NOTATION

v is the particle velocity; V, mean particle velocity; U, velocity of the medium; τ, time of dynamic particle relaxation; n, particle concentration; ℓ, characteristic dimension. Indices: w denotes the parameter at the wall.

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EFFECTS OF VISCOUS DISSIPATION AND JOULE HEAT ON HEAT TRANSFER NEAR A ROTATING DISK IN THE PRESENCE OF INTENSIVE SUCTION

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Heat transfer in the bounday layer of an electrically conducting incompressible liquid near a disk rotating in an axial magnetic field is investigated for the case of intensive, uniform suction. The thermal flux intensity near the disk surface is determined in relation to the magnetic field strength and the rotation speed of the disk with an allowance for the viscous and the Joule dissipation.

The characteristics of the hydrodynamic and the thermal boundary layers at a rotating unbounded permeable disk were calculated in [1, 2] by integrating the equations of motion and energy with averaged convective terms while neglecting the viscous dissipation. Heat transfer near a disk rotating in a conducting medium within an axial magnetic field was considered in the absence of suction [3] and in the case of strong suction [4], using a similar nondissipative approximation. We have considered the effect of viscous dissipation and of the Joule heat on heat transfer in the magnetohydrodynamic boundary layer at a permeable dielectric disk rotating in an electrically conducting incompressible, viscous medium. Let us assume that the difference between the temperature in the main flow and the disk temperature is relatively small [2]. We assume in accordance with [1, 2] that $w = w_0 - k$. Then, if condition $k \gg w_0$ is satisfied, we have the following for the thermal boundary layer at the disk:

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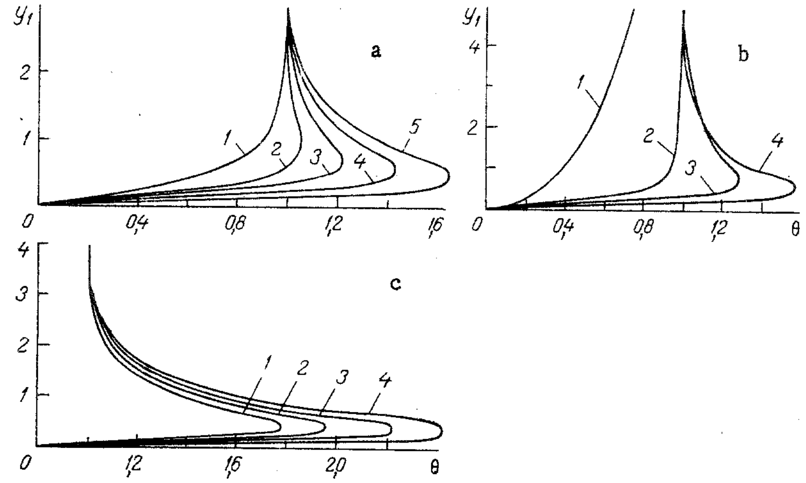

Fig. 1. Distribution of the liquid temperature θ along the boundary layer thickness y_1 for different values of the parameters of the problem (all quantities are in dimensionless form). a) N_0: 1) 0.1; 2) 0.3; 3) 0.5; 4) 0.7; 5) 0.9; b) Pr: 1) 0.1; 2) 0.3; 3) 0.5; 4) 0.7; c) S: 1) 0; 2) 0.5; 3) 2; 4) 4.

$$-\rho c_p k \frac{\partial T}{\partial z} = \varkappa \frac{\partial^2 T}{\partial z^2} + \eta \left(\frac{\partial v}{\partial z}\right)^2 + \sigma B^2 v^2. \tag{1}$$

The second and the third terms on the right-hand side of Eq. (1) describe the specific viscous and Joule dissipated power values, respectively. Using the data from [4] for the flow velocity v, we find after integrating (1)

$$T = T_0 + (T_1 - T_0)[1 - \exp(-\varphi \Pr y)] + \frac{T_0 \Pr N_0 (\beta^2 + 1)}{2\beta(2\beta - \varphi \Pr)} \times$$
$$\times [\exp(-\varphi \Pr y) - \exp(-2\beta y)] \quad \text{for} \quad \Pr \neq 1 + \sqrt{1 + \frac{4S}{k_0^2}}, \tag{2}$$

$$T = T_0 + (T_1 - T_0)[1 - \exp(-\varphi \Pr y)] + \frac{T_0 \Pr N_0 k_0}{4\sqrt{S}} \left(\Pr + \frac{4S}{k_0^2 \Pr}\right)$$
$$\text{for} \quad \Pr = 1 + \sqrt{1 + \frac{4S}{k_0^2}}; \tag{3}$$

where

$$N_0 = \frac{\omega^2 r^2}{c_p T_0}; \quad \varphi = \frac{k_0}{\sqrt{S}}; \quad \beta = \frac{\varphi}{2} + \sqrt{1 + \frac{\varphi^2}{4}}; \quad S = \frac{\sigma B^2}{\rho \omega};$$
$$k_0 = k(\nu\omega)^{-1/2}; \quad y = \frac{z}{l}; \quad l = \left(\frac{\eta}{\sigma B^2}\right)^{1/2}; \quad \Pr = \frac{\eta c_p}{\varkappa}.$$

The subscript 0 refers to the parameters of the medium near the disk surface, while subscript 1 refers to quantities infinitely remote from the disk.

For the case of a nonconducting medium (S = 0), we obtain [5]

$$T = T_0 + (T_1 - T_0)[1 - \exp(-\Pr k_0 y_1)] + \frac{T_0 \Pr N_0}{2(2 - \Pr)} [\exp(-\Pr k_0 y_1) - \exp(-2k_0 y_1)] \tag{4}$$

for Pr ≠ 2,

$$T = T_0 + (T_1 - T_0)[1 - \exp(-2k_0 y_1)] + T_0 N_0 k_0 y_1 \exp(-2k_0 y_1) \tag{5}$$

for Pr = 2. Here, $y_1 = z(\omega/\nu)^{1/2}$.

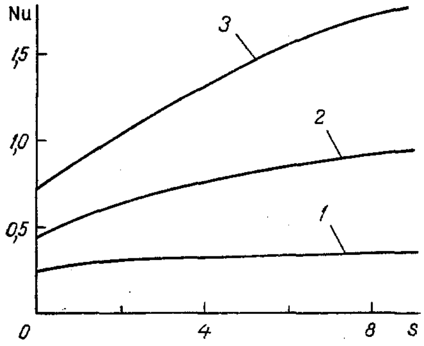

Fig. 2. Dimensionless thermal flux intensity in the boundary layer at the disk Nu as a function of the dimensionless magnetohydrodynamic interaction parameter S for different values of N_0: 1) 0.1; 2) 0.5; 3) 1.

Let us investigate the temperature distribution in the boundary layer for different values of the parameters in the range of Pr, No, and S [3-5].

Figure 1a shows the profiles of the dimensionless temperature $\theta = (T - T_0)/(T_1 - T_0)$ in the case S = 0 for $k_0 = 2$; $n = T_1/T_0 = 1.1$; Pr = 1 and different values of the parameter N_0. For small values of N_0, the relative contribution of viscous heat release is small, and the temperature profile has the form associated with nondissipative flow. For $N_0 > 0.3$, viscous dissipation begins to play the role of an additional heat source, which causes an increase in the temperature variation rate in the bounday layer. The θ profile then assumes a shape whose maximum is larger than unity near the disk surface.

Figure 1b and c shows the θ distributions for the same values of k_0 and n, $N_0 = 1$, and different values of the Pr (S = 0.5) and S (Pr = 1) numbers, respectively. The character of variation of the θ profile in relation to the Prandtl numbers (Fig. 1b) is connected with the relative lessening of the role of thermal conductivity as Pr increases. The increase in the maximum value of θ with an increase in the magnetohydrodynamic interaction parameter S (Fig. 1c) is explained by an intensification of Joule heating of the medium due to the passage of the radial electric current.

The heat-transfer process in the boundary layer is most clearly illustrated by the magnitude of the thermal flux at the boundary between the liquid and the body in the flow. According to [6], we introduce the integral Nusselt number,

$$\mathrm{Nu} = \frac{2\int\limits_0^R q(0)\, r dr}{\varkappa (T_0 - T_1) R^2} \sqrt{\frac{\nu}{\omega}}, \tag{6}$$

where $q(0) = -\varkappa \left.\frac{\partial T}{\partial z}\right|_{z=0}$ is the thermal flux intensity at the disk surface.

Using (2), we obtain

$$\mathrm{Nu} = k_0 \mathrm{Pr} + \frac{\mathrm{Pr}\, N_0(R) \sqrt{S}\, (\beta^2 + 1)}{4(n-1)\beta}. \tag{7}$$

Figure 2 shows the Nu number as a function of the parameter S for n = 1.1, Pr = 1, and $N_0 = 0.1$; 0.5; 1. Analyzing (7), we readily satisfy ourselves that, with an increase in N_0, the dimensionless thermal flux rises considerably due to the intensification of viscous dissipation in the boundary layer. For instance, in the case of a nonconducting medium, the Nusselt number increases by a factor of 3 as N_0 increases from 0.1 to 1. Variation of the S parameter, which characterizes the action of electromagnetic forces, involves changes in the relationship between the contributions of the viscous and the Joule dissipation to the heat release process. For small values of S, viscous heating of the gas plays the main role, and the increase in the Nu number with the rise of S is related to the increase in the velocity gradients with a reduction in the thickness of the hydrodynamic boundary layer. For large S values, the basic effect is produced by the Joule heating of the liquid, the efficiency of which is proportional to the square of the radial current density j_r^2. Our calculations have shown that Joule heating begins to play an important role at high rotation velocities of the disk.

NOTATION

v and w, radial and axial velocity components of the medium, respectively; r and z, radial and axial coordinates, respectively; k, suction intensity at the disk surface; ρ, density; η and ν, dynamic and kinematic viscosity coefficients of the medium, respectively; c_p, specific heat; κ, thermal conductivity; σ, conductivity; B, magnetic induction; T, temperature; ω, angular velocity of the disk; R, disk radius.

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DYNAMICS OF MACROMOLECULES IN CONVERGENT-CHANNEL FLOWS

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The deformation of flexible and rigid macromolecules is analyzed under conditions of convergent-channel flows.

Certain pieces of equipment employed in chemical technology as well as in biotechnology make use of a dispersion medium to compress the stream of a macromolecular solution. For this case it is necessary to evaluate the effect of the shape of the convergent nozzle, the rate of flow, and the characteristics of the macromolecules on the deformation which takes place during the flow in the convergent channel and after passage through the channel (Fig. 1). The simplest of macromolecules have been used for these calculations, i.e., in the shape of flexible dumbbells and rigid axisymmetric ellipsoids. The deformation of the macromolecular flow near the axis of the convergent channel is close to elongational (the radius of the stream of the solution is considerably smaller than the radius of the convergent channel).

Flexible Macromolecules. The behavior of flexible macromolecules in various hydrodynamic situations has been analyzed in a number of papers, among which we will cite [1-6]. Flexible macromolecules are modeled by dumbbells with identical "spheres" and a nonlinear elastic link between them. If we neglect the inertial forces, then, as a consequence of the low macromolecular mass, it is possible to have

$$\overline{F}_1+\overline{F}_f+\overline{F}_B+\overline{F}_{iv}=0. \tag{1}$$

The elastic force $\overline{F}_1 = -3Nk\theta\mathscr{E}(r'/R)\overline{r}'/R^2$. For the nonlinear function $\mathscr{E}(r'/R)$ we take the Warner approximation $\mathscr{E}(r'/R) = [1-(r'/R)^2]^{-1}$. With such an approximation the elastic force sharply increases in proportion to the straightening of the circuit and tends toward infinity as $r' \to R$, which is in accord with physical sense (for any conformation of the circuit, the length of the "head-to-tail" vector of the macromolecule cannot be greater than the length of the totally straightened circuit). The force of hydrodynamic friction which arises as a consequence of the relative motion of the solution and the spheres of the "dumbbell" is given by $\overline{F}_f = \xi(r'/R)(\overline{v}-\overline{r}')$. The parameter of external friction, a function of the conformation of the circuit, is taken [5, 6] to be equal to $\xi = \xi_0 Q(r'/R) = \xi_0\sqrt{Nr'/R}$;

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