DRAG-REDUCING EFFECT OF SOLUTIONS OF SOME HIGH-MOLECULAR COMPOUNDS IN TURBULENT FLOW PAST BODIES

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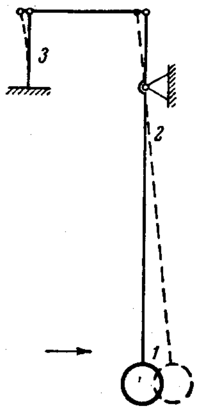
Zhurnal Prikladnoi Mekhaniki i Teknicheskoi Fiziki, No. 3, pp. 95–96, 1965

The recent literature contains data on changes in conditions and reduction of friction drag in the motion of ordinary Newtonian fluids through tubes, when high-molecular substances are introduced into the flow to form low-concentration solutions [1–3].

We have made an experimental investigation to determine the effect of the introduction of polymer solutions on the resistance of a circular cylinder situated in a turbulent flow. The solution was injected into the flow directly from the cylinder, so that the flow conditions remained unaffected except in the immediate proximity of the body.



The investigation was performed using a 1.2-m wide open channel, at a flow depth of 1 m. The body used in the tests was a hollow metal cylinder, 40 mm in diameter and 400 mm long. Its polished surface was covered by a 5 · 5 mm network of 0.5-mm deep longitudinal and circumferential scribings to provide additional regular roughness. This was so that the effect of the polymer solutions should not be masked by the effect associated with the critical Reynolds number. According to [4], the critical region for the type of cylinders employed lies in the Reynolds number range from $2 \cdot 10^4$ to $4 \cdot 10^4$. The degree of roughness of the cylinder, defined as the ratio of depth of scribings to cylinder diameter, was equal to $1.2 \cdot 10^{-2}$.

Along the cylinder generators 0.5-mm holes for the injection the polymer solution were drilled diametrically opposite each other in these rows at the intersections of the scribings. The cylinder was placed transverse to the flow at a depth of 0.3 m from the surface (where the channel flow velocity curve is a straight line) in such a manner that the injection holes pointed upstream and downstream. The polymer solution was supplied to the cylinder (see figure) from a tank, the pressure in which was created by compressed air and maintained at the required level. The polymer supply lines and the supports (2), by means of which the ends of the cylinder were fastened to the measuring system were enclosed by special fairings. The force experienced by the cylinder was transmitted with the aid of a system of levers to an elastic member (3) with strain-gage attachments. The deformations were recorded on separate channels by an oscillograph and an automatic recording device. Polymer consumption was determined by a volumetric method. The flow rate was measured with a pitot tube and a current meter submerged to the cylinder.

The elastic member was calibrated prior to each test by suspension of weights. The maximum error involved in the drag measurements on the model did not exceed 3%.

The procedure used in the tests was to determine at a given flow rate the resistance of the supports alone, then the resistance of the supports plus cylinder without the polymer and, finally, the resistance of the cylinder with supports after the injection of a polymer at a definite concentration.

The solutions employed were aqueous solutions of carboxymethyl cellulose and polyvinyl alcohol, and a solution of aluminum naphthenate in chemically pure kerosene. The solutions varied in concentration from 10 to 0.5%.

The experiments showed that addition of a polymer solution to a turbulent flow at a Reynolds number of $R \sim 6.5 \cdot 10^4$ results in a substantial (from 20 to 34%) reduction in cylinder drag. They also revealed the relation between the reduction in drag and the amount of injected polymer. It was found that the higher the injection rate of polymer from the cylinder, the smaller the drag reduction effect. The explanation for this might be the necessity for rapid equalization of the flow velocity about the body and the rate of polymer injection from the body; otherwise the flow conditions are impaired, the turbulence of the flow increases, and the effect of the polymer solutions is neutralized. It was also found that there is a certain optimum concentration—different for different types of polymer—for which drag reduction is maximum.

In order to check whether the change in flow conditions might be caused by ordinary viscosity, control experiments were performed involving the injection of an ordinary Newtonian fluid—glycerin—whose concentration was so chosen that the viscosity of the glycerin solution was equal to that of the corresponding polymer solution. The drag reduction effect for glycerin was found to lie within the limits of the measuring error. Substitution of ordinary water for the polymer did not affect the instrument readings; at high injection rates, the cylinder drag increased.

Solution	C, %	p, kg/cm²	ζ, %
Polyvinyl alcohol in water	1	0.5	10
	5	2.0	34
	10	2.0	31
Aluminum naphthenate in kerosene	0.5	0.5	10
	2.5	1.0	18
Carboxymethyl cellulose in water	1	0.6	10
Glycerin in water	40	0.5	4

The table shows the concentrations C, in %, and values of the drag reduction ζ, in %, for the polymer solutions studied and glycerin at various tank pressures p in kg/cm² (Reynolds number $R \sim 6.5 \cdot 10^4$).

Analysis of the causes of drag reduction in the model, on the basis of the data obtained, does not permit a unique determination of the physical mechanism of this effect. The drag reduction observed with the present model could have had the following causes;

1) Contraction of the wake due to increased viscosity in the boundary layer and the displacement of the flow separation point downstream.

2) Decrease in intensity of turbulent pulsations both in the boundary layer and in the wake.

3) A change in the nature of the interaction between the medium and the surface of the model (slip).

Tests with glycerin injection into the flow visualization by means of colored polymer and glycerin solutions both showed the contraction of the wake to be independent of the type of fluid injected.

Hence, it may be concluded that the observed phenomenon is associated with the effect of the polymer solution either on the intensity of the turbulent pulsations or on the nature of the interaction between the flow and the surface of the model.

The authors are indebted to B. I. Isaev, L. S. Magaziner, Z. P. Titova, and V. M. Tret'yakov who participated in the experiments, further to V. F. Shushpanov, Yu. L. Yakimov, L. I. Zhigachov, and A. I. Denisov for their help in performing the experiments, and also to professor M. Tulin (Hydronautics Inc. USA) for valuable advice on the experimental setup.

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26 February 1965 Moscow