NOTATION

η_e, effective viscosity, N•sec/m^2; τ, internal friction stress, N/m^2; $\dot{\gamma}$, shear velocity gradient, 1/sec; k, n, m, α, β, rheological constants; η_0, first Newtonian viscosity, N•sec/m^2; η_∞, viscosity of the ultimately destroyed structure, N•sec/m^2; ε_{rr}, ε_{rz}, ε_{zz}, strain-rate components; ρ, density, N•sec^2/m^4; F_r, F_z, projections of mass forces in direction r and z; ω, angular velocity of disk rotation, 1/sec; p, pressure, N/m^2; δ, thickness of fluid film; r, instantaneous radius of disk, m; v_r, v_z, velocity components of fluid in respective directions r and z, m/sec; φ, fluidity of fluid; Q, volume flow rate of fluid, m^3/sec.

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ELECTROCHEMICAL METHOD OF STUDYING HEAT TRANSFER BETWEEN A CYLINDER AND A RISING TWO-PHASE FLOW

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An electrochemical method is used to study the mean coefficients of mass transfer, and it is shown that the experimental data are in complete agreement with a relationship [Eq. (2)] derived from experiments with thermal models.

The results of an experimental investigation into heat transfer between a transversely flushed cylinder and an equilibrium ($\varphi = 1$) rising gas flow containing drops of liquid were presented in [1]. In this problem the volumetric concentration of the suspended drops, i.e., the ratio of the volume of the drops to the volume occupied by the gas, was no greater than $5 \cdot 10^{-2}$. Depending on the concentration of the drops in the two-phase flow, and hence the amount of liquid deposited on the surface of the cylinder, heat transfer occurred both as a result of the heating of the film and its detachment from the surface (q_{de}) and as a result of the heat and mass transfer between the surface and the flow (q_{con} and q_{ev}).

For low concentrations of liquid in the flow, the surface temperature of the liquid film exceeds the equilibrium temperature of the flow, and heat is largely carried away by processes of heat transfer (nonevaporating liquid) or heat and mass transfer (evaporating liquid) between the film and the flow.

For high concentrations the surface temperature of the film is approximately equal to the equilibrium temperature of the flow, and the heat from the cylinder is carried away by convection between the flowing film and the surface of the cylinder, i.e., by the heating and subsequent detachment (separation) of the film.

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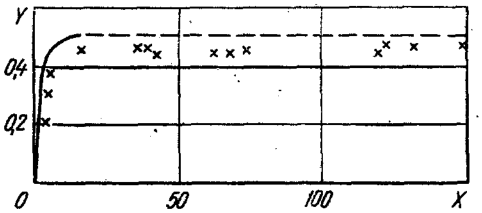

Fig. 1. Generalization of the results of experiments involving thermal measurements and electrochemical analysis. The continuous curve represents the experiments with thermal models; the points represent the results of the electrochemical method.

In the heat experiments we used water, ethyl alcohol, transformer oil, and Diesel fuel ($Pr' = 8$-200) as the liquid. The gas phase was air. The experiments covered the range of two-phase hydrodynamic stability numbers $1.28 < K < 3.2$.

When nonevaporating liquids were introduced into the flow, we found that the heat-transfer coefficient between the surface of the cylinder and the liquid film increased with increasing amount of deposited liquid and tended asymptotically toward a certain limiting value.

We also established as a result of the experiments that, for a constant pressure, as the velocity w_0'' increased, the limiting value of the heat-transfer coefficient did likewise; in the pressure range 0.1-1.0 bar and for a constant dynamic head ($\rho'' w_0''^2 = \text{const}$) the limiting value was almost independent of pressure.

The conclusions drawn from the experiments with thermal models were derived subject to a number of simplifying assumptions.

The main assumption is that the temperature field in the film depends only slightly on the conditions of heat transfer between its surface and the two-phase flow; this assumption demands confirmation.

Since it is generally accepted that q_{de} is determined by the quantity and flow characteristics of the liquid deposited on the surface of the cylinder, in using the structural method of studying the total heat flow density [3] it is appropriate to separate the components q_{con} and q_{ev} from the latter. This may be done if we are in possession of a method enabling us to determine q_{de} without complicating this process by accompanying processes of heat and mass transfer in the two-phase medium, and also enabling us to confirm the existence of a limiting value of the heat-transfer coefficient in a reliable manner.

Great advantages are offered in this connection by the electrochemical method, which establishes the laws of convective heat transfer by separating out the hydrodynamic factors from the overall process and enables us to extend the conclusions so drawn to the laws of convective heat transfer.

As electrolyte we used 0.005-0.025 N solutions of ferro-ferricyanide in distilled water, with the addition of 2 M NaOH. As gas we used nitrogen.

The basic arrangement of the experimental apparatus and the method of measuring the desired parameters were analogous to those described in [2].

The sensor was made of organic glass (Plexiglas) in the form of a cylinder 6 mm in diameter. The cathode was a nickel rod 5 mm long and 6 mm in diameter; it was placed in the middle of the sensor cylinder. A nickel wire was wound on the cylinder on both sides of the cathode at a distance of 2 mm from its ends; this served as anode. To prevent the anode from being polarized, its surface was made much larger than that of the cathode.

The continuous line in Fig. 1 plotted in coordinates of

$$X = \frac{w_0'}{(g\nu')^{1/3}} \Pr'^{1/2}, \qquad Y = \frac{\bar{\alpha}'}{\lambda'} \left(\frac{\nu'^2}{g} \right)^{1/3} \tag{1}$$

represents a correlation of the experimental data obtained in the thermal models.

The equation for calculating $\bar{\alpha}'$ takes the form

$$\frac{\bar{\alpha}'}{\bar{\alpha}_0'} = 1 - \exp\left\{-0.64\,\frac{w_0'}{(g\nu')^{1/3}}\,\Pr'^{1/2}\right\}. \tag{2}$$

Here $\bar{\alpha}_0'$ is the limiting heat-transfer coefficient, for which the following relationship is proposed:

$$\frac{\bar{\alpha}_0'}{\lambda'}\left(\frac{\nu'^2}{g}\right)^{1/3} = 0.45\left(\frac{\rho'' w_0''^2}{\rho' g d}\right)^{1/5}\Pr'^{2/5}. \tag{3}$$

Since the thermal experiments were only carried out for $0.15 < X < 15$ ($w_0' < 0.04$ m/sec), the character of the proposed $Y = f(X)$ relationship for $X > 15$ is denoted by a broken line (Fig. 1); its validity is confirmed to a fair degree of accuracy (deviation no greater than 10%) by the electrochemical results ($0 < X < 150$).

This deviation may be explained by the fact that the thermal experiments were carried out for a constant thermal flux $q_m \approx$ const, while in the electrochemical method, modeling was executed for $t_m =$ const.

Analysis of the experimental data was carried out in the form

$$X = \frac{w_0'}{(g\nu')^{1/3}}\Pr_D^{1/2},\quad Y = \frac{\bar{\beta}}{D}\left(\frac{\nu'^2}{g}\right)^{1/3}. \tag{4}$$

The influence of the value of the $\Pr_D$ number ($\Pr_D < 10^4$) was considered in [2].

Thus, on the basis of our initial assumptions and the results of experiments carried out in thermal models, with the assistance of the electrochemical method, we have confirmed the existence of a limiting heat-transfer coefficient under the conditions specified and derived an equation for determining $\bar{\alpha}'$.

NOTATION

D, molecular diffusion coefficient, m²/sec; g, gravitational acceleration, m/sec²; q_{de}, q_{con}, q_{ev}, thermal flux density associated with the heating of the film, convection, and the evaporation of the liquid, W/m²; t_m, mean temperature of the heat-transfer surface (wall), °C; t_0, temperature of equilibrium two-phase flow, °C; $\bar{\alpha}$, mean heat-transfer coefficient, W/m²·deg; $\bar{\beta}$, mean mass-transfer coefficient, m/sec; λ, thermal conductivity, W/m·deg; ν, kinematic viscosity, m²/sec; ρ, density, kg/m³; $K = w_0''\sqrt{\rho''}/\sqrt[4]{\sigma g(\rho' - \rho'')}$, hydrodynamic stability number of a two-phase flow, constituting a measure of the interaction of the dynamic head of the gas phase with the surface tension at the phase interface and the force of gravity; Pr, Prandtl number; $\Pr_D$, diffusion Prandtl number. Indices: ' and ", respectively, liquid and gaseous phases.

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