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EXPERIMENTAL STUDY OF HEAT TRANSFER IN THE FLOW OF ANOMALOUSLY VISCOUS LIQUIDS IN CIRCULAR AND ELLIPTICAL PIPES

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Results are presented of an experimental study of heat transfer in the laminar flow of anomalously viscous liquids in circular and elliptical pipes.

The study of heat transfer in the flow of anomalously viscous liquids in pipes having cross sections of various shapes is of great theoretical and practical interest for a number of branches of industry. Unfortunately, most of the work on this problem has been devoted to a study of heat transfer in the flow of anomalously viscous liquids in circular and plane-parallel channels and pipes.

The purpose of the present work is to determine experimentally the laws of heat transfer in the laminar flow of anomalously viscous liquids in circular and elliptical pipes. The studies were performed on an experimental arrangement shown schematically in Fig. 1. The working liquid was drawn from the preliminary temperature control tank 1 by the pump 2 through a closed circuit consisting of the pressurized tank 3 with an overflow device, the buffer tank 4, the heat-transfer and damping chambers 5 and 6, the working element 7, and the mixing chamber 11. The flow rate of the liquid was controlled by adjusting the pump speed and the valve 12. The pipe wall of the working portion 7 was kept at a constant temperature by sectional cascade electric heaters. The wall temperature was measured with a set of Chromel—Copel thermocouples 8 made of 0.2 mm diameter wire, and the potentiometer 10. The removable working portions of the arrangement were made of copper and brass pipes 1500 mm long with inner surface roughness corresponding to the 8th class of surface finish. The circular pipes had diameters of 13.6 and 19.8 mm and the semiaxes of the elliptical pipes were 6.3 × 2.4 and 3 × 1 mm. The experiments were performed under steady thermal and hydrodynamic conditions.

Preliminary work with the experimental setup was performed with transformer oil. The working liquids were 5 and 7.5% aqueous solutions of sodium carboxymethylcellulose (CMC) and 3 and 8% aqueous solutions of polyvinyl alcohol (PVA). The rheological characteristics of the solutions were determined on a Rheotest rotary viscometer. The results of the viscometric measurements in the 20 to 80°C temperature range are shown in Fig. 2. In the range of shear rates investigated the rheological behavior of the solutions is well described by the equation [1, 2]

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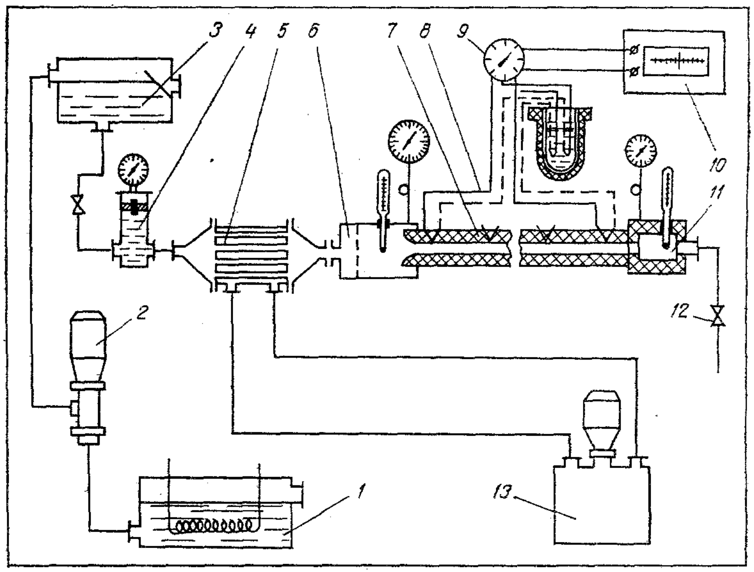

Fig. 1. Schematic diagram of experimental arrangement: 1) preliminary temperature control tank; 2) pump; 3) pressurized tank; 4) buffer tank; 5) heat exchanger of final thermostatic control; 6) damping chamber; 7) removable working section; 8) set of thermocouples; 9) switch; 10) potentiometer; 11) mixing chamber; 12) control valve; 13) thermostat.

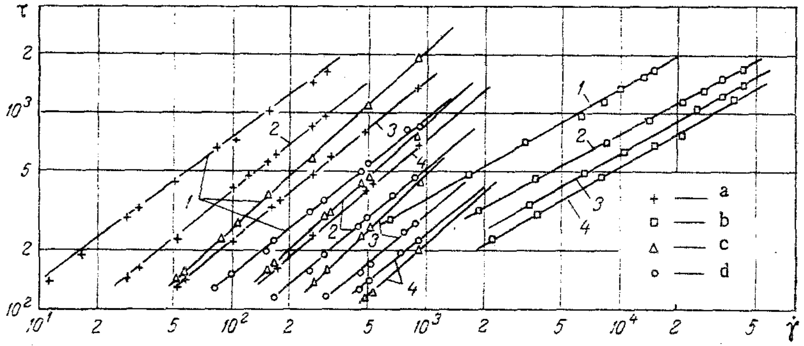

Fig. 2. Results of viscometric measurements: a) 7.5% aqueous solution of Na-CMC; b) 3% aqueous solution of PVA; c) 8% aqueous solution of PVA; d) 5% aqueous solution of Na-CMC; 1) 20°C; 2) 40; 3) 60; 4) 80°C.

$$\frac{\mu_0}{\mu} = 1 + c\tau^n, \qquad (1)$$

where the constant n depends on the concentration and the constant c, on the concentration and the temperature.

The thermophysical characteristics of the solutions were determined by well-known methods [3, 4]. The results of the thermophysical measurements are listed in Table 1. The experimental values of the average heat-transfer coefficients were found in terms of the logarithmic mean thermal head

$$\bar{\alpha} = \frac{Q}{F\Delta\bar{t}_{\log}}. \qquad (2)$$

The temperature of the pipe wall was calculated as the lengthwise weighted mean

$$\bar{t}_{\mathrm{w}} = \frac{\sum_{i=1}^{k} l_i (t_i + t_{i+1})}{2\sum_{i=1}^{k} l_i}. \qquad (3)$$

TABLE 1. Thermophysical Characteristics of Solutions of Polymers

Aqueous solution	ρ, kg/m^3	$c_p \cdot 10^3$, J/kg·deg	λ, W/m·deg
Na–CMC, 5%	1054	3,45	0,523
Na–CMC, 7,5%	1070	3,19	0,453
PVA, 3%	1005	3,72	0,511
PVA, 8%	1014	3,5	0,500

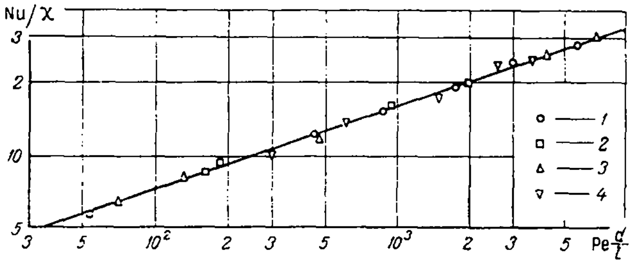

Fig. 3. Comparison of experimental heat-transfer data in circular pipes with Eq. (4). 1) 8% PVA; 2) 3% PVA; 3) 5% CMC; 4) 7.5% CMC.

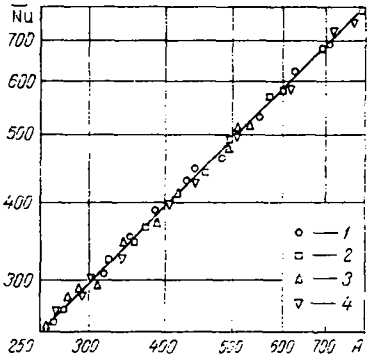

Fig. 4. Correlation graph of $\overline{\mathrm{Nu}} = f$ Pe)$(l/d_e)(\mu_L/\mu_w)$] for laminar flow in elliptical pipes. $A = 4.62\,(\mu_L/\mu_w)^{0.31} \cdot [(1/\mathrm{Pe})(l/d_e)]^{-0.5}$. The notation is the same as in Fig. 3.

Figure 3 shows the results of the experimental study for circular pipes. It is clear from the figure that the experimental data are satisfactorily described by the familiar [5] dimensionless equation for a "power" liquid:

$$\overline{\mathrm{Nu}} = 1.55\,\chi\left(\mathrm{Pe}\cdot\frac{d}{l}\right)^{\frac{1}{3}},$$

$$\chi = \left(\mathrm{Pe}\cdot\frac{d}{l}\right)^{m-\frac{1}{3}}\left(\frac{\nu_{\mathrm{av}}}{\nu_{\mathrm{w}}}\right)^{0.14},\quad m = 0.466 - \frac{0.138}{1+0.07\,\frac{1}{n}}. \tag{4}$$

The experimental points fall nearly on a straight line, showing the validity of Eq. (4) in the range of parameters investigated.

Figure 4 shows the results of an experimental study for elliptical pipes. The experimental data are well described by the dimensionless equation

$$\overline{\mathrm{Nu}} = 4.62\left(\frac{1}{\mathrm{Pe}}\cdot\frac{l}{d_e}\right)^{-0.5}\left(\frac{\mu_L}{\mu_w}\right)^{0.31}. \tag{5}$$

In processing the experimental data the mean temperature of the liquid $\bar{t}_L$ was taken as the controlling temperature and all the parameters of Eq. (5) were referred to this temperature.

The maximum deviation of the experimental values of the Nusselt number from those calculated with Eq. (5) is ± 12%. Equation (5) was derived for the following ranges of parameters:

$$\left(\frac{1}{\mathrm{Pe}} \cdot \frac{l}{d_e}\right) = 6.6 \cdot 10^{-5} - 11.4 \cdot 10^{-4}; \ \left(\frac{\mu_L}{\mu_w}\right) = 1.45 - 10.32.$$

NOTATION

μ_0, largest Newtonian viscosity; μ, effective viscosity; τ, shear stress; $\bar{\gamma}$, rate of shear; c, n, constants in rheological equation; Q, amount of heat; F, area of inner surface of pipe; $\Delta \bar{t}_{\log}$, logarithmic mean thermal head; t_0, t_{out}, temperatures of liquid at pipe inlet and outlet; k, number of thermocouples; l_i, distance between positions of thermocouples; t_i, t_{i+f}, thermocouple readings; Pe, Peclet number; $\overline{\mathrm{Nu}}$, average value of Nusselt number; d_e, l, equivalent diameter and length of pipe. Indices: w, parameter of liquid at temperature of pipe wall; L, parameter of liquid at mean temperature of liquid.

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INVESTIGATION OF THE STRUCTURE OF THE FLOW OF SOLUTIONS OF A POLYMER IN A RECTANGULAR CHANNEL BY MEANS OF A LASER ANEMOMETER

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We describe the results of the experimental investigations of the flow structure on the initial segment when weak solutions of a polymer flow in a rectangular channel.

As is known, the existing methods and instruments for measuring the characteristics of the structure of the flow of a liquid (Pitot—Prandtl tubes, discrete methods, thermoanemometers, etc.) cause a distortion of the characteristics and introduce substantial unjustified errors, especially for solutions of polymer materials [6].

One of the new and promising devices that can be used for investigating the velocity structure of polymer solution flows is the laser Doppler anemometer (LDA). Fewer than 10 studies have thus far been published on the investigation of dilute polymer solution flow using LDAs [1-5, 7, 8].

We attempted to investigate experimentally the velocity structure of the flow of solutions of polyacrylamide (PAA) in the initial segment of a rectangular channel by using a laser Doppler anemometer. A block diagram of the experimental apparatus is shown in Fig. 1.

The LDA, a part of the measuring section, was set up according to the scheme with a supporting beam [3] and consisted of a single-mode laser of the LG-38 type and a transmitting unit, which included a laser beam divider, mirrors, and a focusing lens. The receiver unit included a set of diaphragms, a receiving objective,

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