LAWS OF PROPAGATION OF TURBULENT JETS OF A VISCOUS LIQUID OF VARIABLE COMPOSITION

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The results of an experimental investigation of the propagation of turbulent isothermal jets of helium and argon discharging into an air-flooded space are presented.

The mixing of jets of different gases whose densities can differ owing to a difference in enthalpies and molecular weights is of considerable practical interest.

Thus, the results of an experimental investigation of the gasdynamic and thermal parameters of nonisothermal jets of low-temperature plasma of variable composition are presented in [1]. It is shown, for a wide range of variation of the initial heating of the jet (the ratio $\bar{h}_a = h_a/h_e$ of the enthalpy of the gas at the nozzle cut to the enthalpy of the flooded space), that for flooded jets of low-temperature plasma the profiles of momentum flux and of the flux of excess heat content across the jet can be taken as self-similar.

The problems of mixing of jets of different gases whose densities differ owing to the difference in temperatures and molecular weights are discussed in [2]. The results are presented for a theoretical and experimental investigation of the mixing of axisymmetric jets of different gases with a comoving air stream in a cylindrical pipe at a stream ratio $0 \leq m = V_2/V_1 \leq 2$ and a density ratio $0.24 \leq \omega = \rho_e/\rho_a \leq 8.25$. Profiles of the velocities, temperatures, and concentrations are given. The experimental results are generalized in the form of universal functions. Approximate methods of calculation of turbulent jets of variable composition are offered, as well as individual exact solutions.

As the authors of [2] emphasize, however, the analysis of the test data on the distributions of these parameters in comoving and flooded jets did not make it possible to trace the influence of various factors, including ω, on the mutual arrangement of the profiles in the main section of the jet, whereas for the initial section these profiles had a universal character.

Therefore, the aim of the present work was to obtain data on the qualitative and quantitative representation of turbulent mixing processes in isothermal jets of variable composition and to establish for which flow characteristics one can, with a high probability and physical justification, assume the presence of universal profiles in the cross sections of a flooded jet.

The experimental investigation was conducted on an installation consisting of a high-pressure tank connected, through a reducer and a flow meter, with the receiver of a transient-operation wind tunnel, a two-stage coordinating device, and a block of recording instruments. To smooth out the stream and reduce turbulent pulsations a porous bronze plate was mounted at the nozzle inlet.

The converging outlet channel of the receiver was built in the form of a Witoshinsky nozzle with a degree of compression of about 40 and an outlet diameter of 6.4 mm. The pressure in the chamber and the total pressure in the jet were measured with DD-6 inductive pressure pickups in combination with a VI6-5MA measuring instrument and with subsequent recording on an N-115 loop oscillograph. Along with the recording of the gas pressure in the chamber the gas flow rate, which was kept constant in the course of an experiment, was measured with an RS-5 rotameter.

A Pitot tube with a distance coordination by a track marker was used to measure the dynamic pressure in cross sections of the jet.

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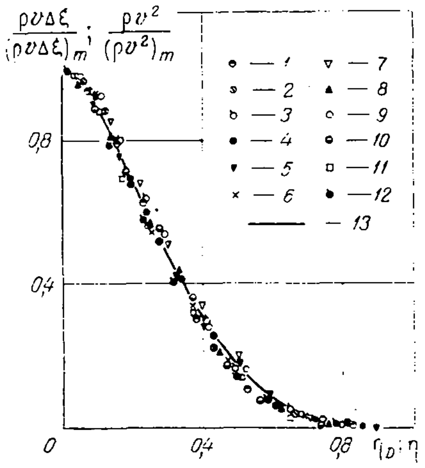

Fig. 1

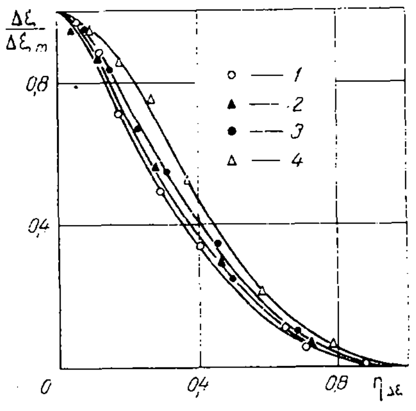

Fig. 2

Fig. 1. Distributions of momentum flux and flux of excess concentration in cross sections of jets. Experiment: ρv^2 — Ar: 1) $\bar{x}$ = 40; 2) 20; 3) 6; He: 4) 50; 5) 30; 6) 8; $\rho v \Delta\xi$ — He: 7) 10; 8) 8; 9) 4; Ar: 10) 30; 11) 20; 12) 12; 13) calculation by (1)-(2).

Fig. 2. Distribution of excess concentration in cross sections of helium jets. Experiment: 1) $\bar{x}$ = 4; 2) 8; 3) 30; 4) 60.

A constant-current thermoanemometer was used to measure the concentration in the jet. A detector with a tungsten filament 2 mm long and 5 μm in diameter was used as the sensitive element. The detector was placed in a cavity having inlet and outlet openings through which the continuous sampling of gas from the investigated point of the stream took place. The ratio of the dimensions of the cavity and the openings was chosen experimentally so that the gas velocity in the cavity hardly affected the operation of the detector. In this case the signal taken from the detector depends on the thermophysical properties of the gas (mainly on its thermal conductivity), which in turn depend on the gas concentration [3].

The anemometer bridge was balanced under conditions when the concentration was $\xi = 0$, which corresponds to a pure gas of one of the components of the mixture (air in the given case).

The detector is calibrated in a medium of a known mixture of helium or argon with air. Dynamic calibration of the system was carried out to determine the time constant of the concentration detector. According to the results of the calibration, M = 0.1 sec, which permitted continuous measurement of the concentrations in a cross section of the jet at a certain rate of movement of the detector. In this case its readings were monitored with static measurements.

An analysis of the systematic and random errors in the measurement of the pressure and concentration, also allowing for the error in the geometrical position, made it possible to establish that the error in the pressure measurement is 3% while that in the concentration measurement is 5%.

The investigation was conducted in the following ranges of variation of the main stream parameters: velocity at nozzle outlet V_a = 35-144 m/sec; Reynolds numbers, calculated from gas parameters at nozzle cut, $Re_a = (0.8\text{-}1.8)\cdot 10^4$; diameter of nozzle cut d_a = 6.4 mm; gases: helium He, nitrogen N_2, argon Ar.

Some results of the experimental investigation of the propagation of turbulent jets of helium, nitrogen, and argon discharging into an air-flooded space are presented in Figs. 1-4. As follows from the figures, in a qualitative respect the distributions of the parameters in the jets correspond to the distributions of the parameters in jets of an incompressible liquid, but there are considerable differences in a quantitative respect.

For example, the distribution of ρv^2 in cross sections of the jet for different gases at $0.75 \leq \omega \leq 7.8$ is presented in Fig. 1. As follows from the data presented, despite the considerable range of variation of the density, the profiles ρv^2 are described by the single function

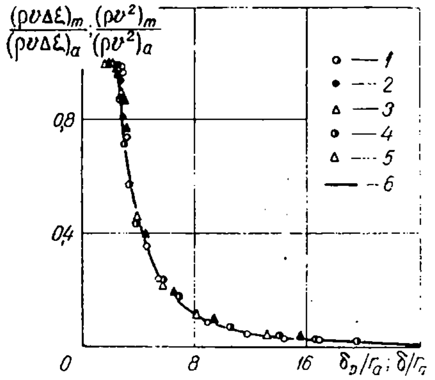

Fig. 3. Distribution of axial parameters $(\rho v^2)_m$ and $(\rho v\Delta\xi)_m$ as functions of δ and δ_D. Experiment: $(\rho v^2)_m$ 1) He; 2) N_2; 3) Ar; $(\rho v\Delta\xi)_m$: 4) He; 5) Ar; 6) calculation by (3).

$$\frac{\rho v^2}{(\rho v^2)_m} = f(\eta) = (1-\eta^{1.5})^4; \quad \sigma = 0.03, \tag{1}$$

which corresponds to the velocity-head distribution in an incompressible liquid. Here and later σ is the rms deviation of the experimental results from the approximating curve.

Profiles of the excess concentration in cross sections of a helium jet at different distances $\bar{x} = x/r_a$ from the nozzle cut are presented in Fig. 2. It follows from the figures that the concentrations at different distances $\bar{x}$ vary considerably; the profiles of excess concentration are non-self-similar and become fuller with an increase in distance from the nozzle cut. The profiles of the flux of excess concentration (Fig. 1), in turn, are self-similar and are described by the same function as for the velocity head if the radial coordinate r is normalized to the corresponding effective thickness δ_D:

$$\frac{\rho v\Delta\xi}{(\rho v\Delta\xi)_m} = f(\eta_D) = (1-\eta_D^{1.5})^4; \quad \sigma = 0.033. \tag{2}$$

The distributions of the axial parameters $(\rho v^2)_m$ and $(\rho v\Delta\xi)_m$ (Fig. 3), beyond the initial section and in the entire range of variation of the initial parameters investigated, proved to be universal as a function of the effective thicknesses δ and δ_D of the mixing zones:

$$\frac{(\rho v^2)_m}{(\rho v^2)_a} = \frac{7.5}{(\delta/r_a)^2}; \quad \frac{(\rho v\Delta\xi)_m}{(\rho v\Delta\xi)_a} = \frac{7.5}{(\delta_D/r_a)^2}; \quad \sigma = 0.03. \tag{3}$$

We note that Eqs. (3) emerge from the integral conditions of conservation of momentum flux and the flux of excess concentration.

For isobaric jets the effective thicknesses δ and δ_D entering into (1)-(3), determined from ρv^2 and $\rho v\Delta\xi$, were found experimentally from functions analogous to those in [1].

The values of δ and δ_D determined in this way are presented in Fig. 4. The measurements of the axial parameters $(\rho v^2)_m$ and $(\rho v\Delta\xi)_m$ are also plotted here. As is seen, it follows from the experimental data that with an increase in the parameter ω the effective thickness δ (3, $\omega = 7.8$, helium) increases and differs markedly from the dependence for δ in the case of $\omega = 0.75$ (argon jet, 4), i.e., the jet becomes wider, while its initial section contracts to $\bar{x}_e = 6$, and as the jet develops at larger distances from the nozzle cut, where $\omega \to 1$, its expansion corresponds to the expansion of a jet of incompressible liquid. The fall in the axial values of $(\rho v^2)_m$ and $(\rho v\Delta\xi)_m$ occurs more steeply in this case (1, Fig. 4).

The results of the experimental data presented in Fig. 4 made it possible to establish the connection between the effective thicknesses δ and δ_D of the mixing zones in the following form:

$$\delta_D = \delta/0.87. \tag{4}$$

It should be kept in mind that the value of 0.87 is a mean value and varies slightly along a flooded jet. But this ratio can be taken as constant for practical engineering calculations.

Thus, the examination and analysis of the functions obtained in a wide range of variation of the initial stream parameters for ρv^2 and $\rho v\Delta\xi$ in isothermal jets of variable composition and for ρv^2 and $\rho v\Delta h$ in jets of low-temperature plasma of variable composition [1], both across the jet, (1)-(2), and along the axis, (3), show that these distributions (within

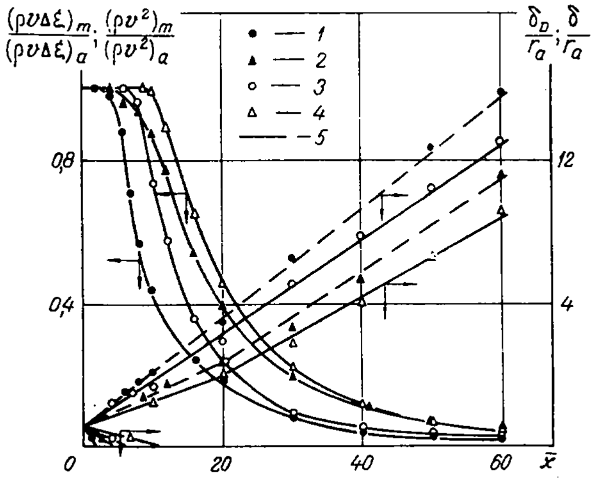

Fig. 4. Distributions of fluxes $(\rho v^2)_m$ and $(\rho v \Delta\xi)_m$ and growth of effective thicknesses δ and δ_D along length of jet. Experiment: $(\rho v \Delta\xi)_m$ and δ_D: 1) He; 2) Ar; $(\rho v^2)_m$ and δ: 3) He; 4) Ar; 5) calculation for δ_D from (4).

the scope of the experimental accuracy) can be taken as practically universal and independent of the kind of gas, of the degree of superheating of the jet, and of its discharge velocity, and they permit the use of integral methods in calculating turbulent jets of viscous liquid of variable composition discharging into a flooded space ($m = 0$).

NOTATION

r, x, cylindrical coordinates; r_a, radius of nozzle cut; $\bar{x} = x/r_a$; $\eta = r/\delta$; $\eta_{\Delta\xi} = r/\delta_{\Delta\xi}$; $\eta_D = r/\delta_D$; δ, δ_D, $\delta_{\Delta\xi}$, effective thicknesses of jet determined from the respective parameters; ρv^2, momentum flux; $\Delta\xi = \xi - \xi_e$, excess concentration; $\rho v \Delta\xi$, flux of excess concentration; $\omega = \rho_e/\rho_a$; ρ, density; $\Delta P = P - P_e$, excess pressure; Re, Reynolds number; $\Delta h = h - h_e$, excess enthalpy. Indices: e, a, m, D, parameters: external, of nozzle cut, at jet axis, and diffusional.

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