STRUCTURE OF THE BOUNDARY LAYER IN A STREAM OF A DISPERSION ALONG A FLAT PLATE

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The boundary layer in a stream of a dispersion along a flat plate is analyzed on the basis of the particles trajectory near the wall and on the basis of test data.

We consider the structure of the boundary layer in an isothermal stream of a gas–solid dispersion by analyzing the trajectory of solid particles near a wall. The particles are assumed spherical, their concentration low and their size small, so that they do not interfere with one another and do not distort the velocity profile of the boundary layer, neither in the laminar nor in the turbulent region. These profiles are described by well-known equations. External forces, the Basse force [1], and the added-mass effect will be disregarded. Then, taking into account the frictional drag of particles according to Oseyen [2], the "buoyant" force according to Saffman [3], the Magnus force [4], and the force of gravity, as well as the torsional and the retarding torques, we write the equation of motion for a particle in terms of x, z components:

$$m\frac{dU_x}{dt} = -6\pi\mu a\left(1+\frac{3}{8}\mathrm{Re}\right)U_x + \pi a^3\rho_1\omega(U_z - V) + \frac{81{,}2\,\mu a^2}{\sqrt{\nu}}\sqrt{\varkappa}(U_z - V) - mg\rho_2, \tag{1}$$

$$m\frac{dU_z}{dt} = -6\pi\mu a\left(1+\frac{3}{8}\mathrm{Re}\right)(U_z - V) - \pi a^3\rho_1\omega U_x, \tag{2}$$

$$I\frac{d\omega}{dt} = -8\pi\mu a^3\omega - 4\pi\mu a^3\varkappa. \tag{3}$$

Here $\mathrm{Re} = a/\nu\sqrt{U_x^2 + (U_z - V)^2}$. The velocity profile of the boundary layer is [5]:

in the laminar region

$$V = V_\infty\left[2\left(\frac{x}{\delta}\right) - 2\left(\frac{x}{\delta}\right)^3 + \left(\frac{x}{\delta}\right)^4\right],$$

where $\delta = 5.83\sqrt{\nu z/V_\infty}$;

in the turbulent region

$$V = V_\infty\left(\frac{x}{\delta}\right)^{\frac{1}{7}},$$

where

$$\delta = 0.211\left(\frac{\nu}{V_\infty}\right)^{\frac{1}{7}} z^{\frac{6}{7}}.$$

Equations (1)-(3) were integrated numerically by a "Promin'" computer. The following parameters were varied: the particle diameter, the particle density, and the gas properties.

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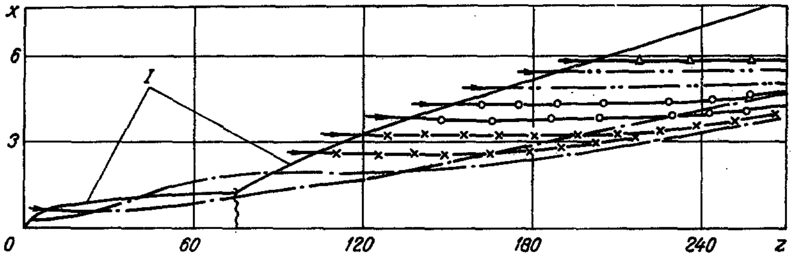

Fig. 1. Trajectories of particles in the boundary layer at a plate (x, z mm). Variant calculated with $a = 2.5 \cdot 10^{-5}$ m, $\rho_2 = 2.2 \cdot 10^3$ kg/m^3, $\nu = 1.51 \cdot 10^{-5}$ m^2/sec, $V_\infty = 20$ m/sec. Curve I represents the edge of the boundary layer.

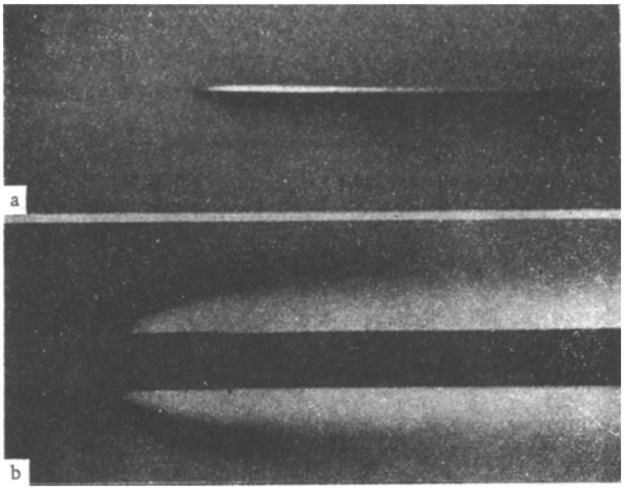

Fig. 2. Stream pattern around plates in an air–graphite suspension: a) thin plate 1 mm and stream velocity 26.3 m/sec; b) thick plate 7 mm and stream velocity 23.5 m/sec.

As the initial values for the integration in the first series of calculations, we assumed $U_{X0} = 0$, $U_{Z0} = V_\infty$, and $\omega_0 = 0$ at the entrance to the boundary layer. Examples of trajectories calculated by this procedure are shown in Fig. 1. Theoretically, the following pattern of motion emerges here: the particles penetrate into the boundary layer, are deflected at the plate surface, and crowd within a narrow zone approximately in the middle of the boundary layer, leaving a sublayer of pure gas at the surface. Calculations have shown that this sublayer is thinner in the case of heavy and large particles, but its thickness increases with increasing viscosity of the gas.

In the second series of calculations we assumed that the particles enter the boundary layer more or less horizontally, i.e., that $U_{X0} \neq 0$. According to these calculations, an initial velocity toward the plate amounting to 3-5% of the longitudinal velocity causes a strong deflection of the solid particles from their trajectory, those with a high transverse velocity actually reaching the wall.

Thus, in a stream of a gaseous suspension there should exist near the wall a zone with a low concentration of particles. The transport of particles into this zone is effected by transverse fluctuations of their velocity, though viscous forces oppose it and dislodge them from the boundary layer.

On a special test stand constituting a closed system with a fluctuating stream of material dispersed in a gas we have made direct observations and have taken photographs (Fig. 2a, b) of a medium-concentration graphite suspension in air flowing along horizontal plates in a channel of a 70×70 mm square cross section with one pair of opposite walls of glass. The transmitting light source was a 500 W photo lamp.

An examination and analysis of the photographs revealed a zone at the plate surface with a much below mean concentration of solid particles, regardless of the flow pattern (the mean velocity of the stream was varied from 15 to 30 m/sec). The noted variation in the magnitude of this zone could be easily explained by the influence of a blunt edge on the flow pattern around thick plates. The flow pattern around a thin plate conforms more closely to the theoretical case analyzed here earlier, while the qualitative agreement between tests and calculations confirms our conclusions concerning the structure of a boundary layer in a gas–solid dispersion.

NOTATION

U_x, U_z	are the components of the particle velocity;
ω	is the angular velocity of the solid particle;
V	is the gas velocity;
V_∞	is the gas velocity outside the boundary layer;
$\varkappa = \partial v/\partial x$	is the transverse gradient of gas velocity in the boundary layer;
a	is the radius of the particle;
m	is the mass of the particle;
I	is the moment of inertia of the particle;
ρ_2	is the density of the particle;
μ	is the dynamic viscosity of the gas;
ν	is the kinematic viscosity of the gas;
ρ_1	is the density of the gas.

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