# SOME PECULIARITIES OF HEAT EXCHANGE IN POROUS MEDIA

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Results are presented of investigations of the heat-exchange intensity in a porous material as a function of the coolant properties.

In order to compute the heat exchange between a porous wall and the coolant within the pores it is necessary to know the magnitude of the heat-exchange coefficients within the pores and their dependence on the conditions for progress of the process.

There is a number of papers [1-5, etc.] in the literature in which heat-exchange processes between a porous material and air blown through it are investigated. Meanwhile, other coolants with Prandtl numbers different from one are also used in cooling systems. There are no papers on an experimental investigation of the regularities of internal heat exchange in porous metals cooled by liquids with Prandtl numbers different from one in the literature.

On the basis of an analysis of the solution of the differential equation for the temperature state of a porous wall and coolant, it is shown in [5] that other conditions being equal the heat-exchange intensity should be determined by the Peclet number. No experimental verification of this conclusion has been made.

The task in the present paper is the experimental investigation of the influence of the thermophysical properties of the coolant on the heat-exchange intensity in a porous metal.

After some simple manipulations, and the introduction of the heat-exchange coefficient referred to the volume of porous material instead of the heat-exchange coefficient referred to the surface of the pore space, the differential equation of the temperature state of the coolant in a porous wall [5] can be written thus:

$$\frac{d^3\theta_t}{d\nu^3} + \mathrm{St}_V \frac{d^2\theta_t}{d\nu^2} - \mathrm{Bi}_V \frac{d\theta_t}{d\nu} = 0. \tag{1}$$

Solving (1) and taking into account that the wall temperature is determined by the expression

$$\theta_T = \theta_t + \frac{1}{\mathrm{St}_V} \cdot \frac{d\theta_t}{d\nu}, \tag{2}$$

we have for the temperature head

$$\theta_T - \theta_t = \left(\frac{1}{2}\sqrt{\mathrm{Bi}_V + \left(\frac{\mathrm{St}_V}{2}\right)^2} - \frac{1}{2}\right) C_2 \exp\left[\left(\sqrt{\mathrm{Bi}_V + \left(\frac{\mathrm{St}_V}{2}\right)^2} - \frac{\mathrm{St}_V}{2}\right)\nu\right] - \left(\frac{1}{2}\sqrt{\mathrm{Bi}_V + \left(\frac{\mathrm{St}_V}{2}\right)^2} + \frac{1}{2}\right) C_3 \exp\left[-\left(\sqrt{\mathrm{Bi}_V + \left(\frac{\mathrm{St}_V}{2}\right)^2} + \frac{\mathrm{St}_V}{2}\right)\nu\right]. \tag{3}$$

It follows from (3) that the mean logarithmic value of the temperature head can be used in calculating the heat-exchange coefficient within the pores. Since $(\mathrm{St}_V/2)^2 \gg \mathrm{Bi}_V$ for the heat exchange in porous metals, the influence of $\mathrm{Bi}_V$ on the regularity of the heat exchange can be neglected.

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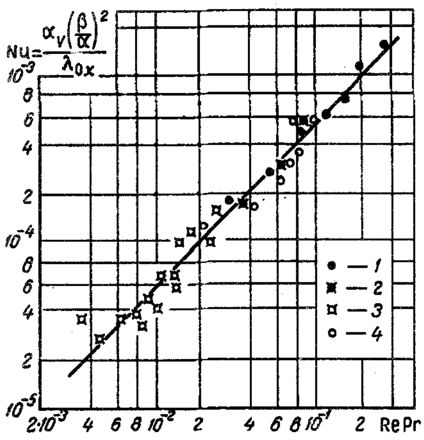


Fig. 1. Dependence of Nusselt number on Peclet number during cooling by liquids with different Prandtl numbers: 1) air; 2) nitrogen; 3) liquid ethyl alcohol; 5) liquid transformer oil.

On the basis of (1) and (2) the critical value of the heat exchange is written as

$$\mathrm{Nu}_V = f\left(\mathrm{Pe};\ \theta_T;\ \frac{h}{L}\right). \tag{4}$$

Experiments were conducted on a sample at low plate heating temperatures. This permits not taking account of the influence of both structural factors and the temperature factor and writing (4) for the case presented as

$$\mathrm{Nu}_V = f(\mathrm{Pe}). \tag{5}$$

The plate on which the investigations were conducted was fabricated by rolling and subsequent sintering from stainless steel powder with a 65 $\mu$ mean size of the initial particles. The plate thickness is 1.3 mm and the porosity is 0.3. The plate was heated by high-frequency currents induced therein from a spiral inductor.

The plate temperature at the coolant entrance and exit was measured by copper–Constantan thermocouples with 0.05 mm diameter of the thermal electrodes soldered to the surface by contact welding; the coolant temperature was measured by the same thermocouples. A perforated copper disk was mounted ahead of the plate to average the stream temperature, which was measured and taken equal to the mean mass temperature of the stream. An air thermocouple of special construction was used after the plate. The thermal electromotive force of the thermocouples was measured by a compensation method by using a PPTV-1 potentiometer and M-195/2 zero-instrument by means of a circuit with one cold layer.

The error in measuring the surface temperature, estimated by the method for pivot thermocouples [6], did not exceed 1.5% of the difference between the surface and coolant temperatures. Calibration of the thermocouples for uniformity to 100°C gave a spread of up to ±0.3% in the thermal electromotive force.

The gas flow rate for cooling the plate was determined by using a double diaphragm. The error in determining the mass-flow rate did not exceed 1.5%. The mass-flow rate for the liquid coolant was determined by a volume method to a ±0.5% error.

The pressure drop on the sample or the pressure ahead of the sample was measured by MO type calibration manometers, differential manometers, and piezometers. The values of the physical constants during processing the experimental data were determined for arithmetical mean values of the pressure and temperature in the plate.

Heat-exchange regularities were investigated for cooling the plate by air, nitrogen, liquid ethyl alcohol, and transformer oil. This afforded the possibility of encompassing the range $0.7 \le \mathrm{Pr} \le 140$.

The problem of investigating the influence of the structural characteristics on the heat-exchange regularity within the pores was not posed herein, hence, the selection of the characteristic dimension of the pore space is of no value. In this case, the ratio between the initial hydraulic drag coefficient of the porous plate and the viscosity coefficient was taken as the characteristic dimension [7].

Results of the experiments are presented in Fig. 1 on a coordinate system with a logarithmic scale (values of the Peclet number are plotted along the horizontal, and of the Nusselt number along the vertical axis). The range of variation of the Peclet number is from $3 \cdot 10^{-3}$ to $3 \cdot 10^{-1}$. The mean-square deviation of the experimental points from the curve obtained by using least squares is ±23%.

The experiments carried out confirm that the influence of the thermophysical properties of the coolant on the heat-exchange intensity within pores can be estimated by using the Prandtl number, which should be inserted in the critical heat-exchange equation to the same power as the Reynolds number.

NOTATION

L is the characteristic dimension;
h is the plate thickness;

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|---|---|
| $\nu = k/L$ | is the dimensionless coordinate; |
| $\theta_T$, $\theta_t$ | are the dimensionless plate and coolant temperatures; |
| $Bi_V$, Pr, Re, $Nu_V$, Pe, $St_V$ | are the Biot, Prandtl, Reynolds, Nusselt, Peclet, and Stanton numbers (the Biot, Nusselt, and Stanton numbers are determined by means of the heat-exchange coefficient referred to the volume of porous material). |

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