FLOW OF POLYMER SOLUTIONS IN WAKES OF POORLY STREAMLINED BODIES

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The effect of a polyethylene oxide polymer solution on the development of flow in the wakes of a disk and a sphere is studied. An increase in the velocity defect and a slight increase in the width of the wake were shown with the help of motion pictures and with measurements by electrodiffusion pickups and a laser Doppler anemometer.

The effect of polymer additions on the flow in free turbulent jets and wakes is now a solidly established fact [1-4]. In this connection it has been noted that in the case of transverse flow over a cylinder both the displacement of the line of boundary layer separation [5] and a change in the intensity and frequency of vortex separation in the wake behind the cylinder [3, 4] are possible. The properties of the flow of polymer solutions in the wakes of poorly streamlined bodies probably also cause changes in the characteristics of the boundary turbulence in the flow along rough surfaces [6]. The present work is devoted to a study of the flow structure in the wakes of axially symmetrical, poorly streamlined bodes — a disk and a sphere. To exclude the effect of the position of the separation line on the development of the near wake the experiments were conducted with the injection of a polymer solution into the stern region of the body. The nature of the flow development in the wake behind a disk 23 mm in diameter placed transverse to the flow was studied using visualization and filming in a water tunnel of the closed type with a working channel of square cross section 100×100 mm^2 and 2 m long and with the feeding of a solution of WSR-301 polyoxyethylene into the wake of the disk. The polymer concentration was 0.5%, the flow rate was 3 cm^3/sec, the flow velocity in the tunnel during the experiment was 0.84 m/sec, and the turbulent intensity of the impinging stream was 2.5%. The WSR-301 solution was forced out with compressed air from a tank. India ink, which was fed into the wake, like the polymer solution, through the hollow support of the disk, was used for visualization. The filming was done with a Konvas-Avtomat camera at a filming speed of 50 frames /sec. As seen from the pictures presented in Fig. 1, the introduction of polymers has a marked effect on the shape and size of the wake. The cross section of the wake and the rate of its growth become smaller than in water. In addition, the region of capture of "nonturbulent" liquid from the surrounding stream is much more strongly expressed. Except for the zone immediately adjacent to the sphere and comprising about four diameters, very strong intermittence is observed in the entire region of the wake.

Measurements of the average and longitudinal components of the pulsation velocity along the axis of the wake were carried out on the same apparatus using the electrodiffusion method [7]. Wedge-shaped and conical electrodiffusion pickups having dimensions of 100 and 20 μ for the active surface in the direction of flow were used in the experiments. Special attention was paid to the calibration of the electrodiffusion pickups, for which the diffusion current was determined by the following equation [8]:

$$i = KDC_0 \left(\frac{\nu}{D} \right)^{1/3} \sqrt{\frac{l}{\nu}} \sqrt{U}. \tag{1}$$

In dilute polymer solutions the values entering into Eq. (1) differ little from the values corresponding to water. The slight dependence of the current on the viscosity ($i \sim \nu^{1/6}$) should also be noted. The

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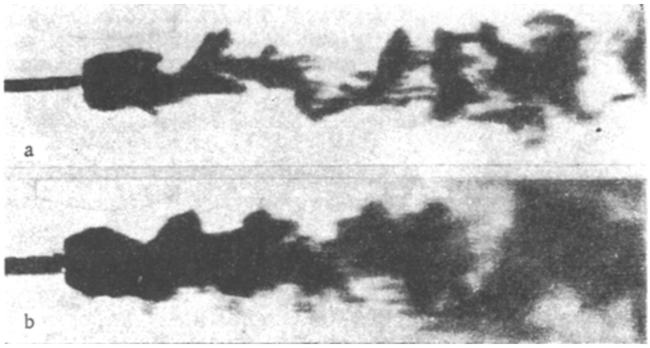

Fig. 1. Motion picture frames of wake behind disk: a) without feeding of polymer solution; b) with feeding of 0.5% solution of polyethylene oxide.

coefficient of diffusion of the reacting ions in turn varies quite markedly with a change in the viscosity of low-molecular weight liquids. However, in polymer solutions even at high polymer concentrations (0.5-1.5%) the coefficient of diffusion of a low-molecular weight admixture varies insignificantly [9].

This circumstance gives the electrodiffusion pickup a certain advantage over a tape thermoanemometer pickup, on whose readings can be superimposed anomalous signals [10] caused by the passage near the pickup's sensing element of associations having a thermal conductivity different from the thermal conductivity of the solvent.

It should be noted that the sensitivity of an electrodiffusion pickup, in contrast to a thermoanemometer, remains high even in measurements in concentrated polymer solutions. For instance, calibration of the pickup in an 0.5% solution of polyethylene oxide showed that the nature of the dependence of the diffusion current on the velocity remains unchanged ($i \sim U^{0.5}$) while the magnitude of the current in the velocity range of 0.5-1 m/sec decreases by about 15%. At the same time the sensitivity of a thermoanemometer decreases more than twofold even in measurements in weak polymer solutions [10]. A block diagram of the measurements is described in [7].

In the course of the experiments the electrodiffusion pickup was mounted at a fixed point on the axis in the wake behind the disk. Instrument readings were taken during flow without feeding in the polymer solution. Then instrument readings were taken with the feeding of a PEO solution into the stern zone of the body. After the instrument readings were recorded the feeding of the polymer was stopped and the instrument readings without the feeding were checked. This procedure was repeated each time with the pickup mounted in a new position.

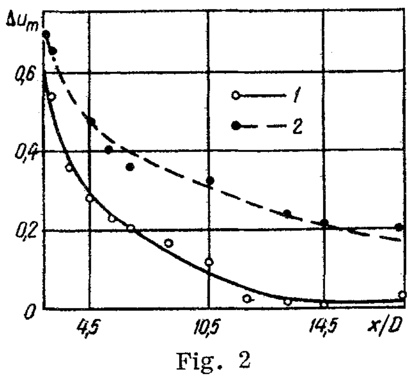

Fig. 2

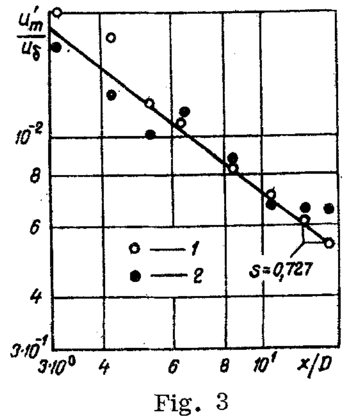

Fig. 3

Fig. 2. Variation in velocity defect at axis in wake of disk: 1) without feeding of polymer solution; 2) with feeding of 0.5% polyethylene oxide solution.

Fig. 3. Decrease in turbulent intensity of longitudinal component of velocity at axis in wake of disk: 1) without feeding of polymer solution; 2) with feeding of 0.5% polyethylene oxide solution.

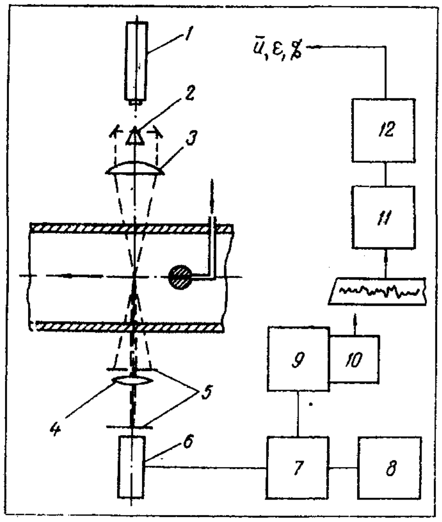

Fig. 4. Diagram of laser Doppler velocity meter.

Here one must take into account the fact that in the feeding of the polyethylene oxide solution the entire volume of water circulating in the closed water tunnel of 300 liter capacity was continually impregnated with polymer. Therefore during each series of measurements a limited amount of polymer solution was fed in so that its concentration in the entire volume did not exceed $1 \cdot 10^{-4}\%$. The pressure drop in the control section of the tunnel was controlled and sufficient time was maintained between each series of measurements to assure the degradation of the polymer solution moving in the instrument. In addition, in order to exclude the possible accumulation of errors owing to drift of the amplifier or contamination of the pickup, at the end of each series of tests the reproducibility of the pickup readings in the control cross sections was checked and the amplifier was calibrated.

Since the polymer concentration at the test points on the axis of the wake under the experimental conditions was many times less than the initial concentration and considering the slight effect of the polyethylene oxide concentration on the calibration characteristics of the pickup it was not necessary to introduce a correction to its readings. The curves of the variation in the velocity defect along the axis of the wake presented in Fig. 2 show that the injection of a polymer solution leads to an increase in the velocity defect, i.e., to a slower equalizing of the velocity at the axis with the velocity of the impinging stream. Such an increase in the "range" of the wake can be explained by the decrease in the intensity of the transverse pulsations and the strong intermittence which also leads to a decrease in the intensity of momentum exchange in the transverse direction.

A graph of the decrease in turbulent intensity along the axis of the wake is presented in Fig. 3 with the plotted experimental points for measurement with and without the feeding of PEO, as well as the data of [11]. The experimental points are approximated well by a power function with an exponent of 0.727 which is typical for wakes.

Attention is attracted by the fact that with an increase in the "range" of the wake the intensity of the longitudinal component of the pulsation velocity remains the same as without the feeding of polymer in the cross sections with $x/D > 6$. Some increase in the pulsation level was even observed in cross sections with $x/D > 12$. Such a consequence of the effect of the polymer admixture can probably be explained by anisotropy of the turbulence which is accompanied by an increase in the intensity of the longitudinal component and a decrease in the intensity of the transverse component of the pulsation velocity.

It must be considered that the data obtained are not corrected for the intermittence of the turbulence. The introduction of such a correction would result in higher values for the longitudinal component of the pulsation velocity, as occurred in a submerged jet of polyethylene oxide [12].

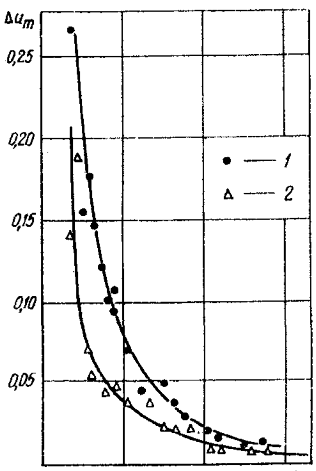

Fig. 5. Variation in velocity defect at axis in wake of sphere: 1) with feeding of 0.5% polyethylene oxide solution; 2) without feeding of polymer solution.

The study of the effect of polymer additions on the flow development in the wake behind a sphere 9 mm in diameter was conducted in a water tunnel of the closed type with a transparent working section of square cross section 40×40 mm^2, 3 m long, Reynolds number $Re = UD/\nu = 1.35 \cdot 10^4$, and a turbulent intensity of the impinging stream of 1.5-2%. A laser Doppler anemometer, whose optical diagram is analogous to that of [2] and is shown in Fig. 4, was used for the measurements. The light beam from the monochromatic source of an LG-36 helium-neon laser 1 was divided into two beams by the divider 2 and the lens system 3 and focussed on a fixed point of the stream. The position of the point could be changed in the longitudinal direction by shifting the entire optical system along a rigid track. Variation in the position of the measurement point in the transverse direction was accomplished by shifting the water tunnel. The light beam, which has been reflected from fine particles in the stream and has acquired a Doppler frequency shift, passes through the objective 4, the diaphragm 5, and falls on the FÉU-84 photoelectron multiplier 6. The voltage taken from the FÉU-84 was amplified by the VZ-14 broad-band amplifier 7 and fed to the S4-8 spectrum analyzer 8. Here the Doppler signal spectrum, averaged over 5 sec, was recorded. The system also provided for the possibility of photographing the signal from the screen of an S1-33 oscillograph 9 using an RFK-5 high-speed camera 10. By conversion of the oscillogram into digital code 11 and insertion into a Minsk-22 electronic computer 12 the probability density function of the velocity distribution could be calculated. The principal characteristics of the motion, the average velocity and turbulent intensity, could be determined from the measured spectrum with allowance for a number of assumptions [2].

Results are presented in Fig. 5 for the measurement of the average velocity defect at the axis of the wake without feeding of polymer and with the unpumped feeding into the stern zone of an 0.5% solution of WSR-301 polyethylene oxide whose flow rate was 0.416 cm^3/sec. The experimental points pertaining to the flow in the wake without the feeding of polymer are approximated by the power function $\Delta u_m \sim (x/D)^{0.8}$. An analogous power dependence is observed for the attenuation of the turbulent intensity along the axis of the wake. It was also noted that u' is equal to the velocity defect with an accuracy of 20%. All these results agree well with the data of the report of Gibson, Chen, and Lin [13]. With the feeding of a polyethylene oxide solution into the wake the measured results agree qualitatively with the results of experiments on transverse flow over a disk, where a decrease was noted in the velocity defect, i.e., an increase in the "range" of the wake.

NOTATION

i	is the diffusion current density;
K	is the constant;
D	is the coefficient of diffusion and diameter of body;
C_0	is the concentration;
ν	is the kinematic viscosity;
l	is the linear dimension;
U	is the average velocity of undisturbed motion at axis of tunnel;
$\Delta u_m = U - \bar{u}/U$	is the velocity defect;
$\bar{u}$	is the average velocity at axis of wake;
x	is the longitudinal coordinate.

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