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ACCELERATION OF SOLID PARTICLES IN A CHANNEL

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On the basis of an anlaysis of the distribution of the parameter of a two-phase flow emerging from a channel we obtain a criterial relation for the velocity disequilibrium of the phases.

A very important factor to be considered when designing experimental setups for studying the processes responsible for the formation of the structure of two-phase (gas—solid particles) jets is that of the magnitudes and fields of velocities of the discrete phase at the exist from the accelerating device, whether it be a supersonic jet or a tube with one cross-sectional shape or other. When choosing the design elements of the setup, we must know the length and cross-sectional size of the accelerating device in order to obtain the desirbed particle velocity.

Our main goal is to obtain a criterial (dimensionless) relation that determines the efficiency of the acceleration of solid particles by the gas flow and the effect that the particle properties and determining geometrical parameters of the accelerating device have on it.

A typical element of a setup for obtaining two-phase flows usually is an accelerating part, constituting a fairly long tube with one cross-sectional shape or other. In the case of supersonic velocities of the carrier phase a nozzle with a flaring conical part is placed at the end of the tube. The critical cross section of the nozzle is usually slightly smaller than the cross section of the tube since a considerable narrowing of the cross section causes particles to accumulate in front of it and then periodically to be ejected into the flow and also induces rather intensive transverse displacements of particles, leading to poorer particle acceleration.

Gas flows with different Mach numbers are obtained by varying the inlet cross section of a nozzle with a constant critical cross section.

To prevent erosion from changing the size of the critical cross section, a cylindrical band is made in it to maintain a constant Mach number. Particles are usually introduced into the initial part of the tube.

An experimental setup, based on this scheme, was used for our studies, whose results are discussed here. The setup was described in detail in [1]. In the experiments we used particles of standard electrocorundum (GOST 3647-80), whose fractions had an average particle size d_s = 16, 23, 32, 44, 88, and 109 μm and a strictly determined particle size distribution function. The particles were irregularly shaped fragments. The specific weight of the particle material was γ_p = 3800 kg/m³. The concentration K (kg particles/kg gas) did not exceed 0.3 and, according to our data and the data of [2], this ensured a mode of "single" particles. Cold air was used as the carrier phase.

Particles were introduced from a batcher in the vertical direction in cross section II of the horizontal accelerating portion III at a distance X from the inlet cross section (see Fig. 2). In the experiment we measured the distribution of the carrier-phase velocity U, the discrete-phase velocity U_s, and the ("smeared") discrete-phase density ρ_s (mass of the discrete phase per unit volume). The discrete-phase velocity U_s was measured with a laser Doppler velocity meter and the density was measured with a laser concentration meter; the design of these instruments, the measuring procedure, and the data processing were described in detail in [3].

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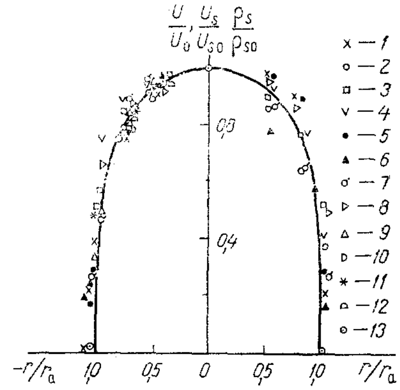

Fig. 1. Distribution of the carrier velocity U, discrete-phase velocity U_s, and discrete-phase density ρ_s in the cross section at the channel exit: U_0 = 104 m/sec; 1) d_s = 16; 2) 32; 3) 88; 4) 109; U_0 = 308 m/sec; 5) d_s = 16; 6) 32; 7) 88; 8) 109; U_0 = 390 m/sec; 9) d_s = 16; 10) 32; 11) 88; 12) d_s = 109; 13) U/U_0.

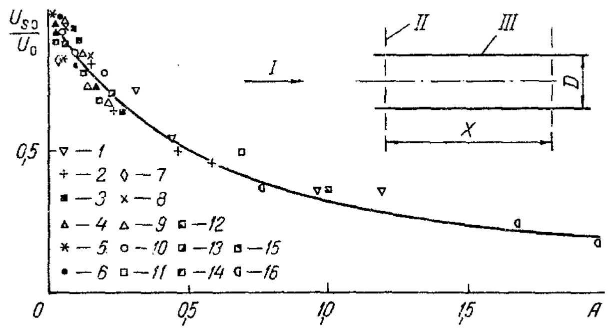

Fig. 2. Velocity disequilibrium of phases during the flow of a two-phase stream in a channel $\left(A=\frac{\rho_p}{\rho_B \cdot 10^3}\frac{d_s}{D}\frac{U_0}{\sqrt{gX}}\right)$: 1) X = 0.9 m; D = 0.0078 m; U_0 = 96.5 m/sec; d_s = 23, 32, 70, 80 μm [4]; 2) X = 0.9; D = 0.0078; U_0 = 43.9; d_s = 23, 32, 70, 88 [4]; 3) X = 0.9; D = 0.0256; U_0 = 44.6; d_s = 23, 32, 70 [4]; 4) X = 0.9; D = 0.0156; U_0 = 26.9; d_s = 23, 32, 70, 88 [4]; 5) X = 0.9; D = 0.0256; U_0 = 11.9; d_s = 32, 88 [4]; 6) X = 0.9; D = 0.0256; U_0 = 26.6; d_s = 32, 88 [4]; 7) X = 4.0; D = 0.080; U_0 = 104; d_s = 23; 8) X = 4.0; D = 0.080, U_0 = 228; d_s = 32, 109; 9) X = 4.0; D = 0.080; U_0 = 304; d_s = 23, 88; 10) X = 4.0; D = 0.080; U_0 = 394; d_s = 23, 44, 109; 11) X = 4.0; D = 0.080; U_0 = 200; d_s = 600; 12) X = 4.0; D = 0.080; U_0 = 306; d_s = 600; 13) X = 4.0; D = 0.048; U_0 = 198; d_s = 23, 109; 14) X = 4.0; D = 0.048; U_0 = 148; d_s = 23, 109; 15) X = 4.0; D = 0.048; U_0 = 98.4; d_s = 23, 109; 16) X = 0.4 m; D = 0.006 m; U_0 = 300 m/sec; d_s = 23 μm.

The results of measurements of the fields of U, U_s, and ρ_s (for X = 4.0 m, 0.048 m, and 0.080 m) are shown in Fig. 1, where U_0, U_{0s}, and ρ_{0s} are parameters at the axis of the jet.

From Fig. 1 we see that all values of U_0 and d_s the profiles of U_s/U_{s0}, U/U_0, and ρ_s/ρ_{s0} virtually coincide and can be described well by one relation,

$$U_s/U_{s0} = U/U_0 = \rho_s/\rho_{s0} = (1 - r/r_a)^{1/n}, \tag{1}$$

where r_a is the radius of the exit cross section and n = 8. The somewhat large spread of data on ρ_s is attributed to the specifics of the ρ_s measurements, but the average values of ρ_s at r/r_a = const fit the above relation well.

It also follows from Fig. 1 that at r/r_a = const

$$U_s/U_{s0} = U/U_0, \tag{2}$$

or $U_s/U = U_{s0}/U_0$, i.e., the particles are accelerated in the same way over the entire cross section of the jet.

The velocity lag of the discrete phase relative to the carrier phase, i.e., U_s/U is the determining quantity in the analysis of the process of particle acceleration in tubes.

Figure 2 shows data from experiments on the velocity disequilibrium on the axis of the jet at a distance of one caliber from the exit cross section of the tube. The distance from the entrance of the particles into the tube (cross section II) to the cross section where the measurements were made varied over the range X = 0.4-4.0 m, tube diameter $D = 6.0 \cdot 10^{-3}$-$8 \cdot 10^{-2}$ m, carrier-phase velocity U_0 = 11.9-394 m/sec, and particle size d_s = 23-600 μm.

Our aim was to determine the velocity disequilibrium of the phases as a function of the particle-acceleration path X in the tube, the characteristic tube diameter D, the carrier-phase velocity U_0, the particle size d_s, and the carrier-phase and discrete phase densities ρ_B and ρ_s.

Processing of the experimental results revealed that over a very wide range of values of the parameters all the data are generalized well by the dimensionless criteiron

$$A = \frac{\rho_p}{\rho_B \cdot 10^3} \frac{d_s}{D} \frac{U_0}{\sqrt{gX}}, \tag{3}$$

where $Fr = U_0^2/gX$, and the velocity disequilibrium of the phases during the flow of a two-phase stream in the tube is described by the relation

$$U_0/U_{0s} = 1 + 2A. \tag{4}$$

Analysis of Eq. (4) shows that it well reflects the physical essence of the process of acceleration of a discrete phase in a bounded space (tube).

Indeed, large heavy particles are accelerated slowly (have a large velocity disequilibrium), especially at high carrier-phase velocities. The effect of the inertial forces manifests itself most clearly here. Small light-weight particles have virtually no velocity lag at low gas velocities.

The particles are accelerated more rapidly as the carrier-phase density increases. The lag also decreases when the path of phase interaction, i.e., X, increases.

The interaction of particles with the tube walls, i.e., the value of D, has a pronounced effect on the disequilibrium. This result is the most interesting here. It turns out that even at $\rho_p/\rho_B \sim 1$ and $U_0/\sqrt{gX} \to 0$, i.e., during the slow flow of a virtually homogeneous two-phase gas in a very long tube, we always have $d_s/D \neq 0$ and, therefore, $U_{s0}/U_0 \neq 1$, i.e., in principle a finite velocity disequilibrium exists during flow in the tube (the particles cannot have the same velocity as the gas). At the same time, the particles can attain the velocity of the carrier gas in an unbounded space ($D \to \infty$) at a sufficiently large value of X.

Equation (4), therefore, enables us to determine the velocity of particles at the exit from a tube of any diameter and length if we know ρ_p, ρ_B, d_s, and U_0 or if we choose the geometrical parameters (D, X) of the accelerating device so as to obtain a two-phase stream with prescribed parameters.

Taking Eq. (2) into account, we can assume that particle acceleration over the entire cross section of the jet occurs in accordance with the law (4).

The discrete-phase flow rate Q_T in the cross section of the jet at the exit from the tube is

$$Q_T = \int_0^{r_a} 2\pi r \rho_s U_s dr. \tag{5}$$

Using (1) and (4), we obtain

$$\rho_{s0} = \frac{Q_T(1 + 2A)}{\frac{32}{45} \pi r_a^2 U_0}. \tag{6}$$

For a round tube (at n = 8)U_{av}/U_0 = 0.837, while $Q_B = \rho_B U_{av} \pi r_a^2$, we have

$$\rho_{s0} = 1{,}18K\rho_B (1 + 2A). \tag{7}$$

Finally from Eqs. (1) with allowance for (4) and (7) we obtain the distribution of the discrete-phase velocity and density at the exit from the tube.

As we see, the distribution of the discrete-phase parameters at the exit from the tube when a two-phase mixture flows through it depends on the carrier-phase parameters, the properties of the discrete pahse, and the geometrical characteristics of the channel. The data obtained can be used as limiting data in calculations of diverse technical equipment, both under study and under design.

NOTATION

U_0, carrier-phase velocity on the axis; U, carrier-phase velocity; U_{av}, average carrier-phase velocity; U_{s0}, discrete-phase velocity on the axis; U_s, discrete-phase velocity; d_s, average size of the solid-phase particles; γ_p, specific weight of the material of the particles; ρ_s, discrete-phase density in the stream (mass of particles per unit volume of stream); ρ_{s0}, discrete-phase density on the axis of the stream; ρ_B, carrier-phase density; Q_T, discrete-phase flow per second; Q_B, carrier-phase flow per second; $K = Q_T/Q_B$, solid-phase concentration in the stream; X, distance from the entry of the discrete phase into the tube to the exit cross section of the tube; D, diameter of the accelerating device; r_a, radius of the exit cross section of the nozzle; and g, gravitational acceleration.

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PROPAGATION OF COMPRESSION WAVES IN A LONG VERTICAL CHANNEL CONTAINING A GASIFIED PACKET

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A solution is obtained for the problem of the pipe flow of a compressible non-Newtonian fluid involving the passage of a pressure pulse in annular and circular channels containing a homogeneous gas—liquid packet.

The study of processes connected with the transmission of compression waves in long channels filled with a non-Newtonian fluid – including gas-liquid packets – is of great interest. The need to solve such problems arises primarily when examining the subject of the prospecting and exploitation of oil and gas deposits. Fields that are being worked nearly always contain plugging and drilling fluids. These fluids, together with oil, have non-Newtonian properties and may contain gas—liquid occlusions of natural gas or air. The solutions obtained for these problems can also be used in the study of the dynamic processes occurring during the transfer of information along a hydraulic channel, during the pipe flow of fluids, in power engineering, etc.

In the course of solving the problems discussed above, it is also possible to study the way in which the transmission of dynamic disturbances in long channels is affected by the nonlinear viscosity and density of the fluid, the shape and dimensions of the cross section of the channel, and the presence of gas occlusions with different dimensions and

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