Turbulent Diffusion of Heat in Jets of Dilute Polymer Solutions

POLYMER solutions which reduce drag friction have been shown[1] to have two different physico-mechanical structures; these are characterized by the presence or absence of continuum viscoelastic properties. Both types of solution, however, contain coarse viscoelastic particles—associates of macromolecules which are responsible for hydrodynamic drag reduction near the smooth surface (Toms effect). The effect (positive or negative) of polymer additives on the development of Kármán vortices has been shown to depend on the structure of the solution[2].

This work investigates the turbulent diffusion of heat in jets of polymer solutions, and shows that the effect of polymer additives on jet turbulence depends on the structure of the solution. Aqueous solutions of polyethylene oxide (Polyox *WSR*-301) and Guar gum were used in the investigations. Polyethylene oxide evidently forms a continuous fluctuating lattice of polymeric chains in aqueous solution, which results in noticeable continuum viscoelasticity. Guar gum forms no such continuous lattice in water, but forms separate viscoelastic associates suspended in the practically Newtonian solvent. Elastic solutions of polyethylene oxide also acquire this structure after being subjected to shear stresses for some time.

Temperature profiles in submerged jets, flowing into a liquid at a different temperature, were measured by a thermocouple mounted in a heat-insulated hypodermic needle 1·4 mm in diameter. The diameter of the nozzle orifice was 3·1 mm. This method is free from the undesirable effects, such as screening, which are associated with the Pitot tube method for measuring velocity profiles. The rate of flow through the nozzle orifice was maintained at 5 m/s and the total error in the measurements did not exceed 1 per cent.

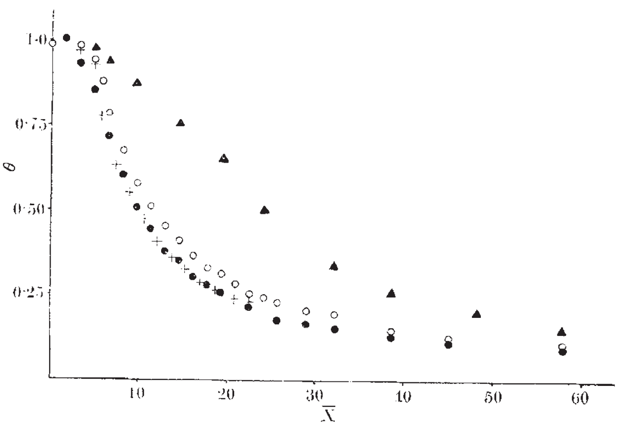

Fig. 1. ○, Water; ▲, elastic solution of polyethylene oxide, 100 p.p.m.; +, solution of polyethylene oxide, 100 p.p.m., broken into associates by a thermostatic pump; ●, Guar gum solution, 500 p.p.m.

The measured difference, ΔT, between the temperature of the liquid in the trough upstream of the nozzle exit and that in a given point of the jet was related to the fixed difference between the temperature of the liquids in the tank and in the trough, ΔT_0, which was 10°–20° in our experiment. Fig. 1 shows the distribution of the value $\theta = \Delta T/\Delta T_0$ along the jet axis, depending on the dimensionless distance to the nozzle $X = x/D$ (D is the diameter of the nozzle orifice). Because solutions of polyethylene oxide readily lose their capacity to reduce drag, non-elastic polyethylene oxide solutions were also tested by observing the reduction in drag experienced by a rotating disk. This reduction was almost the same as in the case of a fresh elastic solution. Fig. 2 shows temperature profiles measured along the jet cross-section at a distance $X = 20$ from the edge of the nozzle. The dimensionless radius $R = r/D$ was plotted along the horizontal axis.

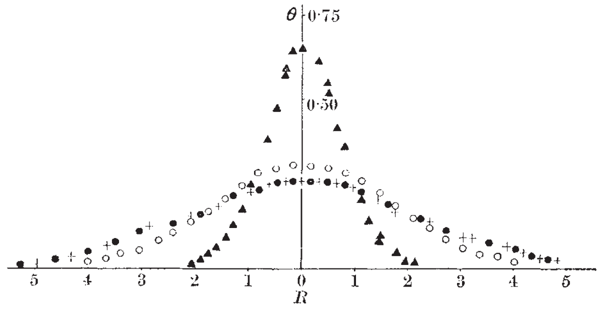

Fig. 2. Symbols same as Fig. 1.

These measurements indicate that the behaviour of submerged jets of polymer solutions depends on the physico-mechanical structure of the solution. The jets of elastic polymer solutions seem to show more long range effects than those of a Newtonian fluid, which indicates a decrease in the turbulent diffusion of heat within the jet. Alternatively, the jets of non-elastic solutions of polyethylene oxide, and of solutions of Guar gum, show fewer long range properties and greater turbulent diffusion than jets of water. Reduction in turbulent diffusion is usually associated with continuum viscoelastic properties of the solution which damp turbulent pulsations; the higher the frequency of the pulsations, the greater the damping effect. An increase in turbulent diffusion in jets of non-elastic solutions is connected with the presence of particle-associates. Increase in frequency and intensity of the Kármán vortices and the results given here are evidence of the disturbing effect of particle-associates on inertial turbulent vortices. This phenomenon is similar to the effect of suspended particles on turbulent drag in the flow core in a tube. Bobkowicz and Gauvin, who investigated reduction in frictional resistance caused by suspended particles moving in tubes, have shown[3] that non-concentrated suspensions of nylon fibres cause a considerable increase of turbulent mixing in the core of the flow.

Submerged jets of polymer solutions have been studied by Gadd[4] and White[5]. White shows that there is an increase in turbulent mixing in the submerged jet of polyethylene oxide solution, whereas Gadd reports a reduction in the intensity of turbulent diffusion in jets of the same solution. The results given here may explain this discrepancy: Gadd and White could have used solutions which differed in structure. Moreover, White measured velocity profiles with a thin Pitot tube, in which screening of the opening by associates would make the readings lower than the actual velocity pressure.

We thank Professor G. I. Barenblatt for his help and V. V. Tikhomirov for assistance in building the apparatus.

S. A. VLASOV
V. N. KALASHNIKOV

Institute of Mechanical Problems,
USSR Academy of Sciences,
Moscow.

Received June 16; revised September 2, 1969.

[1] Barenblatt, G. I., and Kalashnikov, V. N., *Izvestya Akad. Nauk SSSR, MJG*, 3 (1968).
[2] Kalashnikov, V. N., and Kudin, A. M., *Nature* (in the press).
[3] Bobkowicz, A. J., and Gauvin, W. H., *Chem. Eng. Sci.*, 22 (1967).
[4] Gadd, G. E., *Nature*, 212, 874 (1966).
[5] White, D. A., *J. Fluid Mech.*, 28 (1967).