CERTAIN HYDRODYNAMIC AND HEAT TRANSFER CHARACTERISTICS OF A STREAM THROUGH A SYSTEM OF PARALLEL CHANNELS WITH SPILLS

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Results are shown of visual observations concerning the distribution of static pressure, of the transverse velocity to longitudinal velocity ratio, of the flow rates, and of the local heat transfer coefficient in a system of channels with spills.

It is well known that injection and suction are effective methods of controlling a boundary layer and thus the rates of transfer processes. Usually such control is effected by special means.

In this study the authors consider the feasibility of appropriately profiling the surface and thus designing the injection and suction pattern for the purpose of improving the heat transfer. When the medium flows through a system of parallel lengthwise wavy channels staggered by half a wave pitch and separated by barriers with perforations, there appear pressure nonuniformities, i.e., an alternating sequence of injections and suctions of the boundary layer at the barriers [1].

Already the first visual observations of the flow pattern as well as measurements of both the static pressure and the velocity distribution have shown that spills occur at any velocity and have an appreciable effect on the stream hydrodynamics [2].

Further studies of the hydrodynamics in a flow with spills were made on an air model in the form of a lengthwise wavy channel (wave pitch 200 mm, wave height 10 mm) with a uniform rectangular cross section (60 × 40 mm) and with a straight axial barrier either solid or perforated (diameter of holes 1.2 mm, longitudinal and transverse spacing 3.24 and 2.81 mm respectively) 1 mm thick. This barrier divided the lengthwise wavy channel into two parallel channels with lengthwise periodically variable cross sections and staggered by half a wave pitch (Fig. 1a).

The curves in Fig. 1b represent the static pressure measured along the upper (I) channel and along the lower channel (II) with either an impermeable barrier (dashed lines) or a permeable barrier (solid lines) at equal flow rates in the system. It can be seen here that the flow of the medium was accompanied by appreciable pressure drops (Fig. 1c). Replacing the solid barrier (curve 1) by the perforated one (curve 2) resulted in a higher energy loss, lower pressure drops, and a shift of the peak pressure drops downstream. All these effects were due to a redistribution of the fluid between channels. The pressure distribution here is already not so closely correlated to the variation in the channel geometry.

To analytically describe the interference between both streams here is a very difficult problem. A simplified approach (see, e.g. [3]) has yielded a differential equation describing the variation of the flow rate along a channel. The derivation of this equation is also based on equal pressure losses on friction in both channels, an assumption which tests have confirmed to be sufficiently accurate (Fig. 1b). A numerical analysis of this equation on a "Mir" computer has revealed that its solutions are unstable, which can evidently be explained by the disregard of presumably small variations of momentum in the stream when mass is subtracted from or added to it. These changes can be taken into account by using the equations of hydrodynamics for variable-mass streams [4]. An application of such a refinement is, however, feasible only with enough information known about the direction of both the main and the tributary streams. Under these conditions, then, the accumulation of data on the flow characteristics becomes very important.

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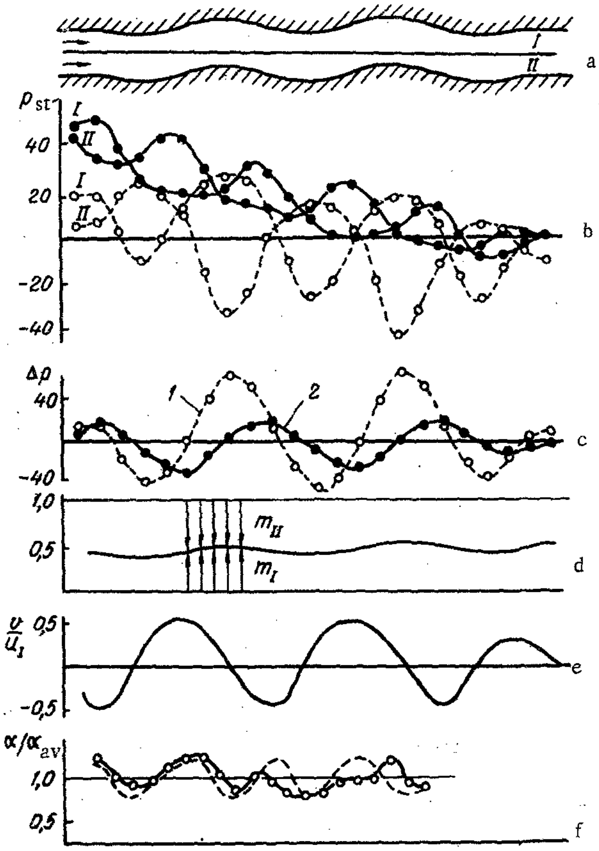

Fig. 1. Results of the study pertaining to the flow in a system of parallel channels with spills: (a) schematic diagram of the test model, (b) distribution of static pressure (mm H_2O) along the upper channel (I) and along the lower channel (II) with a solid barrier (dashed lines) or a perforated barrier (solid lines), (c) distribution of pressure drops (mm H_2O) with a solid barrier (1) or with a perforated barrier (2), (d) variation of the flow rate along the upper channel (m_I) and along the lower channel (m_{II}), (e) distribution of the local spill velocity (v) to the mainstream velocity (u_I) ratio in the upper channel, (e) distribution of heat transfer coefficient test values (solid line).

The method of visualizing the flow process has been described earlier in detail [5]. The pattern near the perforated barrier in the upper channel is shown in Fig. 2. Within the injection zone one notes jets discharging from the perforations and expanding the boundary layer. Within the suction zone, apparently, the boundary layer shrinks as in [6] and the heat transfer improves.

According to our visual observations, replacement of the solid barrier by the perforated one changed the flow pattern in the mainstream into a more complex one: the trajectories of average motion indicated, in a way, an intermediate mode between flow with a solid barrier and flow without a barrier. The trajectories of the spilling fluid formed with the barrier an acute angle gradually varying along the channel.

The magnitude of the effect of injection (suction) on the bulk processes in the sublayer region depended strongly on the ratio of the local spill velocity to the mainstream velocity. Thus, in our case it became necessary to evaluate this ratio.

Local spill velocities can be calculated from the distribution of pressure drops (Fig. 1c, curve 2) by the conventional formula for the discharge velocity. The flow coefficient here is 0.75 (in accordance with [7]).

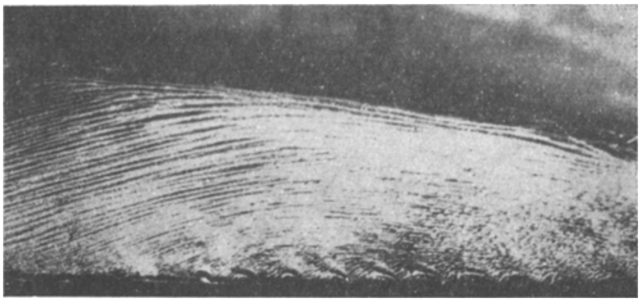

Fig. 2. Visualized flow pattern near the perforated barrier in part of the upper channel.

A graphical integration of the spill velocity profile along the barrier (with its permeability taken into account) yielded the flow rate variations along the upper channel (m_I) and along the lower channel (m_{II}), in fractions of their combined total flow rate (Fig. 1d). Our data were used for plotting the distribution curve of the local spill velocity (v) to mainstream velocity (u_I) ratio in the upper channel along the barrier (Fig. 1e). The transverse velocities were quite appreciable and almost half as high as the longitudinal velocities. Experience has shown that the ratio of these velocities is almost independent of the flow rate through the system and that, therefore, the magnitude of the effect which determines the rate of transfer processes at a permeable surface remains the same regardless of the flow rate — very important in the application of this principle to the design of compact heat exchanger surfaces.

Measurements of local heat transfer coefficients were made using a model with one side of the perforated brass barrier embedded in a steam heated pipe and the entire barrier broken down into a series of short insulated from one another segments. The heat transfer coefficient was determined from the temperature drop measurement across the segments, these segments being treated as thin perforated fins [8]. The resulting values of the heat transfer coefficient represented, of course, only averages between the heat transfer coefficients for the upper and the lower part of the segments.

The test results are shown in Fig. 1f (solid line). The values of the local heat transfer coefficients have been referred to their arithmetic mean. The dashed line corresponds to the distribution of heat transfer coefficients based on the logical assumption that the maximum heat transfer rate should be expected at those points of the barrier where the spill velocity is maximum. The satisfactory qualitative agreement between the curves confirms the correctness of our concepts concerning the mechanism of the heat transfer improvement under these particular conditions.

Experience shows that the mean heat transfer coefficient is almost twice as high at a perforated barrier than at a solid one.

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