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].
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 $2 \times 4.5$ 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 55A01 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 $Re = \frac{vd}{\nu}$ 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 $5 \times 10^{-3}$ 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.