EFFECT OF DISCRETE FLOW DISTRIBUTION ON HEAT TRANSFER AT A VERTICAL SURFACE IN NATURAL CONVECTION

P. M. Brdlik and I. A. Turchin

Inzhenerno-Fizicheskii Zhurnal, Vol. 8, No. 2, pp. 268-272, 1965

The influence of a discrete distribution of injection and suction of air on heat transfer at a vertical flat surface under free convection has been investigated experimentally. The results are presented together with empirical formulas for the heat transfer coefficients.

The influence of a discrete distribution of injection and suction on heat transfer in natural convection has not been studied, in spite of its great practical interest in the design of rational heating, ventilating, and air-conditioning systems in industrial and public buildings. Essentially, the test equipment comprised a heat exchanger consisting of a large number (of the order of 60) of copper plates, each 10 mm high and 300 mm wide, mounted horizontally one above the other on a common frame at intervals of 0.5 mm.

Injection or suction was applied through the slits between the plates. The nature of the construction was such as to allow the distance between transpiration slits to be varied in the range 1-60 cm. The heater was a nichrome wire located in special grooves on the inside of the plate, the length of wire being identical for each plate. The heating elements of all the plates were joined in series and connected to a voltage regulator. With this form of heater the experiments could be carried out at constant heat flux.

Air was supplied to (or sucked from) the working chamber by a fan. The mass flow of air with the fan on was controlled by means of a baffle plate, and the flow rate was measured with a rotameter.

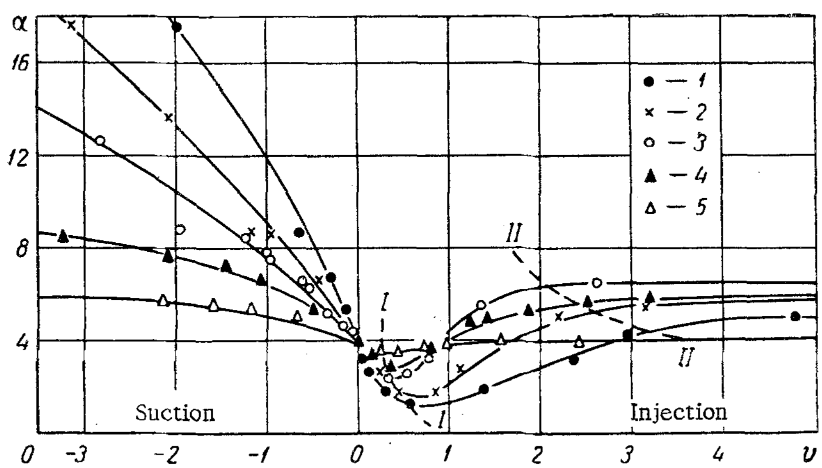

Fig. 1. Influence of discrete distribution of injection and suction on the variation of the mean heat transfer coefficient $\overline{\alpha}_L$ over length L for $t_\omega - t_\infty \approx 20°C$: 1) s = 30.0; 2) 14.7; 3) 7.0; 4) 3.45; 5) 1.71.

The air was heated to the required temperature by passing it through an electric heater, controlled by means of a power variator, which, like the fan variator, was operated from a stabilized voltage source.

Uniform distribution of air over the transpiration slits was achieved by mounting a layer of glass cloth in front of the working plates.

The temperature fields in the boundary layer (including the surface temperature of the plate itself) were determined with an interferometer. Therefore only control thermocouples, made of 0.15 mm chromel-alumel wire, were located in the body of the plate. The temperature of the air arriving at the slits was controlled by means of thermocouples glued to the glass cloth.

Since one of the main problems is to determine the effect on heat transfer of the distance between the slits, the experiments were carried out for various ratios s = L/h (Fig. 1). In the tests h was varied between 10 and 320 mm by closing up the transpiration slits with thin copper plates and putty. The rate of air injection and suction through the slits was varied over the range v = 0-10 m/sec. To avoid heat transfer between the surface of the plates and the injected air, the latter was maintained at a temperature approximately equal to that of the plates by means of an air heater. The temperature difference between the wall and the surrounding air was varied over the range $t_\omega - t_\infty$ = 20-40°C.

In the case of suction (curves to the left of v = 0, Fig. 1), an outwardly regular picture was obtained: with increase in suction velocity and decrease in s the heat transfer coefficient increased, reaching values exceeding by an order of magnitude those for v = 0 (dotted line).

A typical picture of boundary layer formation with discretely distributed suction is shown in the interferograms of Fig. 2., a, b, i, j, k, l. For a large distance between transpiration slits (Fig. 2, a, b) s = 1.71, the boundary layer thickness decreases relatively little from its value for no suction (Fig. 2, c). For a small distance between slits (Fig. 2, i, j, k, l) s = 30, the boundary layer thickness decreases sharply with increase in suction velocity, and, starting at a velocity v = 0.4 m/sec (Fig. 2, k), the boundary layer appears to be "sewn on" to the heat transfer surface, the boundary layers in both cases beginning practically at the transpiration slits.

The local heat transfer coefficient distribution is in full agreement with the character of boundary layer formation: there is a sharp growth in the heat transfer coefficients in the suction zones and a subsequent decrease with distance from the transpiration slits. With increase in the distance between slits the α distribution curves become stretched and form straight lines practically parallel to the x axis.

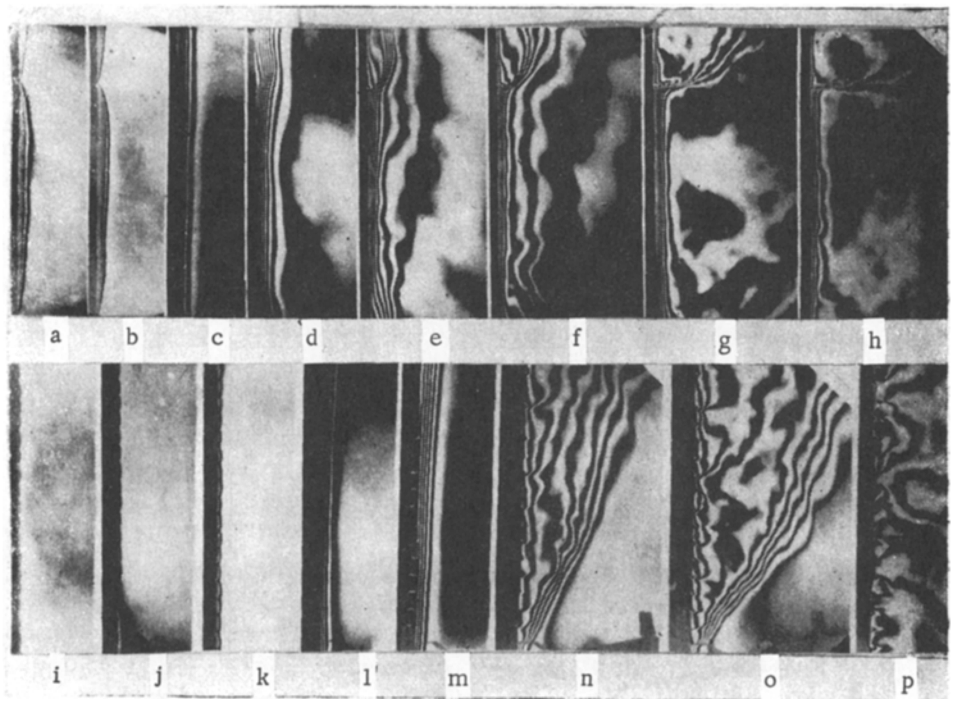

Fig. 2. Nature of boundary layer formation (interferograms) a) v = −3.0 m/sec, b) −2.0, c) 0, d) 0.7, e) 0.7, f) 1.2, g) 2.0, h) 3.5 for s = 1.7; i) (−3.0), j) −2.0, k) −0.8, l) 0, m) 0.3, n) 0.9, o) 1.8, p) 3.0 for s = 30.0.

At low injection velocities, bounded by the region lying to the left of I (Fig. 1), the nature of variation of the heat transfer coefficient with injection velocity is analogous to that for porous injection: with increase in velocity the heat transfer decreases, the more strongly, the more the length of the transpiration slits approaches unity (Fig. 2, d, m).

When the pitch of the transpiration slits is large (Fig. 2, d), a local increase in the boundary layer is observed in the injection zone; this extends along the flow for a certain, practically constant distance (40-45 mm). At the end of the boundary layer the flow is retarded by the jet from the next transpiration slit downstream, and the boundary layer again becomes a little thicker, which leads to a certain decrease in the heat transfer coefficient.

This kind of boundary layer formation leads to the following distribution of local heat transfer coefficients: the coefficient increases sharply from its minimum value and reaches a maximum at a practically constant distance (40-45 mm) from the point of injection; then a gradual decrease takes place, and in front of the next transpiration slit, a certain fall in α is again observed.

With decrease in the pitch of the transpiration slits, the region of slow decrease in the heat transfer coefficient narrows and vanishes for s = 3.45.

With further decrease in pitch the pattern of boundary layer formation at low injection velocities approaches closer to that for porous injection (Fig. 2, m), being characterized by the absence of boundary layer thickening at the injection points and an extension of the velocity range over which heat transfer decreases with increase in injection velocity.

The regular nature of the variation of the heat transfer coefficients with the basic parameters of the process in the region to the left of curve I (Fig. 1) allows us to generalize the test data and to obtain the empirical relation:

$$\mathrm{Nu}_L = 0.50\,\mathrm{Gr}_L^{1/4}\,(L/h)^{2.5\cdot 10^{-3}\mathrm{Re}_L^{0.5}}, \qquad (1)$$

shown graphically in Fig. 3.

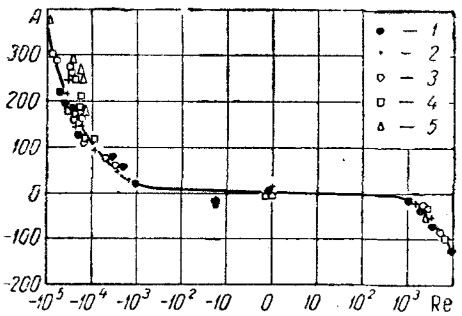

Fig. 3. Experimental data on heat transfer in natural convection with discrete distribution of suction and injection for the first heat transfer region

$$\left(A = \frac{\lg \mathrm{Nu}_L + 0.30 - \lg \mathrm{Gr}_L/4}{2.5\cdot 10^{-3}\lg(L/h)}\right):$$

1-5 – see Fig. 1.

The transition region between curves I and II (Fig. 1) is characterized by the formation of vortices in the injection zone and their propagation downstream, which leads finally to an increase in the heat transfer coefficients with increase in injection velocity. In the zone directly adjacent to the injection point, local boundary layer thickening occurs, this being the greater, the greater the injection velocity (Fig. 2, e, f, g). Subsequently, a vortex forms at the same point with increase in velocity, leading to stratification of the boundary layer: the main boundary layer formed by the underlying heat transfer surface is pushed back, and a new boundary layer forms in the zone near the transpiration slits. At a certain distance downstream from the injection point, depending on the injection velocity, the boundary layers fuse.

As the distance between transpiration slits diminishes, and at the same injection velocities, the main boundary layer, formed by the underlying heating surface, has less and less effect on boundary layer formation between adjacent transpiration slits (Fig. 2, n, o). Here the main influence on the distribution of local heat transfer coefficients is that of the local boundary layer thickening at the injection points.

At injection velocities located on line II (Fig. 1), the air jet from the transpiration slits disrupts the boundary layer (Fig. 2, h, p); and neither injection nor the previous history of the stream has much effect on the heat transfer (except for a very narrow zone directly adjacent to the injection point, where a small thickening of the boundary layer occurs). In Fig. 1 this region lies to the right of curve II. Thus, the mean heat transfer coefficients do not depend on the injection velocity. It is therefore possible to obtain a simple empirical formula for calculating the mean heat transfer coefficient $\bar{\alpha}_h$ over the distance between transpiration slits:

$$\mathrm{Nu}_L = 10\,\mathrm{Gr}_h^{1/4}\,h_0/h. \qquad (2)$$

This formula differs from (1) in that the distance h between transpiration slits replaces L as the characteristic parameter, because in this case the previous history of the flow does not affect the heat transfer. The smallest distance between slits in the experiments, h_0 = 10 mm, has been taken as a scale of reference.

The experimental data are compared with relation (2) in Fig. 4.

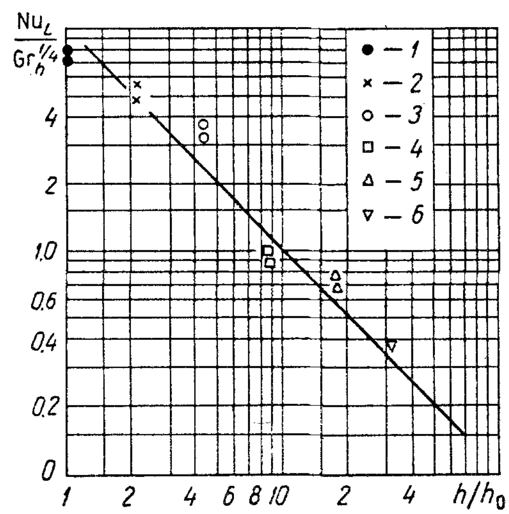

Fig. 4. Experimental data on heat transfer in natural convection with discrete distribution of suction for the third heat transfer region: 1-5) see Fig. 1; 6) s = 1.00.

NOTATION

v – injection and suction velocity; t_ω and t_∞ – temperature of plate and surrounding air; L – height of plate; h – distance between adjacent transpiration slits; $\bar{\alpha}_L$, $\bar{\alpha}_h$ – mean heat transfer coefficients over length of plate and over distance between transpiration slits; s – relative distance between slits.

13 May 1964

Institute of Building Physics, Moscow