The distinct nature of the influence of a solid phase on the heat exchange of concave, convex, and flat walls affords a foundation for assuming that the mechanical and thermal action of the inertial stream of particles on the stream structure in the near-wall zone and the thermal resistance of the viscous sublayer, as well as the increase in the true particle concentration at the wall surface, are of primary value in the intensification of the heat exchange on a concave wall. Hence, an investigation of the influence of the separate factors on the heat-exchange intensification because of the presence of particles and the extension of the test data should be based on a study of the structure of a two-phase gas flow with suspended particles in a curvilinear channel with an estimation of the velocity, temperature, and density of the particles and the gas, the density of the inertial mass flux of the particles incident on the separate sections of the concave wall surface, and the local particle concentration in the near-wall zone.

NOTATION

d, pipe diameter; d_s, particle diameter, G, G_s, mass flow rates of the gas and particles; n, normal to the heat-exchange surface; p, pressure; T, temperature; $(dT/dn)_{n=0}$, normal temperature gradient at the wall on the heat-exchange surface; T_f, T_w, stream and wall temperatures; w, stream velocity; x, distance to the section under consideration; α, local heat-exchange coefficient; $\beta = G_s/G$, coefficient of solid-phase particle discharge concentration; τ, time; λ, coefficient of wall heat conduction; φ, central angle characterizing the channel length; Nu, Nusselt number; Pr, Prandtl number; Re, Reynolds number.

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HEAT TRANSFER DURING THE MOTION OF COLD GASEOUS NITROGEN IN A POROUS TUBE

G. I. Bobrova, L. L. Vasil'ev,
S. K. Vinokurov, and V. A. Morgun

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Heat-transfer processes taking place during the motion of nitrogen in a tube are studied experimentally under conditions in which some of the gas filters through the wall. The effect of suction on the distribution of wall temperature and the intensity of heat transfer is examined.

A number of papers devoted to problems of heat transfer and hydrodynamics during the motion of liquid in channels subject to suction and injection have recently appeared in the literature. These papers have appeared because of the use of porous heat-exchangers in various fields of the chemical and power industries.

During the motion of liquid in a porous tube, suction has a turbulizing effect on laminar flow in the tube, this effect increasing with increasing suction [1-9]; if there is an external flow around the porous walls, suction through the wall laminarizes the external flow.

Heat transfer during the laminar flow of a liquid in a porous tube was analyzed in [1] over a wide range of the filtration rate through the porous wall. It was found that as a result of injection the heat-transfer coefficient at the boundary between the flow and the wall diminished, while as a result of suction it increased, i. e., suction intensified the heat-transfer process. For both suction and injection the section of steady-state

A. V. Lykov Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk.

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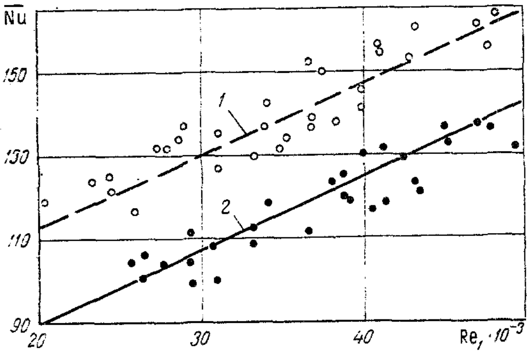

Fig. 1. Dependence of the Nusselt number on the Reynolds number calculated from the average velocity in the tube: 1) Re_{suc} = 27; 2) 16.

heat transfer became so small with increasing Prandtl number that nearly the whole flow was characterized by transient heat transfer.

In an earlier analytical study of turbulent flow [10] it was found that suction increased the heat-transfer coefficient. Thus, for quite a small value of the suction (characterized as the ratio of the suction velocity at the wall to the mean flow velocity), equal to 0.004, the Nusselt number is roughly twice as great as for zero suction.

Generalizing the results of existing investigations, we may conclude that these are insufficient to cover the whole range of problems facing research workers at the present time. In analyzing the hydrodynamics of viscous flow in channels with suction, only two limiting cases have been considered, i. e., large and small values of the suction ratio, remaining constant along the whole length of the channel. This formulation of the problem slightly simplifies the solution, which nevertheless remains quite complicated. In order to simplify the solution, empirical relationships obtained by experimental measurements have sometimes been used.

Unfortunately, existing experimental data regarding heat transfer during the motion of liquid in channels with suction and injection are sparse [11-15].

More experimental data are required to cover a wide range of the fundamental parameters influencing heat transfer and to provide results capable of being generalized in the form of an empirical relationship.

This paper is devoted to an experimental study of the influence of suction on heat transfer during the motion of gaseous nitrogen in a porous tube. The investigation was carried out in the apparatus described in detail in [16]. The apparatus comprises a cryostat containing the experimental tube. The working chamber of the cryostat is 5 m long and 40 mm in diameter. A temperature of 80-100°K may be maintained in the working chamber.

The tube under consideration is placed in the center of the working chamber; its internal diameter is 8 mm, external diameter 20 mm, and length 5 m. The initial section of the tube, 1.2 m long, serves for the thermal and hydrodynamic stabilization of the flow, the working section is 1.8 m long. The tube walls are permeable

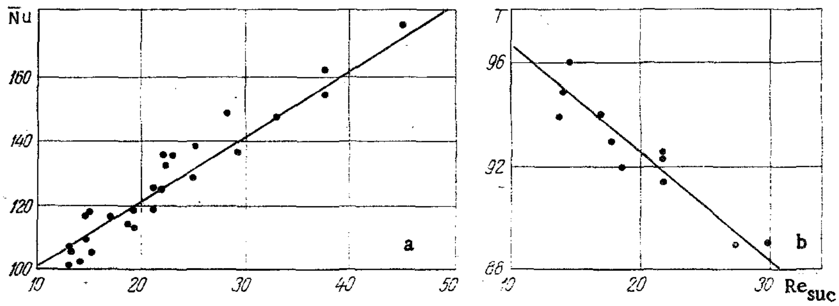

Fig. 2. Dependence of the Nusselt number (a) and the average tube wall temperature (b) on the suction Reynolds number: Re_1 = 45,000; q = 65.7 W/m^2.

to nitrogen, being made of several layers of glass cloth. Nitrogen under a slight excess pressure is fed into the experimental tube and during its motion partly filters into the working chamber under the influence of the pressure drop created between the experimental tube and the working chamber. This pressure drop may be regulated so as to vary the degree of suction. A heater is provided on the surface of the porous tube. The surface and flow temperatures are measured with copper—Constantan thermocouples and the rate of flow, with gas counters. The experiments covered ordinary Reynolds numbers of $(2.5\text{-}4) \cdot 10^4$ and suction Reynolds numbers of 0-50.

The efficiency of the apparatus and the reliability of the results were verified by comparing the experimental data relating to heat transfer in the tube for zero suction with values calculated from the Mikheev equation [17] for the average heat-transfer coefficient during the turbulent flow of liquids in straight, smooth tubes. The experiments carried out in the presence of suction showed that the latter intensified the heat-transfer process, as indicated in the literature. We shall not describe the method of determining the density of the thermal flux in this paper, since this has been set out in full detail in [16].

Figure 1 shows the dependence of the Nusselt number on the Reynolds number calculated from the average velocity of the axial flow inside the tube. The error in determining the Nusselt number is 20%. For a constant Reynolds number the Nusselt number increases with increasing suction, although the character of the change remains as before.

Figure 2a shows the dependence of the Nusselt number on the suction Reynolds number. We see that suction has a considerable influence on the heat-transfer process. Thus on increasing the suction Reynolds number from 10 to 50 the Nusselt number almost doubles.

In a number of devices involving heat transfer of this kind it is important to know how suction influences the temperature distribution along the porous channel. Figure 2b shows the average temperature of the inner surface of the tube as a function of the suction Reynolds number. On increasing Re_{suc} from 10 to 25 the wall temperature falls by 6°K.

The resultant experimental data may be generalized by an empirical relationship of the following form:

$$\overline{Nu} = 0.021 \cdot Re^{0.8} Pr^{0.4} \left(1 + 0.121 \cdot 10^4 \frac{Re_{suc}}{Re_1}\right)^{0.8}.$$

In the absence of suction this relationship agrees with that of Mikheev for heat transfer in impermeable tubes.

NOTATION

Re, Reynolds number; Re_{suc}, suction Reynolds number; Pr, Prandtl number; V_1, volumetric rate of flow in the tube, m^3/h; V_2, volumetric rate of flow of the gas filtering through the tube wall into the annular peripheral channel, m^3/h; $\overline{T}$, average tube wall temperature, °K.

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