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EFFECT OF INITIAL VELOCITY DIFFERENCE BETWEEN PHASES ON EVOLUTION OF TWO-PHASE JET

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UDC 532.517.4

Results of an experimental study are presented concerning the effect which the initial difference between the velocity of the gas and the velocity of the pollutant particles have on the characteristics of an inundated air jet carrying a pollutant in the form of spherical particles of high-density material.

According to an earlier report [1], an experimental study of a turbulent air jet carrying heavy pollutants has demonstrated that, even when the velocity of the gas and the velocity of the pollutant particles are equal, there develops a difference of phase velocities (a flow nonuniformity) at the nozzle throat which then increases along the axis depending on the size and the concentration of particles. Laws governing the propagation of an air jet with heavy pollutants were further studied experimentally, to reveal the dependence of the jet characteristics on the initial difference of phase velocities. This experiment was also performed in the "model" format [1]. A two-phase mixture was formed with a nondisperse powder of spherical particles having a mean diameter of 45 μm (density of pollutant material 850 $kg{\cdot}sec^2/m^4$). Uniform profiles of gas velocity and pollutant velocity as well as of pollutant concentration in the nozzle throat were produced by means of a special shaping device [2] which, moreover, served as means of presetting the initial difference of phase velocities. These experiments were performed with the following initial differences between gas velocity and pollutant velocity: a) pollutant particles initially leading, their velocity being 35 m/sec and the gas velocity being 25 m/sec; b) pollutant particles initially lagging, their velocity being 35 m/sec and the gas velocity being 45 m/sec; c) velocity of pollutant particles and gas velocity initially equal, both 35 m/sec.

The pollutant concentration (ratio of pollutant to air on kg/kg basis) was, in all three cases, near unity.

The profiles of gas velocity and pollutant velocity as well as of relative pollutant concentration in cross sections of the jet up to 20 diameters away from the nozzle throat and r_0 = 15 mm in radius were in this experiment measured by the laser–optical method [3].

Electrocorundum particles smaller than 5 μm were in small quantities added as tracers for visually indicating the motion of the gaseous phase. The accuracy of measurements was within 5-7%.

Here are the results of this experiment.

The graph in Fig. 1 depicts the variation of the axial velocities of gas and particles for two values of the initial difference of phase velocities. Here U^0 is the mean velocity of gas or particles referred to the initial gas velocity and x^0 is the distance from the nozzle throat referred to the nozzle throat radius. Points 1 and 2 correspond to velocities of gas and particles in a flow with a high initial velocity of the gaseous phase. The graph indicates that at the given relation between phase velocities the relative difference between the axial velocities of particles and gas changes quite appreciably from positive to negative value. The velocities of the two phases also follow very different trends: the velocity of gas changes quite appreciably, while the velocity of particles changes only slightly and almost remains constant. In the other case of flow with a high initial velocity of particles, on the other hand, the velocities of gas and particles (points 3 and 4) vary so that their differences changes little and remains almost constant within the given range of distances from the nozzle

"Sergo Ordzhonikidze" Moscow Institute of Aviation. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 3, pp. 371-374, September, 1982. Original article submitted July 2, 1981.

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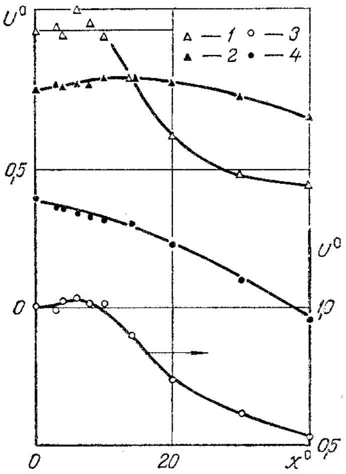

Fig. 1

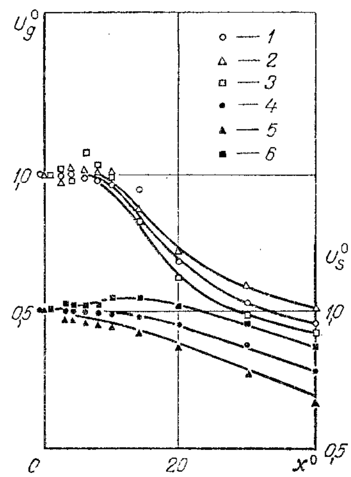

Fig. 2

Fig. 1. Variation of gas velocity (1, 3) and of velocity of solid pollutant particles (2, 4) along the jet axis for two values of initial difference of phase velocities: 1, 2) U_{g0} = 45 m/sec and U_{s0} = 35 m/sec; 3, 4) U_{g0} = 25 m/sec and U_{s0} = 35 m/sec.

Fig. 2. Comparison of axial velocities of gas (1-3) and solid pollutant particles (4-6) in three modes of flow: 1, 4) equal initial velocities; 2, 5) higher initial velocity of particles; 3, 6) higher initial velocity of gas.

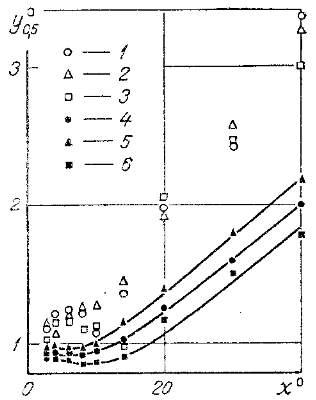

Fig. 3

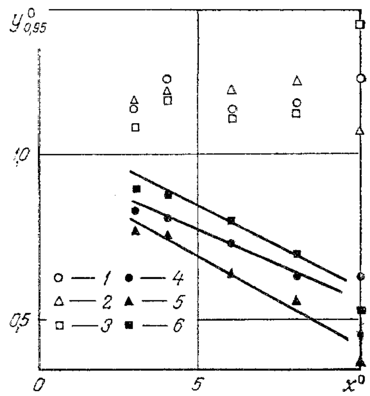

Fig. 4

Fig. 3. Variation of jet boundaries based on half values of gas velocity (1-3) and based on half values of pollutant concentration (4-6): 1, 4); 2, 5); 3, 6) as in Fig. 2.

Fig. 4. Comparison of boundaries of jet cores with uniform velocity of pollutant particles (1-3) and with uniform velocity of gaseous phase (4-6): 1, 4); 2, 5); 3, 6) as in Fig. 2.

throat. The velocities of the two phases, however, vary analogously. A comparison of the axial velocities thus reveals that whichever phase has a higher velocity pulls up the lagging other phase, the character and the results of this interaction of phase being different depending on which phase moves at higher velocity. Thus, in the case of solid pollutant pulling up to the gaseous phase (points 1 and 2) the gas is strongly retarded by particles moving at lower velocity. The velocity of particles in this case first increases somewhat and then decreases. The difference of relative phase velocities increases here rapidly along the jet axis. In a flow with high initial velocity of solid particles (points 3 and 4), on the other hand, the velocity of particles decreases noticeably along the jet axis and the gas accelerates somewhat over the initial segment of the jet.

On the diagram in Fig. 2 are shown together the curves depicting the axial velocities U_g^0 (gas) and U_s^0 (particles) referred to their respective initial values for the three modes of flow. This diagram excellently illustrates the intense momentum exchange between phases during flow in these modes. When the initial velocity of particles is higher, the gas velocity remains higher than it is in the case of equilibrium discharge from the nozzle through the entire given range of distances from the nozzle throat and the velocity of particles remains lower than it is in the case equal initial phase velocities. The opposite effect is noted in the case of flow with an initially higher gas velocity.

The graph in Fig. 3 depicts the boundaries of a two-phase jet in terms of gas velocity and pollutant concentration, defined as lines on which both velocity and concentration are half as high as on the jet axis. The parameter $y^0_{0.5}$ corresponds to ordinates, referred to the nozzle radius, of points where gas velocities an pollutant concentrations have those half values. A comparison of the jet boundaries based on pollutant concentration reveals a more intense diffusion of particles in a two-phase jet discharged with a higher initial velocity of particles than in the case of equilibrium discharge. The diffusion of particles is less intense in the case of discharge with a lower initial velocity of particles than in the case of discharge with equal velocities of both phases. It is to be noted that these results agree with the data obtained in this experiment on the distribution of pollutant concentration along the jet axis. The jet boundaries based on gas velocity do not feature a distinct stratification.

It is well known that diffusion of a pollutant in a turbulent gas jet can be characterized by the turbulent-flow Schmidt number and that the values of the latter for gas jets carrying solid pollutants differ appreciably from those for gas jet of variable composition. The number of determining the value of the Schmidt number for a jet carrying heavy pollutants was already considered in another study [4], but only in the case of equilibrium two-phase flow, i.e., flow with equal velocities of gas and solid pollutant.

The results of this experimental study yield new additional information about diffusion of pollutant in a two-phase jet. The stratification of jet boundaries based on pollutant concentration and depending on the initial difference between velocity of solid particles and velocity of gas indicates that this flow parameter plays a large role in the diffusion of pollutant in a two-phase jet, namely the Schmidt number is lower for a jet discharged with an initially higher velocity of particles than for a jet discharged with an initially higher gas velocity.

The graph in Fig. 4 compares the boundaries of a jet core based on the velocity of gas and on the velocity of solid particles, respectively. Here $y^0_{0.95}$ are the ordinates, referred to the nozzle radius, of points where the velocities are equal to 0.95 of those within the jet core. This graph indicates, as has already been noted [1], that the velocity of pollutant particles hardly varies throughout the entire region where a core with uniform velocity of the gaseous phase exists. Non-uniformity of flow does not, moreover, affect stratification of the jet core boundaries based on velocity of particles. The boundaries of a jet core with uniform gas velocity, on the other hand, feature a distinct stratification: a higher initial gas velocity results in longer jet core based on velocity of the gaseous phase and conversely.

The experimental data of this study indicate that a discrete pollutant transported by a gas jet effectively interacts with the gaseous carrier phase, which is manifested in an intense momentum exchange between phases and in changes in the diffusion of solid pollutant particles.

The difference between average velocities of gas and particles must, most likely, amplify the effect of pollutant on the turbulent flow structure relative to that in the case of equilibrium flow, inasmuch as this difference of phase velocities causes many more particles to participate in the process of momentum exchange with a turbulent gaseous mole.

NOTATION

U_{g0}, initial gas velocity in the nozzle throat; U_{s0}, initial pollutant velocity in the nozzle throat; U^0_g, gas velocity, referred to initial gas velocity in the nozzle throat, at a given point along the jet axis; U^0_s, velocity of particles, referred to initial gas velocity in nozzle throat, at a given point along the jet axis; r_0, nozzle throat radius; and x^0, distance from the nozzle throat referred to the nozzle throat radius.

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