GAS FLOW WITH PARTICLES IN NONSYMMETRIC NOZZLES

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UDC 532.529.5

The results of calculation and of an experimental investigation of the flow of gases with solid particles in a nonsymmetric nozzle are given.

One- and two-dimensional flows of a gas with solid particles in axisymmetric nozzles were considered in [1-3]. The abrasive action of two-phase flows in an axisymmetric nozzle was investigated in [5].

Devices with nozzles where the inlet section is asymmetric or the axes of the inlet and outlet sections are offset are encountered in practice. The asymmetry of nozzles is often produced by inaccuracies in the manufacture of individual parts of the nozzle, adhesion of particles to the walls, or accidental partial obstruction of the through-passage of the nozzle by a large-size solid. Such cases are observed in the nozzles or sandblasting equipment, motors operating on solid fuel, etc.

We shall determine approximately the motion parameters and trajectories of solid particles in a two-dimensional nozzle with a nonsymmetric inlet section. An explanation of the mechanism of nonuniform wear of the outlet section of a nonsymmetric nozzle is given on the basis of calculation data.

For determining the velocity of an incompressible gas in a two-dimensional nozzle, we shall use the expression of the stream function borrowed from [3]. Then the projections of the dimensionless gas velocity on the x and y axes are given by

$$u = \frac{V}{L}; \tag{1}$$

$$v = V\frac{yL'}{L^2}. \tag{2}$$

The dimensional velocity of particles is found from the equation of motion

$$m\frac{dw_s}{d\tau} = -cs\rho\frac{(w_s - w)^2}{2}.$$

By using the expression for the drag coefficient of a particle c [4], we arrive at the following equations of motion of a particle for the x and y axes:

$$u_s\frac{du_s}{dx} = D[D_1 + D_2(w_s - w)^{2/3}](u - u_s); \tag{3}$$

$$\frac{dv_s}{d\tau} = D[D_1 + D_2(w_s - w)^{2/3}](v - v_s), \tag{4}$$

where

$$D = \frac{s\rho}{2m}; \quad D_1 = \frac{24\nu}{d}; \quad D_2 = 4\sqrt[3]{\frac{\nu}{d}}.$$

Moscow Engineering Physics Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 29, No. 4, pp. 690-692, October, 1975. Original article submitted April 11, 1975.

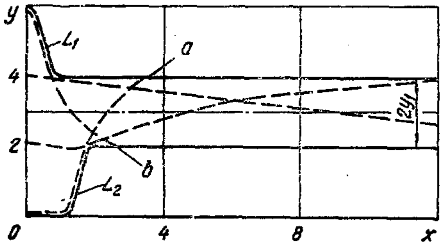

Fig. 1

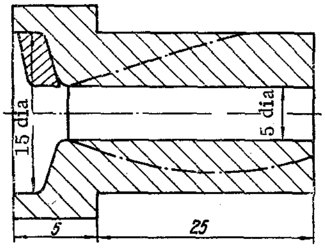

Fig. 2

Fig. 1. Trajectories of particles (dashed curves) in a nonsymmetric nozzle; dimensionless coordinates.

Fig. 2. Nozzle with an asymmetric inlet section; the dashed-dot curves delineate the profile of the nozzle's outlet section after tests.

Equations (3) and (4) are integrated approximately:

$$u_{sk+1} = \Delta x_k D\,[D_1 + D_2 (w_{sk} - w_k)^{2/3}]\left(\frac{u_k}{u_{sk}} - 1\right) + u_{sk};$$

$$v_{sk+1} = \Delta \tau_k D\,[D_1 + D_2 (w_{sk} - w_k)^{2/3}]\,(v_k - v_{sk}) + v_{sk},$$

where $\Delta\tau_k = \Delta x_k / u_{sk}$.

The vertical position of a particle is determined from the expression

$$h_{k+1} = \Delta\tau_k v_{sk} + h_k. \qquad (5)$$

We contemplate the flow of a mixture consisting of air and solid particles (particle diameter, 10 μ) in a two-dimensional nonsymmetric nozzle with a cylindrical outlet section (Fig. 1). The profile of the inlet section of the nozzle is formed by two curves:

$$L_1 = \cos \pi x + 5; \quad L_2 = \cos \pi x + 3.$$

The following initial data were used for calculations: y_1 = 2.5 mm; $\nu = 1.5 \cdot 10^5$ m²/sec; ρ_0 = 1.2 kg/m³; $u_0 = u_{s0}$ = 25 m/sec, v_{s0} = 0; density of the particle material, 3600 kg/m³. The positions of these particles in the initial section of the nozzle are h_0 = 0; 5; 10; 15 mm. The friction of particles against the nozzle wall is neglected.

Figure 1 shows the results obtained in calculating the particle trajectories. It is evident that particles moving past the wall with the profile L_2 have the steepest trajectory (highest acceleration in the direction of the y axis). Calculations show that, under these conditions, the kinetic energy of particles approaching the nozzle wall in the region *a* exceeds by a factor of 2.8 the particle energy in the region b.

The differences in the particle energy must produce nonuniform wear of the nozzle's outlet section. We checked this assumption by performing an experimental investigation. Nozzles made of 40Kh steel were tested by using the device described in [5]. Polydisperse electrocorundum particles with a mean diameter of 50 μ were used as the abrasive phase. Asymmetry of the inlet section of the nozzle was created by pasting on ceramic plates with different thicknesses. The test conditions were the following: concentration of particles, 1 kg/kg gas; absolute pressure at the nozzle inlet, 0.3 MPa; testing time, 20 min.

It has been found that the nonuniformity of wear in the outlet section of a nozzle increases with the degree of asymmetry. The character and the amount of wear for a plate 2.5 mm thick are shown in Fig. 2. It is evident that the wear is greater on the side where the plate creating asymmetry is located.

Thus, the parameters of a gas flow with solid particles in a nonsymmetric nozzle have been determined by using the proposed method. The calculation results explain the nonuniformity in the wear of the outlet section of a nonsymmetric nozzle.

NOTATION

x and y, present coordinates; u and u_s, projections of the velocities of the gaseous and the solid phases on the nozzle axis, respectively; v and v_s, projections of the velocities of the gaseous and solid phases on the normal to the nozzle axis, respectively; w and w_s, velocities of the gas and the particles, respectively; ρ, gas density; c, drag coefficient of a particle; m, particle mass, d, particle diameter; S, cross-sectional area of a particle; V, volumetric gas discharge; y_1, half of the dimension of the nozzle's outlet section; L_1 and L_2, curves of the nozzle profile; τ, time of particle motion; ν, kinematic viscosity coefficient of the gas; Δx_k, integration step; $\Delta\tau_k$, time of particle motion along the section Δx_k; h, solid particle trajectory. Indices: o, flow parameters at the nozzle inlet; s, solid phase; k, step number (k = 0, 1, 2, ...).

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FRICTION LOSSES ON END WALLS OF A VORTEX CHAMBER

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UDC 532.525.3.001.24

The first integrals are obtained by employing the Kantorovich method for the boundary-layer equations for a flow in a vortex chamber, and losses due to friction on the end walls are determined.

In [1] the distribution was investigated of velocities and pressures in a vortex chamber beyond the boundary-layer limits; in [2] its hydraulic characteristics were obtained without friction losses on the walls being taken into account. The experimental data of [3] show that the motion of a vertex flow near the end walls is accompanied by the formation of a radial current near the ends. To improve the design of devices with a vortex flow, the design being based on the solution of boundary-layer equations, friction losses are determined on the end walls as well as the velocity distribution in the boundary layer.

Let us consider the motion of a vortex flow in the zone of the main vortex (Fig. 1) for $r_1 < r < R_K$ [1]. Since the axial component of the velocity is u = 0, the initial system of equations is as follows:

$$\frac{1}{\rho}\frac{\partial p}{\partial x} = 0, \tag{1}$$

$$v\frac{\partial v}{\partial r} - \frac{w^2}{r} = -\frac{1}{\rho}\frac{\partial p}{\partial r} + \nu_T\left(\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} - \frac{v}{r^2} + \frac{\partial^2 v}{\partial x^2}\right), \tag{2}$$

Dnepropetrovsk State University. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 29, No. 4, pp. 693-698, October, 1975. Original article submitted March 18, 1974.