EXPERIMENTAL STUDY OF THE DYNAMICS OF AN AIR-DUST JET

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This paper presents the results of an experimental study of the development of a two-phase jet containing solid particles with initial concentration $H_0 \le 1.0$ kg/kg. The experimental data show that the temperature fields in the jet cross sections in dimensionless coordinates may be correlated by a single universal curve for various sections and various initial concentrations. The effect of solids on the jet boundary layer growth is shown to be greater than expected before. It is found that the increase of the width of the air-dust jet depends not only on the density variation across the mixing zone but also on the effect of the solid particles on the turbulent mixing process. This effect results in slower increase of the width of the jet and, consequently, slower damping of the jet.

Air-dust jets have numerous applications in technology, in particular in the burners of coal-dust

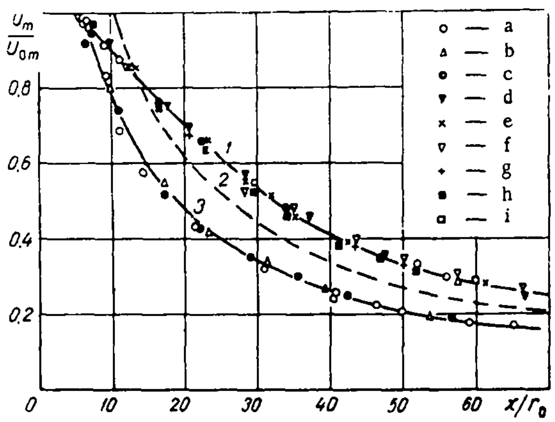

Fig. 1. Damping of the axial velocity: 1) air-dust jet, experimental; 2) air-dust jet, calculated from [1]; 3) air jet. a) d_0 = 21 mm, $\varkappa_0$ = 0 kg/kg, U_{0m} = = 38.2 m/sec; b) 27, 0, 46.7, respectively; c) 35, 0, 22.4; d) 21, 0.65, 20.7; e) 21, 0.65, 35.1; f) 27, 0.65, 19.2; g) 27, 0.56, 31.4; h) 35, 0.65, 19.7; i) 35, 0.65, 23.4.

furnaces. However, the principles governing the development of jets containing significant amounts of heavy solids have not been studied to a sufficient degree. G. N. Abramovich's analytic solution [1] is based on several physical assumptions, some of which have by now been shown to contradict experimental data. Thus, for example, it has been assumed in [1] that the field of dimensionless concentration in transverse cross-sections of the jet is similar to the temperature field and can be described by the relation

$$\bar{\varkappa} = \varkappa/\varkappa_m = 1 - \xi^{1.5}. \qquad (1)$$

This is equivalent to assuming that the transverse mass transfer process does not depend on the substance being transferred. The experimental data of [2–4] show (though they do not settle the question) that the concentration field of a real dust, moving in jets with considerable relative velocities [5], differs from the field represented by (1). A. P. Chernov [6] attempted to supplement the solution of [1] by taking into account the relative motion of the phases, starting from the experimental fact that the ratio of the velocities of the particles and the carrying fluid is constant in a transverse section of the jet [7]. However, he has assumed that this ratio is constant also along the jet. It still is an open question how well the air-dust jet can be represented by the equations of a jet with variable density. All this requires that the analytic solution [1] be compared with experimental data. However, there are no experimental data on the damping of the axial velocity of air-dust jets, if one disregards the extremely restricted data of I. E. Kubynin [2].

In our experiments we studied the dynamics of a premixed air-dust jet, emerging from a long circular tube with diameter d_0 = 21, 27, or 35 mm with various initial velocities (from 15 to 40 m/sec) and various initial concentrations (from 0 to 1 kg/kg). To prepare the mixture, the dust was fed by means of a screw feeder to the mixer, from where the mixture entered into a horizontal acceleration tube. The length of the acceleration section was chosen so that

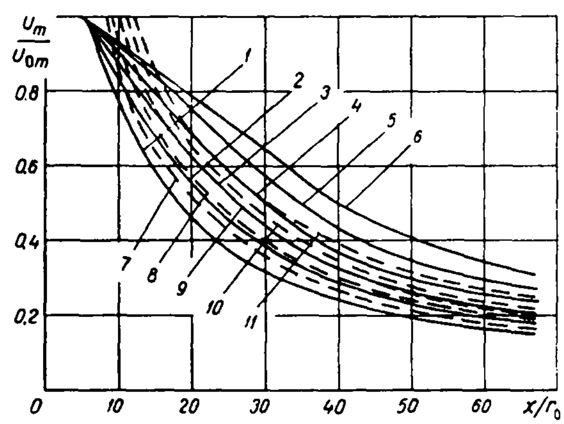

Fig. 2. Damping of axial velocity of an air-dust jet: 1–6) experimental curves; 7–11) calculated from [1] for $\varkappa_0$ = 0.2, 0.4, 0.6, 0.8, and 1.0, respectively.

the characteristic velocity of the solid phase at the tube exit was equal to the characteristic velocity of the air, i.e., so that the dust was fully accelerated.

The solid phase consisted of dust-like ash of Estonian shale with specific gravity $\gamma = 2.5\text{–}2.6\ g/cm^3$ and granulometric composition $R_{200} = 1.5\%$, $R_{150} = 2.5\%$, $R_{102} = 6.5\%$, $R_{75} = 12.5\%$ and $R_{60} = 20.5\%$, with a predominant fraction of particles in the range $\delta = 20\text{–}60\mu$ (typical $R_{20} = 80\%$).

The velocity profile at the nozzle exit was nearly turbulent, and the velocity field of the solid phase was axisymmetric and somewhat sharper. Thus the initial concentration was nearly uniform. The velocities were measured by a special suction tube which has been described in [2] and [4].

As can be seen from Fig. 1, for a given initial concentration $\varkappa_0 = 0.65$ kg/kg the curve of the dimensionless axial velocity is universal for different nozzles over the whole range of initial velocities considered here. The same figure shows a curve of dimensionless axial velocity calculated from [1] for the same initial concentration, and also an experimental curve for pure air, which coincides with the theoretical curve. Similar experimental data on the damping of the axial velocity of an air-dust jet were obtained for $\varkappa_0 = 0$, 0.2, 0.4, 0.6, 0.8, and 1.0 kg/kg (1–6 in Fig. 2). A comparison of these curves with curves calculated from [1] shows that the discrepancy between experiment and theory increases with increasing initial concentration.

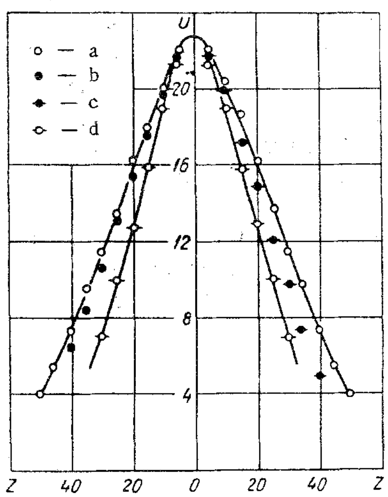

Fig. 3. Velocity field of an air jet and an air-dust jet (U in m/sec, Z in mm) for x = 300 mm, d_0 = 27 mm, U_m = 22.8 m/sec and various initial concentrations: a) $\varkappa_0$ = 0 kg/kg, r_c = 31.0 mm; b) 0.16 and 29.0, respectively; c) 0.31 and 26.8; d) 0.62 and 22.5.

Figure 3 compares the fields of absolute velocities of an air jet and an air-dust jet in a given cross section with a constant value of the axial velocity at the center of the section but various initial concentrations. These data show the significant effect the solid phase has on the velocity field. The velocity field becomes narrower with increasing initial concentration. The experimental points can be correlated by the universal curve $U/U_m = f\,(r/r_{0.5U_m})$ in dimensionless coordinates (Fig. 4). Measurements of the velocity fields in different cross-sections of the jet, emerging from different nozzles with different initial concentrations, confirm this universality. It should be noted, however, that our method of measurement and the design of the experimental set up allowed us to take measurements only over two thirds of the dimensionless width of the jet.

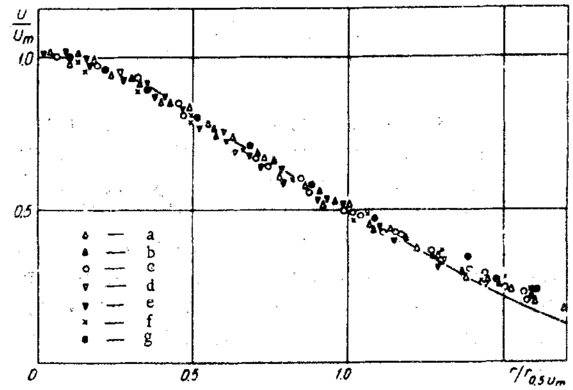

Fig. 4. Velocity profile in transverse cross-sections of the jet. Solid line—Schlichting's profile $U = U/U_m = (1 - \xi^{1.5})^2$: a) $\varkappa_0$ = 0.2 kg/kg, d_0 = 35 mm, x/r_0 = 11.4; b) 0.4, 35, 11.4, respectively; c) 0.4, 27, 9.65; d) 0.4, 27, 17.0; e) 0.4, 27, 29.6; f) 0.6, 27, 17.0; g) 1.0, 27, 17.0.

Thus, the experimental data show that the velocity fields in different cross sections of the air-dust jet are similar, but the damping of the axial velocity

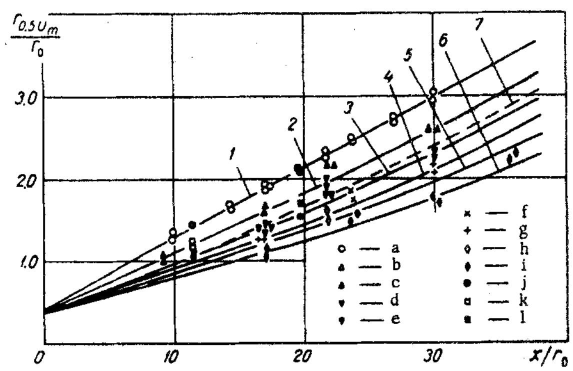

Fig. 5. Half-velocity line in an air-dust jet: 1, 2, 3, 4, 5, 6) experimental curves for $\varkappa_0$ = 0, 0.2, 0.4, 0.6, 0.8, 1.0, respectively; 7) calculated according to [1] for $\varkappa_0$ = 1.0 kg/kg; a) $\varkappa_0$ = 0 kg/kg, d_0 = 27 mm; b) 0.16, 27, respectively; c) 0.2, 27; d) 0.31, 27; e) 0.40, 27; f) 0.46, 27; g) 0.60, 27; h) 0.62, 27; i) 1.0, 27; i) 1.0, 27; j) 0, 35; k) 0.2, 35; 1) 0.4, 35.

differs from the calculated values. Therefore it is interesting to determine the quantitative effect of the solid phase on the increase of the jet width.

Figure 5 shows the dimensionless half-velocity lines for various initial concentrations. Assuming the universality of the transverse fields, these lines characterize the increase of width of the air-dust jet and, consequently, the effect of the solid phase on the transverse mass transfer process.

Figure 5 also shows the half-velocity line for an air-dust jet with initial concentration $\varkappa_0$ = 1 kg/kg, calculated according to [1] taking into account the increase of width of a jet with variable density:

$$\frac{dr}{dx} = c\frac{1+0.5\varkappa_m}{1+\varkappa_m}. \tag{2}$$

A comparison of the curves shows a stronger effect of the solid phase on the development of the jet. This can be explained, apparently, by the additional effect of real inertial particles on the turbulent structure of the jet, and, consequently, on the transverse transfer process. L. G. Loitsyanskii [8], for example, assumes that in the case of high particle loading, the particles partially quench the turbulent pulsations.

This additional effect is proportional to the axial concentration. If we assume that the effect of the variable density on the increase of width of the jet can be represented by (2) also in the case of an air-dust jet, then the additional effect can be represented by the coefficient

$$c_\varepsilon = 1 - \frac{f}{1+\varkappa_0}\varkappa_m. \tag{3}$$

The equation governing the increase of width of the air-dust jet becomes then

$$\frac{dr}{dx} = c\frac{1+0.5\varkappa_m}{1+\varkappa_m}\left(1 - \frac{f}{1+\varkappa_0}\varkappa_m\right). \tag{4}$$

Introducing (4) into the equations of [1] and taking into account the nonuniformity of the initial profile measured in the experiments, we can obtain good agreement between the experimental data and the theory when the value of the coefficient is taken to be f = 0.28. The value of f is, apparently, slightly dependent on the composition of the dust.

NOTATION

$\varkappa_0$—initial mass concentration; $\varkappa$—mass concentration; $\varkappa_m$—mass concentration on the axis; U—velocity; U_m—axial velocity; U_{0m}—maximum velocity at the nozzle; r—radial coordinate; $r_{0.5U_m}$—radial distance from axis to the point where the velocity is one half the axial velocity; R—jet radius; $\xi = r/R$; c and f—empirical constants.

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