INFLUENCE OF POLYMER MOLECULAR-WEIGHT DISTRIBUTION ON HYDRODYNAMIC DRAG REDUCTION IN A TURBULENT STREAM OF SOLUTION

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The molecular weights of polyethylene oxide specimens, their distributions and dispersion coefficients, and the dependence of the Thoms effect on the polymer concentration in the solution are measured. Values of the Thoms effect of the specimens are compared with their dispersion coefficients.

It has been established by recently conducted investigations of the Thoms effect in different types of dilute high-molecular-weight solution flows that its magnitude depends on the physical parameters of the dissolved polymer [1-3].

Different models of a continuous medium [4-10] have been proposed to explain the Thoms effect. The majority are based on taking account of the physical parameters of the dissolved polymer by using its mean molecular weight. However, as experience shows, the use of polymer solutions of the same kind with the same statistical-mean molecular weight does not always yield unique results in hydrodynamic tests. The results of such tests are presented in Fig. 1. The tests were performed on a hydrodynamic apparatus with coaxial cylinders (with the outer cylinder rotating (diameter of outer cylinder 110 mm, gap between cylinders 10 mm, and rotational velocity 30 m/sec). In the figure, the polymer concentration in the solution is plotted along the abscissa; and the value of the solution efficiency Ψ (in percent), computed by means of the formula

$$\Psi = \frac{\tau_0 - \tau}{\tau_0} \cdot 100, \ \%,$$

is plotted along the ordinate.

The curves in Fig. 1 correspond to four different batches of polyethylene oxide with the same mean molecular weight $M_W = 4.6 \cdot 10^6$. It can be seen that although the efficiencies of all the specimens agree at the optimal concentration ($2 \cdot 10^{-4}$), the solutions behave differently at other concentrations.

An analysis of these specimens showed that while having the identical weighted-mean molecular weight the specimens possess different molecular weight distributions. The molecular weight distributions of these specimens, obtained by centrifuging on a "Wesman" brand ultracentrifuge at a rotor speed 447,000 rpm and using the Bailey dependence [11], are represented in Fig. 2. The molecular weight M is plotted along the abscissa, and the normalized value of the distribution function $g_W(M)$ is plotted along the ordinate. As is seen, the specimens represented possess different dispersions. The dispersion of the molecular-weight distribution can be characterized by the coefficient γ [12]:

$$\gamma = \sqrt{\frac{M_W}{M_n} - 1},$$

where M_n and M_W are calculated from the distribution curve obtained by means of the formulas

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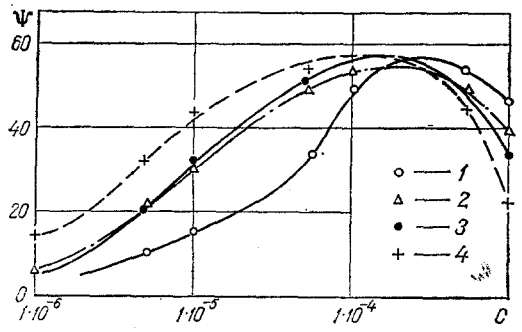

Fig. 1

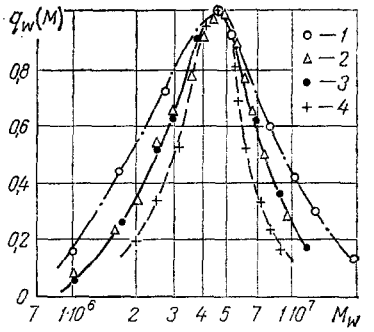

Fig. 2

Fig. 1. Dependence of the drag reduction on the polymer concentration in the solution.

Fig. 2. Molecular-weight distribution of polyethylene oxide specimens.

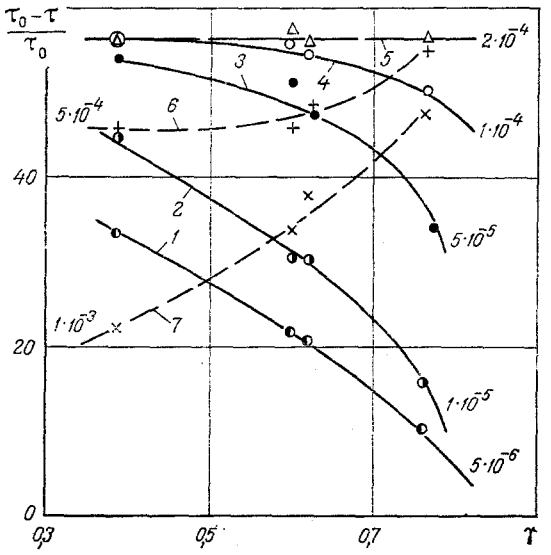

Fig. 3. Dependence of the drag diminution on the dispersion coefficient of the molecular-weight distribution; C = $5\cdot10^{-6}$; 2) $1\cdot10^{-5}$; 3) $5\cdot10^{-5}$; 4) $1\cdot10^{-4}$; 5) $2\cdot10^{-4}$; 6) $5\cdot10^{-4}$; 7) $1\cdot10^{-3}$.

$$M_W = \sum_{i=0}^{\infty} M_i W_i, \quad M_n = \sum_{i=0}^{\infty} \frac{1}{\sum_{i=0} \frac{W_i}{M_i}}.$$

In our experiments the dispersion coefficient of the distribution varied between 0.41 and 0.77. Let us note that γ is close to 0 (for $M_n \cong M_W$) for a Gaussian distribution.

The molecular weight distributions turned out to be close for two specimens in Fig. 2; their coefficients were 0.625 and 0.64, respectively. As is seen from Fig. 1, the efficiencies of these specimens are almost identical (curves 2 and 3). When these coefficients differ, a sharp difference in the efficiency of the solution is observed in hydrodynamic tests (curves 1-4). This follows most graphically from Fig. 3.

The dependence of the Thoms effect (in percent) on the coefficient γ is represented in Fig. 3 for a polymer concentration in the solutions in the range $5\cdot10^{-6}$-$1\cdot10^{-3}$. Curve 5 in Fig. 3 corresponds to the optimal (according to Fig. 1) concentration of polyethylene oxide in a solution with $M_W = 4.6\cdot10^6$. In this case the efficiency of the solution is independent

of the coefficient γ of the molecular-weight distribution with the experimental accuracy of 4%. However, as is seen from curves 1, 2, 3, and 4 for the corresponding concentrations $5 \cdot 10^{-6}$, $1 \cdot 10^{-5}$, $5 \cdot 10^{-5}$, and $1 \cdot 10^{-4}$, with the reduction in the coefficient γ; i.e., when the molecular weight distribution approaches a Gaussian distribution, the efficiency of the polymer solution increases with the reduction in polymer concentration in the solution relative to this optimal concentration. Conversely, as the concentration of the polymer solutions increases (curves 6 and 7), relative to the optimal value, their efficiency worsens with the dispersion coefficient approaching the Gaussian value (for M_W M_n).

Therefore, the data obtained permit the conclusion that to describe adequately dilute polymer solution flows with variable (or constant) but not optimal concentration, it is necessary to take into account not only the mean molecular weight of the polymer, but also the molecular weight distribution.

NOTATION

C, concentration; M_i, mean value of the molecular weight within the i-th partition of the weight distribution; M_n numerical-mean molecular weight; M_W, weighted-mean molecular weight; τ, friction stress on the wall in the solution; τ_0, friction stress on the wall in water; Ψ, reduction in the hydrodynamic drag; γ, dispersion coefficient of the molecular-weight distribution; W_i, fraction of the M_i-th molecular weight in a given distribution.

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