A POSSIBLE MECHANISM TO ACCOUNT FOR THE EFFECT OF ADDED POLYMERS ON TURBULENCE

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It is an experimentally established fact [1–4] that introducing small amounts of soluble polymers into a turbulent flow of water reduces the drag. In [5, 6] direct observation of the mixing of soluble dyes revealed that this effect is related with the damping of the turbulent fluctuations, particularly in the high-frequency region. These facts urgently require detailed study.

It is clear that the individual polymer molecules cannot affect the flow regime—they are few in number and their size is negligibly small (10^{-5}–10^{-4} cm) as compared with the Kolmogorov internal scale of turbulence.

In our opinion, in its general features the mechanism of turbulence damping reduces to the following. When the long polymer molecules enter the flow, they surround a quite large number of water molecules forming a sort of supramolecular structure in the solution. The resulting globules are not small, they have an order of magnitude greater than or equal to the internal scale of turbulence of the fluid flow without the polymer additive. However, their density is only negligibly different from that of water.

Descriptively speaking, it is possible to picture these globules as fairly rigid floating individual formations of density equal to that of the fluid. The action of these formations on the eddies will strongly depend on the scale of the latter. If the eddy scale is much greater than the size of the globule, it transports the globule as a whole without being directly affected. However, if the scale of the eddy is comparable with the size of the globule, then such eddies must be heavily damped at the globules; this also produces extra dissipation at high frequencies, thus suppressing the high-frequency part of the spectrum.

For the experiments described in [5], an estimate of the Kolmogorov internal scale of turbulence $\lambda_0 = (v^3/\varepsilon)^{1/4}$ gives ($v \sim 10^{-2}$ cm^2/sec, $\varepsilon \sim 10^2 - 10^4$ cm^2/sec^3) $\lambda_0 = 10^3 - 10^{-2}$ cm. Therefore, for the existence of the above-described damping mechanism it is necessary that supramolecular structures with a characteristic scale of the same or higher order exist in the polymer solution.

In order to detect supramolecular formations in the investigated polymer solution we performed experiments of three types: on a capillary apparatus, on a filter apparatus, and on a falling-ball Hoppler viscometer.

As the experimental medium we used an aqueous solution of the sodium salt of carboxymethylcellulose, which gives the best effect in drag solution experiments. The concentration of the solution did not exceed 0.4%. For comparison we also used an aqueous solution of glycerin.

Table 1

Ball	Diameter, mm	Time to fall, sec	Viscosity, 10^{-2} p
1	15.80	224.0	2.80
2	15.63	30.6	3.06
3	15.15	4.1	4.17

The capillary and filter apparatus consisted of a cylinder 0.5 m tall, into which the test solution was poured. The lower removable cover contained a connection to which interchangeable brass discs fitted with ten steel calibrated capillaries of different diameters (0.02, 0.03, 0.05, and 0.07 cm) were clamped.

This apparatus had a special adapter for attaching filters instead of capillaries. During the experiments the flow time was determined. The viscosity of the polymer solution, determined on an Ostwald capillary viscometer (diameter of capillary 0.08 cm, length of capillary 10 cm) was 2.8×10^{-2} poise. The glycerin solution, tested on the same viscometer, had the same viscosity.

Table 2

Ball	Diameter, mm,	Time to fall, sec	Viscosity, 10^{-2} p
1	15.80	505.8	6.73
		487.3	6.48
		396.0	5.27
		343.2	4.56
2	15.63	24.6	2.62
		24.5	2.60
		24.5	2.60
3	15.15	3.8	4.15
		3.8	4.15
		3.8	4.15

It was established that in capillaries of diameter greater than 0.02 cm the flow rates for glycerin and a solution of carboxymethylcellulose are comparable. The latter solution does not flow at all out of a capillary 0.02 cm in diameter, whereas the glycerin flowed out at a rate of 12 cm/sec.

The same experiments were carried out with a filter with a permeability of 1.35×10^{-5} cm^2 for water, i.e., with a mean pore diameter of the order of 10^{-2} cm. The rate of flow of glycerin was 1.3 cm/sec, the polymer solution was hardly able to pass through the filter at all.

The Hoppler viscometer is an inclined glass tube which is filled with the test liquid. In the upper part of the tube (diameter 1.60 cm) there is placed a ball of diameter somewhat smaller than the inside diameter of the tube. The viscosity is determined from the time the ball takes to fall. There is a set of balls of different diameter. Each is intended for measuring the viscosity in a certain range.

Table 1 gives the corresponding results for balls of different diameter falling in an aqueous solution of glycerin, whose viscosity was found from independent capillary viscometer measurements to be 2.80×10^{-2} poise.

In the range 0.3–7.0 centipoise the viscosity should be determined with a ball 1.58 cm in diameter. Table 1 also gives the formally calculated (apparent) viscosity from measurements with two other balls of smaller diameter. These data are needed for comparison with the apparent viscosity of a solution of the sodium salt of carboxymethylcellulose.

The polymer solution tested was prepared in such a way that its viscosity as measured on the capillary apparatus coincided with the viscosity of the glycerin solution.

Data on the time taken by the ball to fall through the polymer solution are given in Table 2, from which it can be seen that the apparent viscosities of the polymer and glycerin solutions roughly coincide for the second and third balls (difference in diameters of balls and cylinder 0.037 and 0.085 cm, respectively). However, determination of the viscosity of the polymer solution with the first ball (difference of diameters of ball and cylinder 0.02 cm) gives a value considerably in excess of that for the viscosity of the glycerin solution and of that for the polymer solution determined on the capillary viscometer. The time taken by the first ball to fall in the polymer solution is roughly 2.5 times greater than in the glycerin solution.

Table 2 gives the fall times (and the corresponding apparent viscosities) for a series of successive falls. For the first ball these times progressively decrease.

On the basis of these three types of experiments we may conclude that in a polymer solution giving a turbulence damping effect openings of the order of 10^{-2} cm are almost or wholly impermeable, which definitely indicates the presence in the solution of structural formations in polymer solutions in the work of P. A. Rebinder and his school [7] and V. A. Kargin and his school [8], which has no direct bearing on turbulence damping.

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