INFLUENCE OF POLYMER ADMIXTURES ON THE ORIGIN OF VORTICES IN THE WAKE BEHIND SLENDER CYLINDERS

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Results are presented of an experimental investigation of the influence of polyoxyethylene and Guar gum admixtures on the magnitude of the Reynolds number corresponding to the origin of vortices in the wake behind transversely streamline slender cylinders of different diameters.

The effect of polymer admixtures reducing the friction drag on the vortex street in the wake behind a cylinder has been studied in [1-3]. Substantial distinctions between the motion of the polymer solution and Newtonian fluid flow have been noted. It was reported in [1] that vortex detachment in the flow of a dilute aqueous solution of polyoxyethylene around a slender cylinder occurs at a higher frequency than in a pure water flow. Displacement of the point of boundary-layer detachment on a cylinder during the flow of carboxymethyl cellulose solutions was noted in [2]. The vortex street in the flow of aqueous polyoxyethylene and Guar gum solutions around slender cylinders of different diameters was studied in [3]. It has been shown that in contrast to Newtonian fluid flow for which a unique relation between the Strouhal number (the dimensionless vortex frequency) and the Reynolds number exists, there is no such uniqueness in the flow of polymer solutions. Different dependences of the dimensionless frequency on the Reynolds number exist for filaments of different diameter. Despite the fact that admixtures of both Guar gum and polyoxyethylene result in the reduction of the hydrodynamic friction drag, their effect on the vortex street turns out to be distinct. This is associated with the distinction in the structure of the solutions investigated, which has been noted earlier in [4].

A complex three-dimensional fluctuation mesh of polymer molecules occupying the whole fluid volume originates in freshly prepared solutions of such polymers as polyoxyethylene. The presence of the complex mesh results in spinning of the solutions. Long filaments can be drawn from the solutions. Such fluids possess continuous viscoelastic properties.

Guar gum solutions do not possess the properties of spinning even at high concentrations. There are no noticeable continual viscoelastic properties in these solutions; however, a reduced friction drag is also observed in the flow of these solutions. This common property of the polyoxyethylene and Guar gum solutions is related to the existence of large-scale domains therein, which are distinguished from the surrounding fluid by their viscoelastic properties. Such domains (associates of polymer macromolecules and solvent molecules) will behave as nondeformable particles under high-frequency perturbations, which will result in a reduction in turbulent friction in particular.

Polyoxyethylene solutions rapidly lose their continual viscoelastic properties during degradation in a shear flow. The continuous mesh which occupies the whole fluid goes over into a fluctuation mesh localized in the associates. The spinning property vanishes, but a reduced hydrodynamic friction is observed as before in the turbulent flow. A further degradation results in pulverization of the associates and the disappearance of the effect of removing the drag.

Favoring these representations is a large quantity of experimental facts verifying both the existence of the associates [4-9] and the nature of the change in structure of the solutions under degradation [3, 5, 10].

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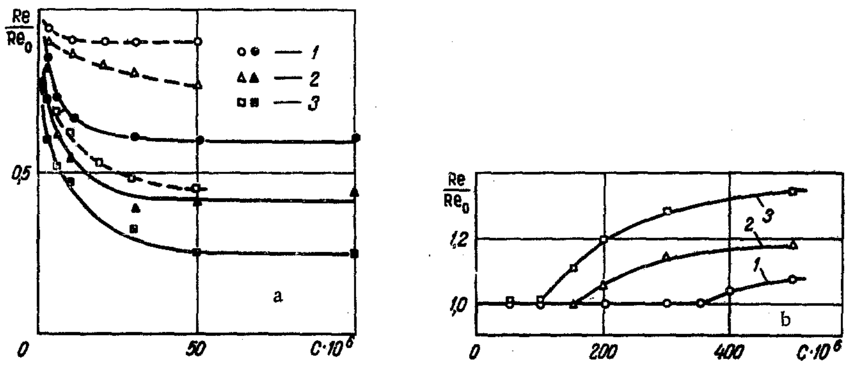

Fig. 1. Dependence of the Reynolds number corresponding to the appearance of a vortex street on the wire diameter d around which flow freshly prepared solutions of Polyox WSR-301 polyoxyethylene (a) and Guar gum solutions (b) of different concentrations. For a) wire diameters of 1, 0.55, and 0.25 mm correspond to curves 1-3, while for b) wire diameters of 1, 0.52, and 0.25 mm correspond to curves 1-3.

The influence of different polymer admixtures on the time a vortex street appears in the wake behind a streamlined cylinder as a function of its diameter and also the structure of the polymer solution and its concentration are studied in this paper.

The experimental apparatus was a wide tank with two short converging nozzles on the bottom. The cross-section of one nozzle was circular with a 1 cm diameter, and the other was oblong with 2 × 4.5 cm dimensions. Wires calibrated along the diameter were mounted in the exit sections of the nozzles. Wires up to 0.5 mm in diameter were mounted in the circular nozzle. Wires of greater diameter were mounted along the long axis of the section of the oblong nozzle. A wedgelike film sensor with 55A81-type quartz coating from the company DISA was mounted 10 diameters behind the wire. The sensors were mounted so that the edge of the wedge with the heated film was in a plane perpendicular to the wire. In such a sensor mounting all the vortices shed from the wire would flow over the sensitive film. The flow out of the nozzles was alternating.

The velocity of the flow around the wires was determined in the experiments by means of the discharge measured by a volume method and by means of the known nozzle section. The velocity was also checked by means of readings on a DISA 55AOI thermoanemometer. The appearance of vortices in the wake was determined on the screen of an oscilloscope connected to the thermoanemometer. The flow velocity v was determined at the time of the appearance of the vortices as was the Reynolds number $Re = vd/\nu$ corresponding to the origination of a nonstationary flow by means of the known wire diameter and the fluid viscosity which had been determined experimentally. Experiments conducted in pure water showed that a Karman street appears at a Reynolds number approximately equal to 41 for a Newtonian fluid. This agrees with the measurements conducted earlier [3].

Results of measuring the values of the Reynolds number corresponding to the appearance of a vortex street behind wires of different diameters around which freshly prepared solutions of Polyox WSR-301 polyoxyethylene flowed are presented in Fig. 1a. Plotted along the vertical axis is the ratio between the measured Reynolds number and the Reynolds number corresponding to Newtonian fluid flow, while the solution concentration is plotted along the horizontal axis. A total of 10-12 measurements correspond to each point in the graph. The dark points and continuous curves have been obtained for the flow of solutions prepared by mixing dry polymer powder with water directly in the tank of the apparatus in a proportion corresponding to the concentration being tested. The dashed curves and light points have been obtained in the flow of solutions prepared by diluting a solution with a 5×10^{-3} concentration to that needed directly before the test. The time of holding the concentrated solution from mixing to beginning of the test was 2 h.

Given in Fig. 1b are the results of analogous measurements with Guar gum solutions. The Guar gum solutions were prepared by mixing the dry polymer powder with water in a 10^{-3} concentration and holding for 3 days* prior to dilution and testing.

* The difference between the data on the critical Reynolds number presented in this paper and in [3] is associated with the difference in the method of preparing the Guar gum solutions, as was verified specially by checking tests. The solutions in [3] were prepared in the concentration needed at once, and then held for several days.

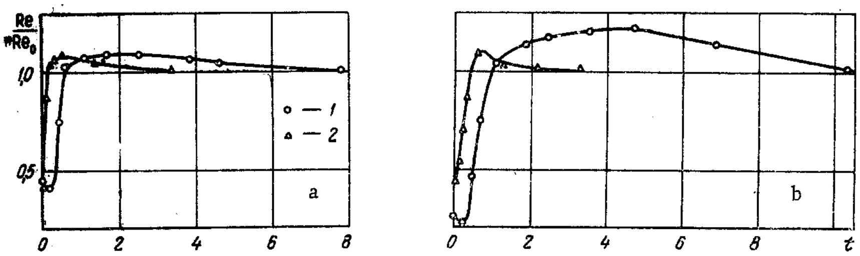

Fig. 2. Dependence of the relative Reynolds number corresponding to the appearance of a vortex street, during the flow around 0.52-mm-(a) and 0.25-mm-diameter (b) wires on the time of degradation of Polyox WSR-301 polyoxethylene solutions of 10^{-4} (curve 1) and $3 \cdot 10^{-5}$ (curve 2) concentrations. $Re_0 = 41$, t in hours.

As is seen from Fig. 1a, b, the polyoxyethylene admixtures result in diminution of the threshold value of the Reynolds number, while dissolution of the Guar gum causes an increase. Such a distinction in the behavior of the polyoxyethylene and Guar gum solutions is associated with the continual viscoelastic properties of the former and the existence of a continuous fluctuation mesh therein. The viscoelastic properties of freshly prepared polyoxyethylene solutions are quite unstable and depend substantially on the character of preparing the solution. The difference between the continuous and dashed curves in Fig. 1a indicates this.

Since, as has already been noted, the polyoxyethylene solution loses the continuous fluctuation mesh as degradation appears and goes into a solution containing associates of the type of the Guar gum solution, then it should be expected that the value of the threshold Reynolds number observed during the flow of the polyoxyethylene solution should increase with degradation and should exceed the value observed in the Newtonian case at a certain time. Further degradation, causing pulverization of the associates, should result in a gradual diminution in the threshold value of the Reynolds number to the Newtonian value. Such a picture is actually observed in tests.

Shown in Fig. 2a, b is the change in the relative Reynolds number corresponding to the appearance of a Karman street during the degradation of polyoxyethylene solutions with 10^{-4} and $3 \cdot 10^{-5}$ concentrations. Figure 2a corresponds to a wire of 0.52 mm diameter and Fig. 2b, to 0.25 mm. Degradation of the solution was accomplished by the pump of an EZE (GDR) thermostat which was placed in the tank of the apparatus. The solutions under investigation were prepared in the necessary concentration at once and shear degradation was started (the thermostat pump was switched on) 2 h after mixing in the case of the solution with the 10^{-4} concentration and 1.5 h afterward for the $3 \cdot 10^{-5}$ concentration.

The connection between the phenomenon of vortex formation behind the streamlined body and the hydrodynamic friction at a rough surface is evident. Generation of turbulence at a rough surface is associated with vortex shedding from the roughness projections. The flow in the gap between coaxial cylinders with large roughness was investigated experimentally in [10]. It was shown that freshly prepared solutions of polyoxyethylene manifest a significant reduction in drag. As shear degradation appears the drag reduction goes over into a rise and only afterward does the influence of the polymer gradually degenerate. A rise in the drag in a Guar gum solutions was determined in the same situation throughout the test. Results with a change in the sign of the influence of the polyoxyethylene admixture on the friction at a rough surface during degradation of the solution are analogous to the results in this paper: the Reynolds number corresponding to the appearance of vortices in the wake behind wires in a freshly prepared solution is less but grows as degradation appears, and starting with a certain time, exceeds the corresponding value of the critical Reynolds number for a Newtonian fluid.

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USE OF LASER DOPPLER ANEMOMETER FOR THE INVESTIGATION OF TURBULENT FLOW OF POLYMER SOLUTIONS

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The results of measurements of the mean velocity, the intensity of the longitudinal and the transverse components of the fluctuation velocity, and Reynolds stresses in the wake of a disk with polyoxyethylene solution injected in the aft zone are presented. The measurements were made by a laser anemometer.

The drawbacks of the contact methods of measuring the averaged and fluctuation velocities of fluids, in particular, of polymer solutions, are due to the necessity of introducing the measuring devices into the flow that gets distorted thereby. These drawbacks led to the miniaturization of the measuring elements, on the one hand, and to the development of noncontact methods of measurement, on the other. One of the most promising measuring devices is the laser Doppler anemometer.

The method of measuring turbulent fluctuations with the use of laser technology utilizing the Doppler effect has been well substantiated by Goldstein and Hagen [1]. They demonstrated for the first time the possibility of computing the characteristics of a turbulent flow using the spectral analysis of the Doppler signal. The broadening of the Doppler signal is considered as a function of the probability density distribution of the values of the velocity in the flow. This method was further developed in [2-6].

At present, the most widely used laser Doppler systems are the "intersecting reference beam" system proposed by Goldstein [7] (one beam is used as the local oscillator), the "dual scattering" system developed by Brayton [8] (only the scattered light is detected from both beams), and the "Doppler meter" system introduced by Rudd [9] (all the forward propagating radiation, both scattered and nonscattered, is detected).

The "dual scattering" (differential) system is used in the present work. In principle, all these systems are equivalent and the use of each of these systems is dictated by the specific situation.

Let us consider the theoretical basis of the laser Doppler technique and the interpretation of the obtained output signals. The radiation scattered from the point of intersection of two coherent beams emitted by a single laser source is mixed in a photodetector to obtain beats of the Doppler frequency proportional to the initial flow velocity at this point, which is given by the following expression:

$$f_D = \left(\frac{n\overline{W}}{\lambda_0}\right)(\bar{e}_1 - \bar{e}_2). \tag{1}$$

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