

The temperature profiles at different jet sections in the initial and transition regions are represented in Fig. 6. A comparison between the self-similar temperature profile obtained numerically and the self-similar solution of the heat-propagation equation (Fig. 3)

$$\Delta T = 1 - \frac{\int_0^z z^{-\frac{1}{2}} (1 - z^{3/2})^{\sigma-1} dz}{\int_0^1 z^{-\frac{1}{2}} (1 - z^{3/2})^{\sigma-1} dz} \quad (20)$$

indicates the agreement between these solutions over the whole jet cross section.

NOTATION

d , slot width; U , fluid velocity at the exit from the slot; ν , coefficient of kinematic fluid velocity; σ , Prandtl number; $Re = Ud/\nu$, Reynolds number; T , temperature; T_0 , T_∞ , T_w , values of the temperature at the slot exit, the quiescent medium, and the wall, respectively; $\bar{x} = x/dRe$, $\bar{y} = y/d$, dimensionless longitudinal and transverse coordinates; $\bar{u} = u/U$, $\bar{v} = (v/U) \cdot Re$, dimensionless longitudinal and transverse velocities; u_{max} , maximum velocity in the jet cross section; $\Delta T_1 = T_0 - T_\infty$ for cases A and B; $\Delta T_1 = T_w - T_\infty$ for case C; $\bar{\Delta T} = (T - T_\infty)/\Delta T_1$, excess temperature; q , heat or thermal flux; $\bar{\psi}$, stream function ($\bar{u} = \partial \bar{\psi} / \partial \bar{y}$); $\bar{\delta} = \delta/d$, dimensionless boundary-layer thickness at the wall in the initial section of the jet; \bar{Q} , excess heat content; $C = (T_0 - T_\infty)/(T_w - T_\infty)$, dimensionless excess fluid temperature at the exit from the slot (case C).

LITERATURE CITED

1. L. A. Vulis and V. P. Kashkarov, Theory of a Viscous Fluid Jet [in Russian], Nauka, Moscow (1965).
2. B. P. Beloglazov, Dokl. Akad. Nauk SSSR, 198, No. 3 (1971).
3. A. Angeaux, Mathematics for Electrical and Radio Engineers [Russian translation], Nauka, Moscow (1964).
4. B. P. Beloglazov and A. S. Ginevskii, Uch. Zap. Tsentr. Aéro-gidrodinam. Inst., 5, No. 4 (1974).

DIFFUSION IN A LAMINAR BOUNDARY LAYER OF A TURBULENT JET INCIDENT ON A PLATE

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UDC 532.522.2:532.7

Solutions are found for the stationary and nonstationary equations of convective diffusion on the basis of an experimentally detected hydrodynamic flow picture of an ideal fluid. The agreement between the results of boundary-layer soundings, obtained by different methods, is shown.

The requirements of practice evoked the necessity to investigate the process of metal surface dissolution under the effect of axisymmetric turbulent jets of aqueous solutions flowing perpendicularly into the surface. In particular, such a method of dissolving a metal surface is used in the production of electrical circuits for electronic apparatus.

The process of dissolving copper under these conditions is characterized by the constant delivery of a mass of solution to the surface, whereupon a heterogeneous reaction occurs on

Translated from *Inzhenerno-Fizicheskii Zhurnal*, Vol. 32, No. 4, pp. 674-682, April, 1977.
Original article submitted April 13, 1976.

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the interphasal surface in a volume of solvent being constantly renewed during regular renewal of the reaction surface and removal of the reaction products. The peculiarities of the process of jet dissolution of a surface began to be investigated recently [1]. It turns out that despite the chemical substance of the dissolution process, the reaction rate therein is determined by the physical process — the transfer of material. The power-law dependence of the reaction rate constant β of metal surface dissolution on the initial velocity of the jet of aqueous solution detected in tests is the proof of this. (As is known [2, 3], it is valid to consider the presence of a dependence of the dissolution rate on the stream velocity as proof of the progress of a process in the diffusion region.) In this case, the heterogeneous dissolution reaction proceeds according to convective diffusion laws, and the distribution of the flux of material is determined by the hydrodynamic fluid flow conditions.

It is known that when the transport of material is related directly to the motion of the medium, investigation of the dissolution process can be a means to determine the velocity fields. In this sense, the results of boundary-layer soundings near a solid surface during the perpendicular inflow of a turbulent jet of aqueous solution is of undoubted interest.

The process of dissolution of a metallized plate of a foil dielectric was investigated under the effect of a perpendicular axisymmetric turbulent jet of an aqueous CuCl_2 solution escaping from a straight-through atomizer with an effective diameter $d_{\text{ef}} = 0.25$ cm of the exit hole. The thickness of the copper foil was $\nabla = (5 \cdot 10^{-3} \pm 1 \cdot 10^{-3})$ cm and was commensurate to the diffuse boundary-layer thickness with respect to the stream of solution acting on it.

The plates were at a distance $X_0/d_{\text{ef}} = 120$ from the atomizer exit hole (in the region of the developed turbulent section of the jet), and the size (radius) of the reaction surface on the plate (R) was 17 cm. Its metal surface was separated into strips of width $a = 0.25 \cdot 10^{-1}$ cm, protected from dissolution in the aqueous solution by a special $2 \cdot 10^{-4}$ -cm-thick coating. The relative value of the distance b between the protected strips was $b/a = 1, 5, \text{ and } 10$. In these cases, the reaction surface was not homogeneous but an inhomogeneous surface equally accessible to the stream of solution. Its sections of width b , commensurate with the boundary-layer thickness of the stream on the plate, were subjected to dissolution. As has been shown in [4], the reaction surface can be considered effectively homogeneous.

The difference in the thicknesses between the surface of the protective coating and the surface of the dielectric ($H_x, 10^{-4}$ cm) was measured (for a $63\times$ magnification) in order to avoid the introduction of a 20% error in measuring the thickness of the dissolved copper foil at any of the points of the reaction surface microsection. The quantity H_x is characterized by the quantity of copper dissolved from the surface in the x direction of the jet of solution on a section of width b . The quantity of dissolved copper in the y direction ($H_y, 10^{-4}$ cm) was measured on this same section b of the reaction surface and determined the maximum magnitude of the copper dissolved from the edge of the protective coating (see Fig. 3a).

Therefore, the results of the measurements characterized the process of material transport at a distance of $\sim 5 \cdot 10^{-3}$ cm from the solid surface (dielectric), i.e., at a laminar boundary-layer depth on the order of 0.2 times its thickness [3] for $\text{PrCuCl}_2 \approx 150$. The initial CuCl_2 jet parameters are as follows: $\text{Re} = U_0 d_{\text{ef}}/\nu = 4 \cdot 10^4$, $\text{St} = \beta/U_0 = 0.55 \cdot 10^{-3}$, and $t_0 = 45^\circ\text{C}$.

The results of repeated measurements of H_x and H_y at each point of the reaction surface are represented in Fig. 1 in the dimensionless coordinates $H_x/H_y = f(r/R)$, where r is the running coordinate on the reaction surface, and they exhibit the change in H_x/H_y within the limits 0.8–1.9 (curve 1). A dependence characterizing the ratio $H_x/H_y = f_I(r/R)$ subjected to a jet with the same parameters perpendicularly incident on the surface, but with uniformly parallel motion of the atomizer with its emerging CuCl_2 jet solution relative to the reaction surface (curve 2), is presented here. Hence, the atomizer motion parallel to the reaction surface was characterized by the Reynolds number $\text{Re}_a = v_a \nabla/\nu \leq 1$.

Reciprocating motion of the jet solution perpendicular to the surface stabilizes the dissolution process over the width of the reaction surface and increases the value of the ratio H_x/H_y to two as a result of increasing the dimensionality of the stream incident on the surface.

The ratio H_x/H_y measured within the viscous fluid boundary-layer limits characterize the hydrodynamic conditions at the reaction surface and indicates (on the basis of the proportionality between the material flux in this region and the stream velocity to the first power [3]) the equality

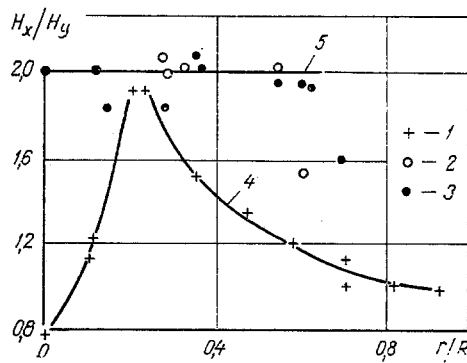


Fig. 1

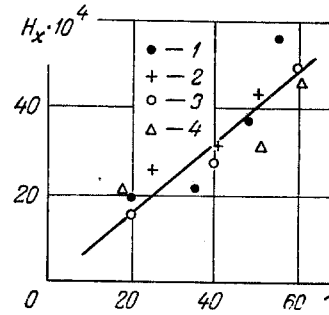


Fig. 2

Fig. 1. Change in the relative quantity of copper dissolved in the cross section of an aqueous CuCl_2 solution jet at a distance $5 \cdot 10^{-3}$ cm from a solid surface: 1) atomizer fixed relative to the reaction surface ($\text{Re} = 4 \cdot 10^4$, $t_0 = 45^\circ\text{C}$, $\text{St} = 0.55 \cdot 10^{-3}$, $b/a = 1-5$); 2, 3) atomizer performs reciprocating motion ($\text{Re} = 4 \cdot 10^4$, $t_0 = 45^\circ\text{C}$, $\text{St} = 0.55 \cdot 10^{-3}$, $\text{Re}_a = 0.45$, $b/a = 1-5$); 5) theoretical value $v_x/v_y = 2$ for the potential flow of a uniform stream incident on a solid surface [5]; 4) the distribution $v_x/v_y = f(r/R)$ in a CuCl_2 jet issuing from a fixed atomizer.

Fig. 2. Change in the quantity of dissolved copper H_x , cm for a residency time τ in a CuCl_2 jet for $r/R = 0.03$: 1, 2) atomizer fixed relative to the reaction surface; 3, 4) atomizer performs reciprocating motion. $\text{Re} = 4 \cdot 10^4$, $t_0 = 45^\circ\text{C}$, $\text{St} = 0.55 \cdot 10^{-3}$, $b/a = 1-10$.

$$v_x/v_y = 2. \quad (1)$$

As is known [5], this latter relationship is characteristic for motion of an ideal fluid stream flowing perpendicularly onto a surface. Therefore, the results of sounding the boundary layer near the surface indicate the cessation of the influence of stream turbulence on material transfer in a laminar boundary layer and the possibility of considering the flow within the boundary layer as potential flow with an adequate degree of accuracy.

Let us investigate the peculiarity of a steady (in time) process for dissolving an effectively homogeneous metal surface in this case.

The process of material transfer in the laminary boundary-layer region of an axisymmetric stream can be described by a two-dimensional diffusion equation

$$v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} = D \left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} \right). \quad (2)$$

Here v_x , v_y are the stream velocity components in directions perpendicular and parallel to the surface, c is the concentration, and D is the coefficient of diffusion of the solution.

This equation, represented in the coordinates x , ψ and expressed in the Mises form, will be

$$\left(\frac{\partial c}{\partial x} \right)_\psi = D \left(\frac{\partial}{\partial \psi} v_x \frac{\partial c}{\partial \psi} \right), \quad (3)$$

where ψ is the flow velocity potential. Then, taking into account that $\psi = (a/2)[(v_x^2/4a^2) + (v_y^2/a^2)]$, $v_x^2 + 8a\psi$, and that there is no Stefan stream in the reaction, the change in concentration in the x direction equals

$$\left(\frac{\partial c}{\partial x} \right)_\psi = D \sqrt{8a} \frac{\partial}{\partial \psi} \sqrt{\psi} \frac{\partial c}{\partial \psi} \quad (4)$$

and is a solution of (3).

The general form of the solution of a dimensionless differential equation of convective diffusion in the region of an axisymmetric turbulent boundary layer of a stream is considered in [6].

The initial section of a fluid jet issuing into a medium with different physical properties (into air), which is considerably removed from the reaction surface, is characterized by a concentration close to the initial distribution. For high values of the Peclet number $Pe = U_0 R/D \approx (10^7-10^9)$, this axisymmetric flow domain can be described with sufficient accuracy by a diffusion kinetics equation

$$v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} = 0 \quad (5)$$

and admits of the solution $c = \text{const}$.

Besides the investigation of a steady (in time) process of metal surface dissolution in a stream perpendicular to it, the analysis of a nonstationary (in time) process of copper dissolution within a laminar boundary layer for a certain specific value of the function ψ described by the equation

$$\frac{\partial c}{\partial \tau} + \left(\frac{\partial c}{\partial x} \right)_\psi = D \sqrt{8a} \frac{\partial}{\partial \psi} \sqrt{\psi} \frac{\partial c}{\partial \psi} \quad (6)$$

in the absence of a Stefan stream is of practical interest.

Equation (6) represents the material balance, and an analysis of the process of particle origination (during copper dissolution) on the reaction surface is possible when taking account of this phenomenon by boundary conditions.

The problem of nonstationary copper dissolution in a diffusion layer at a reaction surface for $\psi = \psi_0$ is considered one-dimensional below.

A dissolution boundary of width b is propagated from the outer surface into the copper bulk. In a time $d\tau$ the dissolution boundary progresses a magnitude $d\eta$. During this time the spacing section is evidently separated into two domains: domain 1, where copper dissolution has already occurred, and domain 2, where dissolution has not yet occurred. Domain 1 is characterized by a copper concentration C_1 in the solution and by the diffusion coefficient D_1 , while domain 2 is characterized by a solid copper concentration (density) C_2 and a diffusion coefficient D_2 .

As the dissolution boundary progresses a magnitude $d\eta$ per unit surface of width b into the bulk of the copper foil, a stream of material from domain 2 into domain 1 is produced which equals

$$J = \left[-(C_M - C_0) \frac{d\eta}{d\tau} \right]_{\psi_0} - D_2 \left(\frac{dC_2}{dx} \right)_{x=\eta} \quad (7)$$

where $-D_2(dC_2/dx)_{x=\eta}$ is the flux of material going from domain 2 into domain 1 by diffusion. (The minus sign shows that the material is transferred from sites with high concentrations to sites with lower concentrations.)

The flux J equals the diffusion stream of material transferred through the domain 1 onto the plate surface:

$$J = -D_1 \left[\left(\frac{dC_1}{dx} \right)_{x=\eta} \right]_{\psi_0} \quad (8)$$

Equating (7) and (8) for $x = \eta$, we obtain

$$\left[(C_M - C_0) \frac{d\eta}{d\tau} \right]_{\psi_0} = D_1 \left[\left(\frac{dC_1}{dx} \right) \right]_{\psi_0} - D_2 \left(\frac{dC_2}{dx} \right)_{x=\eta} \quad (9)$$

This latter expression is an equation for the phase interface expressed in nonlinear form. An approximate solution of this nonlinear equation is possible because of the closeness of the concentration change to a linear law within the laminar boundary layer. Let us assume

$$C_1(x, \tau) = C_0 + \frac{C_M - C_{\text{sat}}}{\eta} x, \quad (10)$$

$$C_2(x, \tau) = \text{const} = C_M.$$

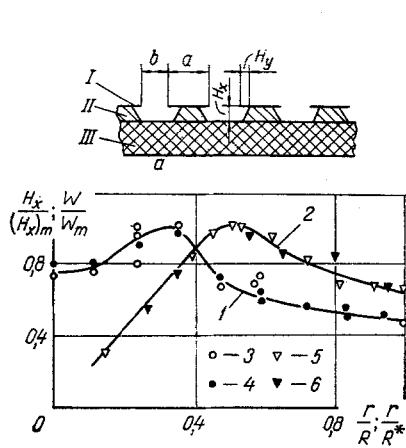


Fig. 3

Fig. 3. Distribution of the relative material flux and the relative velocity in the cross section of turbulent axisymmetric jets flowing perpendicularly into a solid surface: 1) the distribution $H_x/H_y = v_x/v_y = f(r/R)$ under the effect of a plane jet CuCl_2 ($\text{Re} = 4 \cdot 10^4$, $t_0 = 45^\circ\text{C}$, $\text{St} = 0.55 \cdot 10^{-3}$, $b/a = 1-5$); 2) $W/W_m = \phi(r/R^*)$ in a circular air jet [7] ($W_0 = 10-39$ m/sec, $t_0 = 20^\circ\text{C}$, $x_0/d = 30$, $d = (2.1-3.0)$ cm) at a distance $5 \cdot 10^{-1}$ cm from the solid surface; 3, 4) dimensionless values of the measured H_x in the CuCl_2 jet cross section; 5, 6) dimensionless magnitude of the values of W measured in [7] in the air jet cross section; a) measurement diagram for the quantities H_x and H_y during dissolution of an effectively homogeneous reaction surface [I) protective layer; II) metal; III) dielectric].

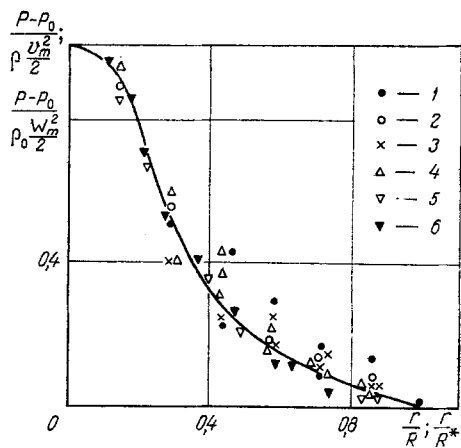


Fig. 4

Fig. 4. Relative pressure distribution in the cross section of turbulent axisymmetric jets perpendicularly incident on a solid surface; 1-4) test points obtained during dissolution of a metal surface in a CuCl_2 jet solution for the initial parameters indicated in Fig. 3; 5, 6) results of measurements obtained in [7] for the initial air jets parameters indicated in Fig. 3.

Substituting (10) into (9), we obtain

$$(C_M - C_0) \frac{d\eta}{d\tau} = D_1 \frac{C_M - C_{\text{sat}}}{\eta}, \quad (11)$$

where C_{sat} is the limit (at saturation) concentration of the solution.

Integrating, we find

$$\frac{\eta^2}{\tau} = \frac{2D_1(C_M - C_{\text{sat}})}{(C_M - C_0)}, \quad (12)$$

which reflects the measure of the rate of change in concentration in the x direction, while the quantity

$$\beta_\tau = \frac{d\eta}{d\tau} = \frac{\sqrt{2D_1(C_M - C_{\text{sat}})/(C_M - C_0)}}{2\sqrt{\tau}} \quad (13)$$

is its rate of change.

The analysis performed permits determination of the time for total dissolution of the copper τ_{max} in a section of width b when the phase interface reaches the location $\eta = (H_x)_m$:

$$\tau_{\text{max}} = \frac{(C_M - C_0)(H_x)_m^2}{2D_1(C_M - C_{\text{sat}})}. \quad (14)$$

Thus the rate of copper dissolution on a section of width b equals

$$\beta_c = \frac{\sqrt{2D_1(C_M - C_{\text{sat}})/(C_M - C_0)}}{2\sqrt{\tau_{\text{max}}}}. \quad (15)$$

The quantity β_c computed in this manner for the case of dissolution of copper $(H_x)_m = 50 \cdot 10^{-4}$ cm thick under the effect of a CuCl_2 etching solution ($D_1 \approx 0.2 \cdot 10^{-5}$ cm²/sec, $C_0 = 0.11$ g/cm³, $C_{\text{sat}} = 0.85$ g/cm³, $C_M = 8.96$ g/cm³) is $\beta_c = 3.25 \cdot 10^{-4}$ cm/sec.

The results of measuring the rate of copper foil dissolution for regimes close to the computed case are represented in Fig. 2. Dissolution of $\nabla = 50 \cdot 10^{-4}$ -cm thick copper occurred for a different time τ of its residency in the boundary layer of a CuCl_2 jet flowing into a plate for $\text{Re} = U_0 d_{\text{ef}}/\nu = 4 \cdot 10^4$, $\text{St} = \beta/U_0 = 0.00055$, $X_0/d_{\text{ef}} = 120$, and $b/a = 1-10$.

It can be seen that copper dissolution in sections of the relative width $b/a = 1-10$ is identical in the cases investigated and is characterized by the uniform sinking of the phase separation line and by a value of the ratio $\beta_l = H_x/\tau$ on the order of $1 \cdot 10^{-4}$ cm/sec, which agrees with the computed value β_c . (The discrepancy between β_c and β_l is within the limits of accuracy in determining the computed value of the diffusion coefficient D_1 of the solution.)

In conclusion, it is interesting to present results of a distribution of the dissolved quantities of copper along the radius of the reaction surface in dimensionless form $H_x/H_m = f_0(r/R)$, as well as a distribution of the relative pressure $(P - P_0)/\rho v_m^2 = F(r/R)$ found on the basis of a direct proportionality between the flux velocity and the thickness of the dissolved copper in a laminar boundary layer (Figs. 3 and 4). (Here H_m is the maximum thickness of the copper dissolved within the reaction surface.) Given there for comparison are experimental data obtained in [7] during measurement of the velocity and excess pressure fields by a Pitot tube at a distance $x = 5$ mm from the solid surface in a turbulent axisymmetric air jet flowing in at a 90° angle. The test results [7] are represented in the dimensionless coordinates $W/W_m = \varphi(r/R^*)$ and $(P - P_0)/\rho_0 W_m^2 = \varphi(r/R^*)$, where R^* is the size of the stream cross section (to $\partial P/\partial r \rightarrow 0$), and W_m is the maximum value of the velocity in the stream cross section.

The correlation between the dimensionless velocity and pressure profiles obtained by different methods in streams with different physical properties is visible.

A discrepancy occurs in the distribution of the dimensionless velocity near the axis of the axisymmetric jet. A finite quantity of dissolved copper is observed here, and, therefore, the stream velocity is not zero. Sufficiently intense motion of the solution parallel to the surface in this region of the section might be the explanation.

The almost constant value of the difference between the dimensionless velocity profiles in Fig. 3, measured by different methods, indicates a difference in the relative velocity profile of circular (curve 2) and plane (curve 1) jets.

NOTATION

d_{ef} , size of the exit hole of the atomizer nozzle from which the turbulent fluid jet (aqueous solution) issues; X_0 , distance from the nozzle exit hole to the metal surface perpendicular to the jet axis; b , width of the metal surface sections being dissolved by the jet solutions; a , width of the metal surface sections protected from the effect of the solution; r , running coordinate in the stream cross section; R , size of the reaction surface; x , y , coordinates at the reaction surface in the direction of the jet axis of symmetry and in the transverse direction; H_x , H_y , thickness of the metal dissolved from the surface in the x and y directions; v_x , v_y , flow velocity components at a stream point in the x and y directions; ψ , stream velocity potential; t_0 , u_0 , initial (at the nozzle exit) values of the temperature and velocity of the fluid jet; β , dissolution reaction rate constant; v_a , velocity of motion of an atomizer with an emerging fluid jet parallel to the reaction surface; ∇ , thickness of the metal surface being dissolved; ν , D , ρ , kinematic viscosity, diffusion coefficient, and density of the fluid; $\text{Re} = U_0 d_{\text{ef}}/\nu$, Reynolds criterion for jet solution escape; $\text{Re}_a = v_a \nabla/\nu$, Reynolds criterion for the flow of a jet solution in reciprocating motion around obstacles protected from dissolution; $\text{Pe} = (U_0 \cdot R)/D$, Peclet number; $\text{St} = \beta/U_0$, Stanton criterion; τ , time; c , running concentration of the solution; C_1 , D_1 , concentration and diffusion coefficient of the solution in a section of width b ; C_2 , D_2 , concentration and diffusion coefficient of the solid phase in a section of width b ; C_M , concentration of the solid phase; C_{sat} , limit (at saturation) concentration of the solution; $x = \eta$, location of the phase interface; $J_{\text{lim}} = [-(C_M - C_0)(d\eta/d\tau)]_{\psi_0}$, limit diffusion flux of dissolved material; $-D_1[(dC_1/dx)_{x=\eta}]_{\psi_0}$, diffusion flux of material transferred into the boundary layer; $-D_2(dC_2/dx)_{x=\eta}$, material flux transferred by diffusion from the solid phase domain in a section of width b ; $\beta_\tau = d\eta/d\tau$, rate of progress of the interphasal boundary into the metal bulk; τ_{max} , time of total dissolution of the metal surface of thickness $(H_x)_m$; $(H_x)_m$, maximal thickness of the

metal coating; $v_x/(v_x)_m$, relative stream velocity component at a point of the fluid jet boundary layer; $(v_x)_m$, maximum value of the velocity component in the cross section of the fluid jet stream; W/W_m , relative velocity in the cross section of an air jet incident on a solid surface; W_m , maximum value of the velocity in the stream cross section; $P - P_0$, excess pressure in the stream; P_0 , atmospheric pressure; ρ_0 , air jet density; R^* , width of the air jet cross section at the solid surface.

LITERATURE CITED

1. G. S. Antonova, G. A. Batova, L. N. Dukova, A. I. Lukashova, and G. L. Melikova, *Vopr. Radioelektron.*, Ser. TPO, No. 2 (1973).
2. D. A. Frank-Kamanetskii, *Diffusion and Heat Transfer in Chemical Kinetics* [in Russian], Nauka, Moscow (1967).
3. V. G. Levich, *Physicochemical Hydrodynamics* [in Russian], Izd. Akad. Nauk SSSR (1952).
4. O. M. Todes and A. P. Shapiro, *Kinetika i Kataliz*, No. 1, 324 (1960).
5. L. Prandtl, *Hydroaerodynamics* [Russian translation], IL, Moscow (1949).
6. G. S. Antonova, *Inzh.-Fiz. Zh.*, 32, No. 3 (1977).
7. P. M. Brdlik and V. K. Savin, *Structural Thermophysics* [in Russian], Moscow-Leningrad (1966), p. 192.

ISOTHERMAL SLIP OF A BINARY GAS MIXTURE ALONG A SOLID SURFACE

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UDC 533.6.011

This paper investigates Couette flow of a binary mixture of a rarefied gas between two flat plates. An analytical expression for the rate of isothermal slip of a binary mixture of the rarefied gas along the surface is obtained.

There are a large number of references (see, e.g., [1-5]), dealing with slip of a gas along a surface. However, because of the difficulties in computing the distribution function, only slip of a Maxwellian gas and of a gas interacting according to the solid sphere law were considered in [2-5]. The gas slip was investigated by a variational method in [6] for arbitrary direction of the molecules. The molecular distribution function was sought in the form of an expansion of a near-Maxwellian distribution function with the mean-mass mixture velocity. The validity of this from the physical point of view must be subject to doubt. In fact, far from the surface, in the Navier-Stokes flow region, the difference between the partial and the mean-mass velocities is a small quantity of order $K_n = (\lambda/L) \ll 1$ (λ is the mean free path, and L is a characteristic hydrodynamic length). However, near the surface, where $K_n \sim 1$, a state of the gas mixture can exist where the difference between the partial and the mean-mass velocities is on the order of the mean-mass velocity [7].

A modified semi-three-dimensional method of moments, developed by the present author in [8], has been used to investigate Couette flow of a binary mixture of a rarefied gas between two parallel plates. An expression has been obtained for the slip velocity with arbitrary law of interaction of the molecules with each other and with the surface. It should be noted that because of the transfer of viscous momentum across the Knudsen layer by diffusion velocities, the slip coefficient is reduced by 20% for a specific ratio between the parameters of the mixture components.

We now consider the problem of Couette flow of a binary mixture of gases between two surfaces a distance $2L$ apart. The upper surface moves with velocity u_y in the direction of

Translated from *Inzhenerno-Fizicheskii Zhurnal*, Vol. 32, No. 4, pp. 683-686, April, 1977.
Original article submitted April 28, 1976.

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