$$\left(\frac{1}{\mathrm{Pe}}\cdot\frac{l}{d_e}\right)=6.6\cdot10^{-5}-11.4\cdot10^{-4};\ \left(\frac{\mu_L}{\mu_w}\right)=1.45-10.32.$$

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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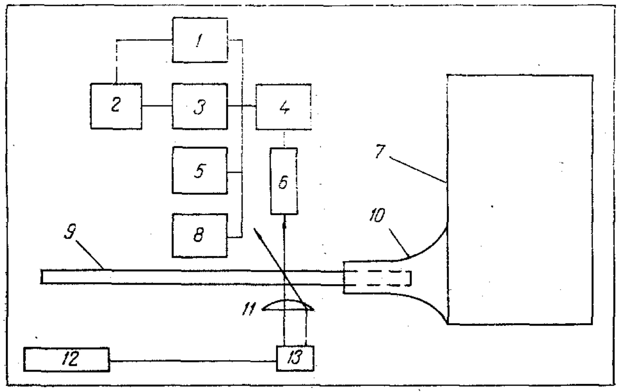

Fig. 1. Block diagram of the experimental apparatus: 1) S5-2 harmonic analyzer; 2) Ch3-24 frequency meter; 3) S5-3 harmonic analyzer; 4) UZ-7A amplifier; 5) S4-8 spectrum analyzer; 6) photoreceiver unit; 7) constant-pressure tank; 8) S4-12 spectrum analyzer; 9) rectangular channel; 10) nozzle; 11) lens; 12) laser LG-38; 13) beam divider.

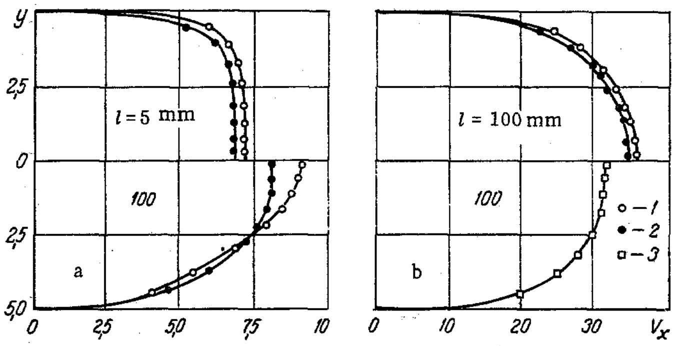

Fig. 2. Velocity profiles for the flow of PAA solutions in a rectangular channel: 1) PAA concentration 0.2%; 2) 0.05; 3) 0.005; y, mm; V_x, cm/sec.

and FEU-79 photomultiplier. The recording apparatus included a UZ-7A broad-band amplifier, S4-8 and S4-12 frequency spectrum analyzers, and S5-2 and S5-3 harmonic analyzers. In order to improve the readout accuracy, the frequency of the harmonic-analyzer heterodynes was monitored with a Ch3-24 electronic-count frequency meter. The hydrodynamic test stand consisted of a horizontal rectangular channel with a cross section with a = 100 mm and b = 10 mm, a transition nozzle, and a constant-pressure tank. In order to maintain a rectangular velocity profile at the inlet to the channel, the channel itself was placed inside the nozzle (Fig. 1).

In the study we determined the longitudinal average velocities of flow V_x from the following measured quantities:

$$V_x = \frac{\lambda f}{\sin \Theta},$$

where λ is the wavelength of the laser radiation ($\lambda = 0.63 \cdot 10^{-6}$ m for the laser we used); f is the Doppler frequency (measured with a spectral apparatus); Θ is the angle of intersection of the laser beams (in our case 13°24').

The velocity measurements were made at distances of 2, 5, 10, 20, 50, and 100 mm from the flow inlet to the channel. The velocity diagram at each cross section was constructed on the basis of 16 experimental points (spaced 0.67 mm apart). The error in the velocity measurement did not exceed 2%.

In order to conduct the investigations, we prepared aqueous solutions of PAA. By a prescribed method for the dilution of a highly concentrated solution, we obtained uniform solutions containing 0.005, 0.05, and 0.2% PAA by weight. After the polymer was added, the flowing liquid remained transparent. It should be noted that when lengthy experiments are carried out according to the closed scheme, the possibility of partial destruction in the polymer solution cannot be excluded. The distribution of flow velocities on the initial segment of the rectangular channel was determined both for laminar and for turbulent flow. The Reynolds numbers were found on the basis of equivalent diameters, and the average velocity on the basis of the volumetric flow rate.

Figure 2a shows the results obtained at cross sections 5 mm and 100 mm from the inlet to the channel for laminar flow ($Re_d = 1100$) for various PAA concentrations. The ordinate axis shows the distance from the walls of the channel, and the abscissa axis shows the longitudinal average velocity of the flow. For comparison, we show in Fig. 2b the velocity distribution for turbulent flow ($Re_d = 5400$) at a distance of 100 mm from the inlet to the channel for various PAA concentrations.

It can be seen from Fig. 2 that on the initial segment a velocity profile is formed. The velocity distribution depends substantially both on the cross section selected and on the regime of flow of the polymer solution. The added polymer substantially affects the kinematic characteristics of the flow. As the solution becomes more concentrated, the velocity field is deformed. In the case of laminar flow the velocity diagram becomes elongated along the stream and becomes less full. Analyzing the nature of the deformation of the velocity field, we can assume that the velocity diagram for water with polymer additives on the initial segment of a rectangular channel resembles the velocity diagram on the uniform-flow segment, i.e., the initial or accelerated segment is reduced.

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TRANSIENT AND STEADY-STATE RHEOLOGICAL BEHAVIOR IN STRUCTURED HYDROCARBON SYSTEMS

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Crude paraffin-rich petroleum has been used to examine the structural changes in non-Newtonian hydrocarbon systems in steady-state and transient modes of flow, which include various relaxation processes.

The rheological behavior of crude petroleum is of some considerable interest [1-5], particularly since oil rich in paraffin hydrocarbons constitutes an increasing proportion of oil output, which gives considerable interest to the structural changes occurring under strain. Crude oil of this type constitutes a structured two-phase system with coagulation features, so one needs to know the laws governing the thixotropic behavior of the structure under shear.

The various phenomena involved in the disruption of the structure and the recovery have not been examined in detail, especially for alkane-rich petroleum in transient states of deformation and also at low shear rates (around 10^{-3} sec^{-1}), where the structural changes are the most pronounced.

Here we present results on the rheological features of two types of oil from the Mangyshlak deposit differing in alkane levels, and the data provide some additional information on these points.

We used a Weissenberg rheogoniometer of cone–plane type of diameter 5 cm and cone angle 2° in the working part. The results were processed in the normal way for this method [6]; the measurements were made at 20°C.

The structural changes may be deduced from three types of data: flow curves, stress-variation curves during strain, and stress relaxation after strain. We were able to relate the data from such curves to features of the structure.

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