CONVECTIVE HEAT EXCHANGE ON A PLANE SURFACE IN THE CASE OF A PERPENDICULAR JET FLOW OF AIR THROUGH A PERFORATED WALL FOR SMALL Re NUMBERS

P. A. Novikov and G. L. Malenko

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The results of an experimental investigation of the mean heat-transfer coefficients on a surface blown by a flow of air leaking in from a perforated plate are presented.

A considerable amount of work has been done on the heat exchange on surfaces blown by turbulent jets [1-6]. During the last few years there has been considerable interest in studying the heat exchange on surfaces blown by laminar flows in a rarefied medium (cooling of microelectronic apparatus, the thermostatic control of certain objects operating under vacuum conditions, etc.).

The purpose of the present paper is to describe an experimental determination of the mean heat-exchange coefficients on a plane surface blown with a broadside rectangular beam of circular air jets, leaking from a perforated plate, and to establish how the intensity of the heat exchange depends on the basic geometrical and operating parameters.

The experimental arrangement employed is shown in Fig. 1. A perforated plate 5 is placed between a cover 3 and the body 10. Using a controllable insert 9, a specified height of the operating channel between the perforated plate and the heat-transfer surface could be chosen ($h = 3$, 8, and 13 mm). The heat-transfer surface consists of five copper plates under which were autonomous electric heaters.

The perforated plate had dimensions of $300 \times 78 \times 1.5$ mm. The diameter of the perforations was 1 mm, and the distance between them was 2 mm, arranged in a line. The ratio of the total area of cross section of the openings to the total surface of the plate was 19%.

The flow of air arriving at each section was measured with a separate rotameter 2 and was controlled by a value 1. The main operating parameters were as follows: the flow of air through one section was $(0.062\text{-}0.31)\cdot 10^{-3}$ kg/sec, the velocity of the jet in the opening was 0.07-0.35 m/sec, Reynolds's number was 3.8-18.9, and the pressure of the medium was $(6.0\text{-}8.0)\cdot 10^{4}$ N/m^2.

When calculating $\bar{\alpha}$ we took as the defining temperature the temperature difference between the copper plate and the flow of air at the entrance to the perforated plate $T_W - T_0$. When determining the Nu and Re numbers we took as the characteristic dimension the diameter of the perforations d. An attempt to use the height h as the characteristic dimension did not give positive results.

Figure 2 shows data on the local heat exchange for $T_W = \text{const}$. It can be seen from the figure that the local values of the heat-exchange coefficient decrease as the effect of the "waste air" increases. For example, for the initial part (plate No. 1), where, as commonly assumed, the flow of waste air is not yet formed, the value of the heat-exchange coefficient is greatest. For the following part (plates Nos. 2-5) the heat-exchange coefficient is somewhat lower. A similar form of change was also observed in [3], despite the fact that the Reynolds's number there was considerably greater: $(332\text{-}3.7)\cdot 10^4$. It can also be seen from the figure that the heat-exchange coefficient for plates No. 2-5 for the same flow of blown gas is practically constant.

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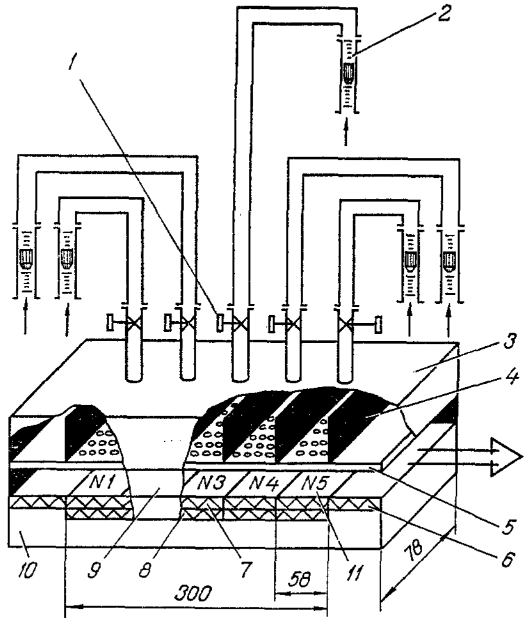

Fig. 1. Sketch of the working part of the experimental equipment: 1) control valve; 2) RS-1G rotameter; 3) cover; 4) partition; 5) perforated plate; 6) guard end heater; 7) main heater; 8) guard heater; 9) control insert; 10) body; 11) heat-transfer plate.

An analysis of all the physical variables describing the cooling of the surface blown by a beam of circular jets shows that in our case the experimental data can be described by an equation of the form

$$\mathrm{Nu} = c\mathrm{Re}^m\mathrm{Pr}^{0.33}\left(\frac{h}{d}\right)^n.$$

Figure 3 shows experimental data on the convective heat exchange plotted in logarithmic coordinates. As can be seen from Fig. 1, as the height of the channel h increases, the heat exchange falls considerably. Thus, the straight line 3 for h = 13 mm is lower than straight lines 1 and 2 for h = 3 mm and h = 8 mm, respectively. In contrast to these results, for a turbulent flow of air the maximum value of the heat-exchange coefficient is obtained for h/d = 8 [7, 8].

The slope of the straight lines to the abscissa axis is 0.55. A value close to our value for the power of the Reynolds's number Re was also obtained for an infinite single jet [9]. According to these data m = 0.5.

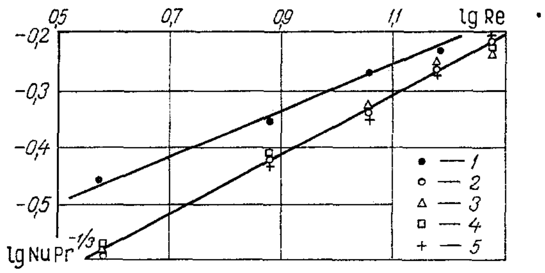

Fig. 2. Effect of a transverse flow of air on the intensity of convective heat exchange in a plane channel: No. 1-5) plates.

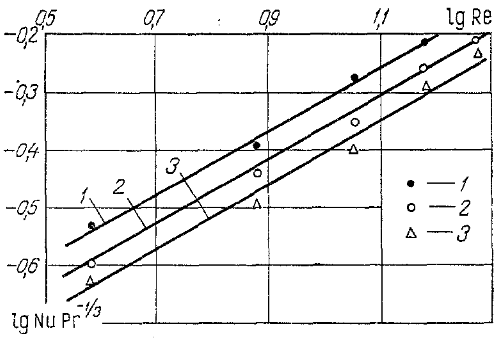

Fig. 3

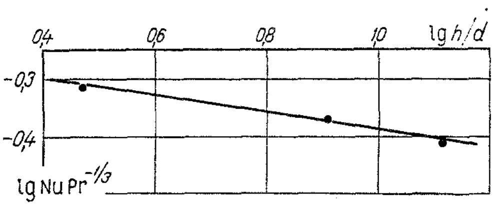

Fig. 4

Fig. 3. Heat transfer on a plane surface for a perpendicular flow of air through the perforated wall: 1) h = 3 mm; 2) 8 mm; 3) 13 mm.

Fig. 4. Effect of the geometrical parameter h/d on the heat transfer for a perpendicular supply of air through the perforated wall.

Figure 4 shows the effect of the geometrical parameter on the intensity of the heat exchange in a channel, from which it can be seen that the index for h/d is a negative number.

By processing the experimental data we obtained the following empirical relationship describing the experimental results with an accuracy of ±14%:

$$\mathrm{Nu} = c\mathrm{Re}^{0.55}\mathrm{Pr}^{0.33}\left(\frac{h}{d}\right)^{-0.15}.$$

In this case the value of the coefficient c was as follows: at the initial part c = 0.163, and for plates Nos. 2-5, c = 0.135.

Hence, an analysis of the experimental data has shown that for perpendicular blowing through perforations and low air flow rates the heat exchange from the plane surface is considerably less than for turbulent flow. When the flow of air is increased, e.g., by a factor of 3 keeping the remaining parameters unchanged, the mean heat-exchange coefficient increases by a factor of ~2. Consequently, by an appropriate choice of the flow of gas this method of cooling can be quite acceptable for cooling certain types of apparatus.

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