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SIMULATION OF DISPERSED MIXTURE PARTICLES IMPACT IN FORCED WATER CONDUCTS OF THE REZAKSAY RESERVOIR

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Abstract:
The article shows the simulation of the collision of particles of a dispersed mixture in pressure conduits. The phenomenon of particle collision is considered, which leads to the formulation of similarity requirements, which are difficult to fulfill in real conditions.

Keywords: modeling, particle impact, dispersed mixture, pulsating pressure, velocity gradient, turbulence, characteristic velocity.

When modeling the movements of a dispersed mixture, additional influences of factors are associated with the phenomenon of averaging the pulsating pressure over the surface of the particle, the distortion of the high-frequency part of the flow turbulence spectrum, the dependence of the coefficients C_p and C_τ on the structure of the relative velocity pulsations and, the influence of the velocity gradient $\frac{\partial U_\alpha}{\partial x_\beta}$ is small, and the effect on the particle can be calculated from the scheme of its unsteady motion in an oscillating infinite fluid with a velocity of $u = V - U$, if the following estimates are satisfied for the initial flow:

$$\left.\begin{array}{l} \frac{Ud}{\nu} \prec\prec 4; \left|\frac{\partial U_\alpha}{\partial x_\beta}\right| \frac{d^2}{\nu} \prec\prec 24; \frac{d}{\lambda} \prec\prec 1 \\ \left|\left(\frac{1}{\rho_s + \frac{1}{2}\rho} + \frac{1}{\frac{3}{2}\rho}\right) gradP\right| < \frac{U'}{\lambda_t} \end{array}\right\} \quad (1)$$

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Here are the λ and λ_t - space and time Taylor scales of turbulence:

$$\lambda = \frac{U'_\beta}{\left(\frac{\partial U_\beta}{\partial x_\alpha}\right)}, \quad \lambda_t = \frac{U'_\beta}{\left(\frac{\partial U_\beta}{\partial t}\right)},$$

The prime at the variables means the calculation of the root-mean-square value. Estimates (1) are rarely performed in real threads. [1]. However, if this circumstance is neglected in the first approximation, then the conditions for the similarity of particle motion can be written in the following form:
from the ratio of inertia and resistance forces:

$$\pi_1 = \frac{m\left(1+\frac{\rho}{\rho_s}C_m\right)U'_0 u_0}{C'\rho\frac{u_0\nu}{d}\frac{\pi d^2}{4}d} = C'_0\,\mathrm{Re}''_d = C'_0\frac{U_0}{u_0} = idem \qquad (2)$$

from the ratio of the forces of inertia and gravity:

$$\pi_2 = \frac{m\left(1+\frac{\rho}{\rho_s}C_m\right)U'_0 u_0}{mgd} = C'_1\frac{U_0}{w}\frac{u_0}{w} = C''_1\frac{u_0}{w}\mathrm{Re}''_d = idem \qquad (3)$$

from the ratio of external forces (gravity and pressure gradient):

$$\pi_3 = \frac{w|gradP|}{mgd} = \frac{|gradP|}{\rho_s g} = \frac{\rho U_0^2}{\rho_s gl} = idem \qquad (4)$$

Here:

$$\left.\begin{aligned}
C'_0 &= \frac{2}{3}\left(\frac{\rho_s}{\rho}+C_m\right)\frac{1}{C'}; C_0 = \frac{2}{3}\left(\frac{\rho_s}{\rho}+C_m\right)\frac{1}{C};\\
C_1 &= \frac{2}{3}\frac{1}{C}\left(\frac{\rho_s}{\rho}+C_m-1-\frac{\rho}{\rho_s}C_m\right)\\
C'_1 &= \frac{1}{3}\frac{1}{C'}\left(\frac{\rho_s}{\rho}+C_m-1-\frac{\rho}{\rho_s}C_m\right)\\
\mathrm{Re}''_d &= \frac{u_0 d}{\nu}
\end{aligned}\right\} \qquad (5)$$

Estimates (5) are obtained from a qualitative analysis of the interaction of a particle with a turbulent field considered in Lagrangian variables [8].
The form of function $C(\mathrm{Re}'_d)$ depends rather strongly on the shape of the particles. For elongated particles, the transition from one (viscous) self-similar zone, within which $C' = const$, to another (turbulent) self-similar zone

($C = const$) occurs in a relatively narrower range of Reynolds numbers ($20 < \mathrm{Re}'_d < 80$), than for spherical particles [10].

In relations (2) - (4) the characteristic velocities of the main flow U_0 and the relative motion of the particle in the liquid u_0 are used. The motions of the particle are similar if the scales of these velocities remain the same.

Obviously, all conditions (2) - (4) are met if the particle diameter changes in proportion to the linear scale of the model, the hydraulic fineness w - is proportional to the characteristic velocity U_0, and the coefficient C - remains constant. In practice, this is possible if the particles in nature are large enough so that their size on the model is not less than 1 mm ($\mathrm{Re}'_d > 100$). In all other cases, one can only speak of approximate similarity, when one or another criterion has relatively little effect.

The introduction of conditions (1), (3) related to the structure of turbulence into the consideration excludes the possibility of accurately reproducing the motion of particles on a model that is different from nature. Indeed, a decrease in the geometric scale of the hydraulic model requires a decrease in the flow velocity and particle size. In this case, the Taylor scales of turbulence λ do not decrease, but increase [5]. In this regard, the interaction of the turbulent field with the particle is distorted. For example, the smoothing of the pulsation over the surface of the particle on the model is less than in nature.

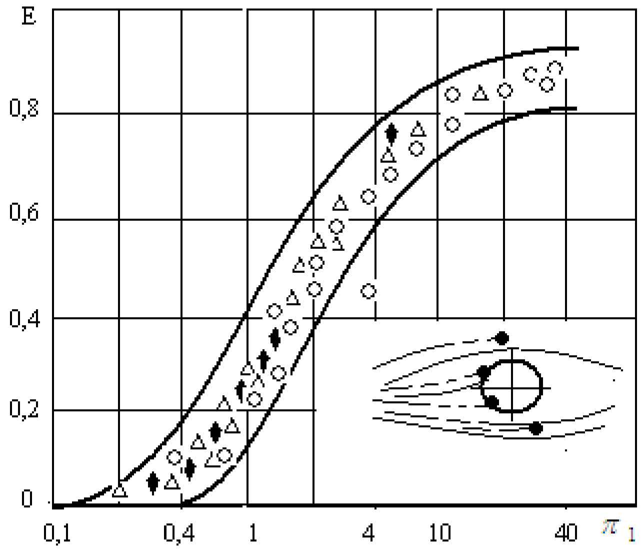

Fig.1. Capture coefficient of particles by a straight circular cylinder depending on the ratio of inertia forces and particle drag.

The influence of criterion π_1 (2) can be traced in relation to the characteristic problem of the collision of a particle with an obstacle. A number of works are devoted to this problem, references to which can be found in [6].

The role of inertial forces in comparison with drag forces is characterized by a capture coefficient of E, determined by the ratio of the number of captured particles to the number of particles on the way, falling into the projection of the streamlined body on the direction of motion. In Fig.1. shows the functions of the criterion $\pi_1 = \frac{4mU_0}{\rho \nu d^2}$ of the value of the coefficient E, calculated without taking into account the effect of the added mass of the particle ($C_m = 0$) [6].

Two curves in Fig.1. outline the area of possible influence of the change in the lines of fluid currents near the obstacle due to the difference in Reynolds numbers. The points on the graph correspond to the results of observations of the deposition on the cylinder from the air flow of very small particles (diameter 1.5 and 15 μm).

According to Fig.1. it can be concluded that criterion π_1 practically does not affect the motion of particles at its small and large values. If $\pi_1 < 0{,}5$ particles follow the streamlines of the fluid. With values of $\pi_1 > 10$ the particle trajectories will be determined mainly by their collisions with obstacles and with each other.

At a concentration of particles large enough to make particle collisions highly probable, additional particle-to-liquid relative slip begins to appear. If a particle with a diameter of d moves at a speed of ϑ_1 relative to the individual particles of the mixture, then, obviously, it will collide with all particles whose centers are located inside a cylinder with a diameter of $2d$, whose axis is collinear with the velocity of ϑ_1. In the volume of $\frac{\pi(2d)^2 L}{4}$ there are somewhat fewer such particles than

$$N = \frac{c\frac{\pi}{4}\pi(2d)^2 L}{\frac{4}{3}\pi\left(\frac{d}{2}\right)^2} = \frac{6cL}{d} \qquad (6)$$

where c - is the volume concentration of the suspension. Assuming $N = 2$, we find the average particle path length between impacts at the minimum particle mobility.

$$L \approx \frac{d}{3c} \qquad (7)$$

This estimate differs markedly from the average distance between particles. Indeed, assuming the particles are located at the nodes of a cubic lattice with a side of L_0, we find from the condition of a uniform distribution of these "cubes" in space:

$$c = \frac{8\frac{4}{3}\pi\left(\frac{d}{2}\right)^2}{(2L_0)^2};\ L_0 = d\sqrt{\frac{\pi}{6c}}; \qquad (8)$$

The average distance between particles in such a lattice is obviously equal to

$$\bar{L}_0 = \frac{L_0}{2}\left(6 + 12\sqrt{2} + 8\sqrt{3}\right) \approx 1{,}42L_0; \qquad (9)$$

Let us pay attention to the fact that the mean free path of a particle among relatively slow-moving particles is much greater than the distance between the particles. If the particles have a non-zero velocity component normal to ϑ_1, then the collision probability increases and L decreases towards L_0.

Under the assumptions made, the mean time of motion is t, C, and the particle between impacts is of the order:

$$t \approx \frac{L}{\vartheta_1} = \frac{d}{3\upsilon_1}$$

If this time is less than the characteristic times of free motion of a particle (deposition or turbulent transport with a small change in velocity), then the influence of particle collisions is significant. With different particle sizes, collision between them is inevitable even with laminar motion. The collision of particles is manifested in the fact that the velocities of hydraulically larger particles decrease, while the velocities of hydraulically smaller particles increase. Particles of all sizes reduce their speed when they hit a wall. All these processes act uniquely - they increase the energy loss of the carrier fluid. The presence of particles, however, can qualitatively change the flow regime - cause a decrease in the intensity of turbulent exchange and, due to this, a local decrease in energy losses for suspension transport at certain (rather low) concentrations of particles [2].

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Conclusions. An individual description of particle collisions requires the introduction of many parameters. For example, the simplest case of collision of symmetrical particles requires the introduction of at least two dimensionless "recovery factors" of normal $K_n \in (-1,0)$ and tangential $K_\tau \in (-1,0)$ velocity components, defined as the ratio of the corresponding components of the relative velocity of the contacting points of non-deformable particles[1, 11]. The consideration of particle collision phenomena leads to the formulation of similarity requirements, which are difficult to fulfill under real conditions. In practice, the requirement for the similarity of particle collision processes by some authors is reduced to the condition of invariance in nature and on the model of the ratio of the average velocities of the solid and liquid phases [12].

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