a tube [3, 4]; 2) the heat flux distribution over the perimeter of a tube [5] and over the perimeter of an annular channel (one- and two-sided heating) [2, 6]; 3) the ratio of the heated perimeter to the cross-sectional area of the channel (circular tubes, annular channels with inside, outside and two-sided heating, bundles of rods) [6]; 4) the heated length of the tube [7]. On the basis of these experiments it is also possible to estimate the order of the length of the neighboring boiling sections. For a boiling subcooled liquid it is hundredths, and for a boiling vapor-liquid mixture tenths of a meter.

The effect of the flow prehistory on burnout can be checked by interfering with the flow in neighboring cross sections, e. g., by introducing various kinds of turbulence generators, mixers, etc., to equalize the vapor content over the channel cross section. Thus, in [2] it was found that a centering device in an annular channel caused an increase in the critical heat flux.

Thus, in using the flow parameters of the liquid or vapor-liquid mixture averaged over the cross section in which burnout occurs it is necessary to consider the effect of nucleate boiling in neighboring sections of the channel on nucleate boiling burnout. The length of the neighboring boiling sections may be less than or equal to the heated length of the channel. The effect of the neighboring boiling sections on burnout must be taken into account in performing experiments on the critical heat flux and in analyzing, interpreting, and generalizing the results. The same effect should also be taken into account in simulating apparatus cooled by a boiling liquid. The test data obtained on models can be transferred to the actual apparatus: 1) if the characteristic parameters are equal in the channel cross section considered, 2) if there is the same law of distribution of the heat flux along the length and perimeter of the channel over the length of the neighboring boiling sections; 3) if the lengths of the neighboring boiling sections are equal. The heated length of the channel and the variation of the heat flux outside the neighboring boiling sections may be different. We still do not have an expression for the length of the neighboring boiling sections.

NOTATION

q_{cr} is the critical heat flux; $w\rho$ is the mass flow velocity of liquid or vapor-liquid mixture; $X = (i' - i)/r$ is the relative enthalpy of flow; i' is the enthalpy of liquid at saturation point; i is the enthalpy of flow of liquid or vapor-liquid mixture; r is the heat of vaporization; D is the transverse dimension of channel; L is the length of neighboring boiling sections; $\Gamma = di/dl$ is the liquid enthalpy gradient along the length of the channel; l_0 is the heated length of the channel; $q(l)$ is the law of heat flux variation. Subscripts: b is the value in the channel cross section in which burnout occurs; L is the value over the length of the neighboring boiling sections.

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ENGINEERING FORMULAS FOR CALCULATING THE FRICTION ON A PERMEABLE SURFACE IN A TURBULENT GAS FLOW

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Simple formulas are proposed for calculating the friction on a permeable surface in a turbulent gas flow.

In several theoretical studies of a turbulent boundary layer with blowing, satisfactory agreement has been obtained between the calculated and experimental values. However, in most cases, theoretical calculations are laborious and inconvenient for engineering purposes. This note presents simple formulas for calculating the coefficient of friction on a permeable plate in a turbulent gas flow.

The proposed formulas were obtained on the basis of an approximation of the curves calculated from the theoretical formulas of [1].

We write the coefficient of friction as a function of the blowing parameter in the exponential form

$$c_f/c_{f_0} = \exp\,(-k\,\alpha). \tag{1}$$

This is convenient, since from the results of [1] it has been established that the coefficient k is almost independent of the blowing parameter α. The coefficient k depends on other parameters, for example, the molecular weights of the main-stream and blown gases. An analytic expression giving k as a function of the parameters of the problem can be established by approximating the theoretical relations obtained in [1].

In the particular case of a subsonic isothermal flow we obtain the following approximation for the coefficient k:

$$k = \frac{1}{2}\left(\frac{m_2}{m_1}\right)^{0.6}. \tag{2}$$

Similarly, we can establish the relation between k and the other parameters; however, it should be noted that k depends most strongly on the ratio of molecular weights.

From (1) and (2) we obtain a formula for calculating the friction on a permeable surface in a subsonic isothermal gas flow in the form

$$\frac{c_f}{c_{f_0}} = \exp\left[-\frac{\alpha}{2}\left(\frac{m_2}{m_1}\right)^{0.6}\right]. \tag{3}$$

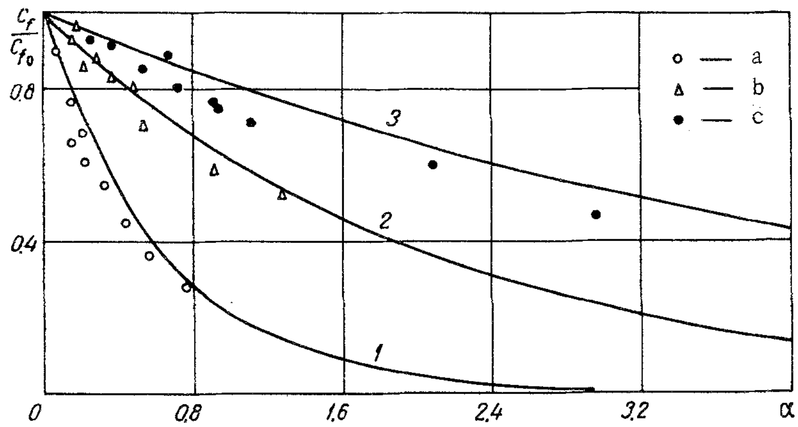

Fig. 1. Comparison of friction coefficient calculated from (3) and the experimental data of [2]. The curves 1, 2, 3 and experimental points a, b, and c correspond to helium, air, and freon-12 blown into an air stream.

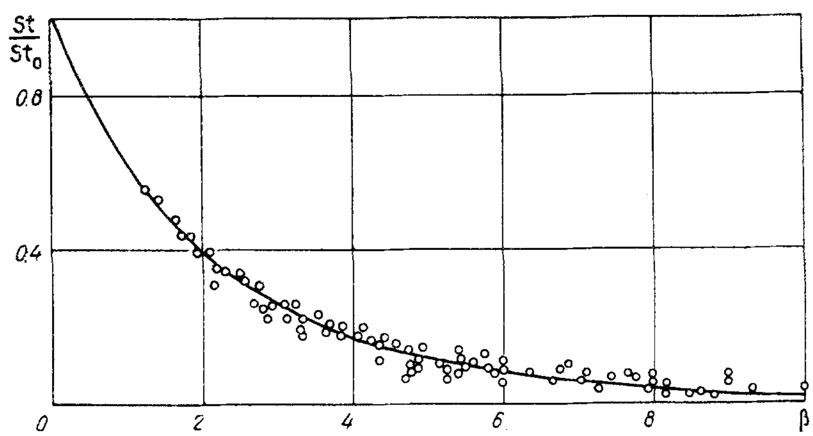

Fig. 2. Comparison of values of the Stanton number St calculated from (5) and the experimental data of [3].

It is clear from Fig. 1 that the calculated values of the friction coefficient are in satisfactory agreement with the experimental data.

If the blown gas and the main-stream gas are the same, the equation for the coefficient of friction simplifies to

$$c_f/c_{f_0} = \exp(-\alpha/2). \quad (4)$$

Using Eq. (4), from [1] we can obtain the following expression for the Stanton number St:

$$\frac{St}{St_0} = \beta \exp\left(\frac{1-Pr}{1+Pr}\beta\right) \Big/ \left[1 + \frac{2}{1+Pr}\beta \exp\left(\frac{\beta}{1+Pr}\right) - \exp\left(\frac{1-Pr}{1+Pr}\beta\right)\right]. \quad (5)$$

It is clear from Fig. 2 that there is good agreement between the calculated values of St (at Pr = 0.72) and the experimental data up to large values of the blowing parameter β.

NOTATION

c_f is the coefficient of friction; c_{f_0} is the coefficient of friction on impermeable surface;

$$\alpha = \frac{(\rho v)_w}{\rho_\infty U}\frac{2}{c_{f_0}}, \quad \beta = \frac{(\rho v)_w}{\rho_\infty U}\frac{1}{St_0}$$

are the blowing parameters; $(\rho v)_w$ is the injected gas flow; ρ_∞, U are the density and velocity in the core flow; k is a coefficient; St_0 is the Stanton number on the impermeable surface; Pr is the Prandtl number; m is the molecular weight. The subscripts 1, 2 relate to the blown gas and the main-stream gas, respectively.

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EFFECTIVE BOUNDARY CONDITIONS IN STATIONARY HEAT CONDUCTION PROBLEMS

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In a number of cases problems of nonstationary heat conduction relating to heat propagation in layered media may be substantially simplified by introducing approximately effective boundary conditions at the interfaces. These approximations are usually based on the low heat capacity of one or more of the media involved in the problem [1, 2].

A similar simplification can also be achieved in stationary problems when in certain media the variation of the temperature field is small in certain directions.* In particular, if at the surface of a massive solid there is a perfect thermal contact with a thin shell of another material not containing heat sources and the boundary conditions are given at the outer surface of the shell, then it is sometimes possible to introduce approximately effective boundary conditions directly at the surface of the massive solid.

1. A body is bounded by the plane z = 0 on which there is a shell bounded by surfaces z = a, F(x, y) = 0. The boundary conditions have the form

$$\left(\alpha \frac{\partial u}{\partial z} + \beta u\right)_{z=a} = g(x, y), \quad u|_{F(x,y)=0} = \omega(z), \quad (1)$$

the thermal conductivities of the body and the shell being, respectively, K and K_1. Starting from the expansion of the temperature function u for $0 \le z \le a$ in a Maclaurin series in z, we obtain at the surface z = 0 the boundary condition

$$\left(\alpha' \frac{\partial u}{\partial z} + \beta u\right)_{z=0} = g(x, y) + R_1, \quad \alpha' = \frac{K}{K_1}(\alpha + \beta a). \quad (2)$$

For the error R_1 we have the estimate

$$|R_1| \leqslant \frac{a}{2}(2\alpha + \beta a)(M_1 + M_2), \quad (3)$$

where

$$M_1 = \max\{\max|\Delta_{xy} u(x, y, 0)|, \max|\Delta_{xy} u(x, y, a)|\},$$

$$M_2 = \max\left|\frac{d^2\omega}{dz^2}\right|, \quad \Delta_{xy} = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}.$$

2. The small region S_0 of the surface z = 0 of a body is covered with a thin shell bounded by an outer surface S at which the boundary condition is given in the form

$$\left(\alpha \frac{\partial u}{\partial n} + \beta u\right)_S = g(x, y), \quad (4)$$

where n denotes the exterior normal to S.

Averaging the temperature function over the region occupied by the shell and starting from the condition of heat flow balance in the shell we obtain on S_0 the boundary condition

$$\left(\alpha' \frac{\partial u}{\partial z} + \beta u\right)_{z=0} = \bar{g} + R_2, \quad \alpha' = \frac{K}{K_1}\frac{S_0}{S}\alpha, \quad (5)$$

and for R_2

*Pointed out by G. A. Grinberg.