As an example, Fig. 4 presents the experimental [3] and theoretical [by formula (22)] dependences of w_m on L_x for water and acetone for three oxidized specimens of MFS. On the basis of the above, it was assumed in the calculations that $\cos \Theta = \cos 60° = 0.5$. There is satisfactory agreement between the experimental data and the calculation.

NOTATION

Π, porosity of the structure; Π_{lm}, limit porosity; d_B, fiber diameter; l_B, length; $d_{\Pi t}$, size of the contact spot; K_{KC}, coefficient of liquid permeability of the capillary structure; p_K, capillary pressure; Δp_l, viscous pressure losses in the liquid; w, filtration rate; w_m, mean axial speed of the liquid; L_x, distance from the beginning of absorption; τ, time from the beginning of absorption; φ, angle between the longitudinal axis of the specimen and the horizontal plane; Θ, boundary wetting angle; σ, capillary constant of the liquid; μ, dynamic coefficient of viscosity of the liquid; c, c_1, c_2, c', proportionality coefficients.

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HEAT EXCHANGE IN GAS FLOW THROUGH ROUGH PIPES WITH SURFACE SUCTION

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UDC 536.242

The article presents the results of determining the Nusselt numbers upon flow of nitrogen and helium through cermet pipes. The effect of roughness and of the suction of part of the flow on the Nusselt numbers is shown.

Turbulent flow through rough pipes with suction on the wall has not yet been sufficiently studied either theoretically or practically. There exist some works investigating heat exchange upon turbulent flow through a smooth pipe with surface suction [1, 2] but there are no data on heat exchange in rough pipes with suction.

The theoretical analysis of heat exchange upon turbulent gas flow in permeable channels is based on the idealized model of turbulence which does not quite correctly describe the real process, and it is difficult to use the results of the analysis in practice because they are very complicated. We therefore made an attempt

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Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 41, No. 1, pp. 13-16, July, 1981. Original article submitted June 25, 1980.

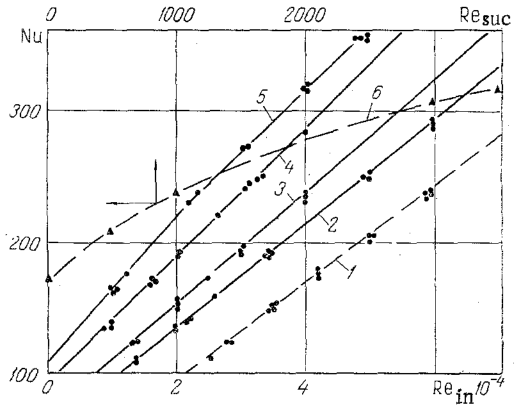

Fig. 1. Dependence of the Nusselt number on the Reynolds number at the inlet and on the Reynolds number for suction: 1) $Re_{suc} = 0$; 2) 500; 3) 1000; 4) 2500; 5) $Re_{suc} = 4 \cdot 10^3$; 6) $Re_{in} = 4 \cdot 10^4$.

to generalize the accumulated experimental data and to suggest a criterial dependence describing heat exchange upon turbulent gas flow in a rough cermet pipe with surface suction on the wall.

Bobrova et al. [3] and Vasil'ev et al. [4] present the results of investigations of heat exchange in pipes with surface suction when nitrogen or helium flows through them. In [3], a criterial dependence of the Nusselt number on the Prandtl numbers, Reynolds suction and the Reynolds numbers at the inlet in the range $Re_{suc} = 0\text{-}50$, $Re_{in} = (2.5\text{-}4) \cdot 10^4$ is given.

Vasil'ev et al. [4] studied the effect of surface suction on heat exchange, when cool gaseous helium flowed through a heated cermet pipe, for the range $Re_{in} = (1.6\text{-}4.5) \cdot 10^4$ and $Re_{suc} = (2\text{-}3) \cdot 10^3$.

In this work the authors also studied the range of Reynolds suction numbers $(0\text{-}4) \cdot 10^3$ which may apply to permeable rough pipes of limited length.

The experimental setup was described in detail in [4]; it is an ordinary horizontal cryostat. The length of the working space is 3 m, the diameter is 40 mm. Vacuum insulation with a pressure of the residual gases of the order of $1.33 \cdot 10^{-3}$ N/m^2 was used. The sintered pipes were mounted along the axis of the working space with the aid of teflon rings. After having passed through the section of hydrodynamic stabilization, the gas flow entered the porous pipe, and on account of the pressure gradient in the axial and the peripheral channel, it was partly filtered off through the wall.

The temperatures were measured with thermocouples of copper–copper alloyed with iron. Their sensitivity in the range 10-15°K was 15 μV/deg, and the dependence of the thermo-emf on the temperature in this range is not linear. The thermocouple readings were stable in time, they did not change on account of repeated heating and cooling. We measured the temperature of the flow moving inside the pipe and washing it on the outside, the walls were measured at four points along the circumference and at five cross sections longitudinally. In evaluating the heat exchange coefficient, we took as the rated wall temperature its mean value over the cross section. To measure the temperature of the stream flowing through the pipe, the thermocouple bead was mounted on the axis in those cross sections where the wall temperature was measured. The position of the bead was determined according to the size of the electrodes, each of which was led out through holes diametrically situated in the wall; these holes were then thoroughly caulked, i.e., the thermoelectrodes of the thermocouple were extended over the diameter. Their readings were used in evaluating the temperature difference between the wall and the stream, and also for determining the expenditure, speeds, and physical parameters of the gas. To measure the temperature of the stream washing the porous pipe from outside, i.e., in the peripheral channel, the thermocouples were placed in syringes which were then carefully caulked into the pipe wall. The length of the syringe above the outer surface was equal to half the thickness of the ring, i.e., the bead of the thermocouple was situated in the axis of the stream flowing through the peripheral channel. At these temperatures the physical parameters of the gas and the flow velocity were determined.

The porous pipes used in the experiment were made from bronze powder with a particle size of 0.25-0.315 mm by sintering. The porosity of the pipe wall was 40%, the coefficient of permeability was $7 \cdot 10^8$ cm^2, maximum pore size was 190 μm, mean pore size 60 μm. The pipe dimensions were the following: length 600 mm, inner diameter 12 mm, outer diameter 17 mm. The inlet section of the pipe with the ratio $l/d = 300$ had the same inner diameter. Relative roughness was 0.012.

A series of experiments was carried out to determine heat exchange without suction, i.e., in rough pipes for the same range of Re_{in} numbers. Curve 1 in Fig. 1 represents the dependence of the Nusselt numbers on the Reynolds number for a rough pipe. The height of the roughness hillock δ was determined in this case as the averaged fraction radius. It is known from the literature that in rough pipes heat exchange occurs more intensively and that the Nusselt numbers in them may be larger than in smooth pipes with the same $\mathrm{Re_{in}}$ numbers.

In investigations of heat exchange in cermet pipes for the range $\mathrm{Re_{in}} = (1\text{-}6)\cdot 10^4$ it was found that Nu is almost twice as large as in smooth pipes, i.e., it is approximately the same as in pipes whose roughness is due to machining.

The nature of the roughness in sintered pipes is utterly different, and the distance between hillocks is approximately equal to the mean particle diameter. The obtained experimental results are described by the following dependence:

$$\mathrm{Nu} = 0{,}041\mathrm{Re_{in}^{0{,}8}}\mathrm{Pr}^{0{,}43}. \tag{1}$$

Heat exchange upon flow in pipes with suction is characterized by a change of the heat exchange coefficient along the pipe in consequence of the change in speed along the pipe. We therefore preliminarily determined the maximally permissible proportions of the flow that may be filtered off through the pipe wall so that the local Nu values over the investigated length do not differ by more than 10-15%. In processing the experimental results it was assumed that the filtration rate is constant along the pipe.

Experiments carried out with suction for the entire range of $\mathrm{Re_{in}}$ showed that suction intensifies the process of heat exchange. Figure 1 shows the dependence of the Nusselt number on $\mathrm{Re_{in}}$ and on different values of $\mathrm{Re_{suc}}$.

The range of the investigated values of $\mathrm{Re_{suc}}$ determines the conditions corresponding to stable gas flow without recurrent streams. It can be seen from Fig. 1 that with increasing gas velocity, i.e., with increasing $\mathrm{Re_{in}}$, the heat exchange becomes more intense and Nu increases. With increasing suction with the same $\mathrm{Re_{in}}$ numbers, the Nusselt numbers increase, and a change in suction exerts a considerable influence on Nu. Figure 1 shows the dependence of Nu on $\mathrm{Re_{suc}}$ with constant $\mathrm{Re_{in}} = 4\cdot 10^4$. The magnitude of the suction through the pipe wall was varied within the range $\mathrm{Re_{suc}} = 0\text{-}4\cdot 10^3$. The depicted dependence in the investigated range is not linear.

All the experimental data obtained by us in rough pipes with suction are described by a dependence of the following kind:

$$\mathrm{Nu} = 0{,}041\mathrm{Re_{in}^{0{,}8}}\mathrm{Pr}^{0{,}43}[1 + 0{,}06\,(\mathrm{Re_{suc}}/\mathrm{Re_{in}})^{0{,}57}]. \tag{2}$$

When suction is zero, this dependence is transformed into formula (1).

NOTATION

$\mathrm{Re_{in}}$, Reynolds number calculated by flow velocity at the inlet cross section of the pipe and the physical parameters for the temperature of the stream in the same section; $\mathrm{Re_{suc}}$, Reynolds number for suction calculated by the flow velocity in the peripheral channel; the thickness of the ring was taken as the characteristic dimension and the physical parameters were taken for the temperature of the stream at the section in the middle (lengthwise) of the pipe; Nu, Nusselt number corresponding to the heat exchange at the interface between the stream and the inner wall of the cermet pipe and calculated by the physical parameters for the temperature of the stream in the middle (lengthwise) of the pipe.

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