum is $\Delta\zeta \sim 0.5\%$, then for $\mu = 5 \ldots 7$ the difference is $\Delta\zeta \sim 3\%$.

The calculations described above do not account for the effect of gas flow on the collisional splitting of particles. According to [1] this factor leads to a decrease in Φ_{ji} (compared to the case where the particles interact in a gas medium at rest) by the quantity

$$\Delta\Phi_{ji} = 0.18\,\mathrm{We}_i^{0.67}\mathrm{Re}_{ji}^{0.4}\mathrm{Lp}_i^{0.12}\Delta_{ji}^{-2.27} \tag{4}$$

($\mathrm{We}_i = \rho_{gas}\delta_i(u_{gas} - u_i)^2/\sigma$ is Weber's number). Values of the parameter Φ_{ji} for the base variant are shown in Fig. 5 which were calculated with corrections (4) (with the same labeling as that used in Fig. 1). The data show that the difference between values of the "collision efficiency" which corresponds to the use of either Eq. (1) or Eq. (3) is much less. Large sections of the dashed curves lie below the solid curves. In addition, the difference between the integral flow parameters is less. As an example, some data for three calculation variants are given in Table 1 (the numerator shows percentage values of ζ, %, and the denominator shows values of δ_{43}^{a} in μm).

Therefore, when accounting for the effect of gas flow, the decrease in momentum loss due to refinement of Φ_{ji} is about 10% of ζ.

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STUDY OF INERTIAL SETTLING OF POLYDISPERSED PARTICLES AT THE CRITICAL POINT OF A SPHERE

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The flow of an incompressible gas with particles past a body at high Reynolds numbers is studied in many works, for example, in [1-6], where in the calculation of the characteristics of inertial settling of an impurity the particles are assumed to be monodispersed. At the same time, in real gas suspensions the particle sizes are always different. Polydispersity of particles even in the case when their interaction with one another is ignored, substantially complicates the picture of the motion of the impurity near the body. Particles of different sizes are deflected by the gas flow differently. As a result, the fractions are redistributed in space and the initial particle-size distribution function of the average density of the dispersed phase changes. In this case it is difficult to set up and solve the "kinetic" equation describing the evolution of the distribution function. In this paper we propose a method for calculating the flux density of settling polydispersed particles at the front critical point and the flux-density distribution function over the fractions. In so doing just as in [1-6], it is assumed that the particle concentration is small, and the effect of the particles on the gas flow and the interaction of particles with one another are ignored.

In the case when the impurity concentration is negligibly small, the problem of the flow of a gas suspension past a body reduces, as is well known, to a sequence of two simpler problems the construction of the flow field of the carrying medium near the body and the calculation of the particle trajectories in this field. If the Reynolds number is large, then the viscosity of the gas in the problem of flow past the body is usually ignored. Estimates [1, 3, 4] and a direct calculation [7] show, however, that there exists a quite wide range of parameters of the flow of the gas suspension where the viscous boundary layer on the surface of the body substantially affects the motion of the impurity and, therefore, in the general case it cannot be neglected in determining the characteristics of inertial settling of the particles. In this paper the flow field of the gas near the sphere is given just as in [7], based on a model which includes the external potential flow and the viscous boundary layer. It is shown in [8] that the use of such a model in the calculation of the flux density of the settling particles gives a quite high accuracy at the critical point, if Re $\gtrsim 10^5$.

In the problem under study the dominant force exerted by the carrying gas on a dispersed particle is the aerodynamic drag force [1, 4, 7]. Stokes' law [1-4] or the "standard curve" [5-7], which is obtained for an unbounded uniform gas flow past a particle, is often used for the aerodynamic drag coefficient of the particle. At the same time, it is known [9] that when the particle motion in the viscous medium is slow, near a solid surface its aerodynamic

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