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REDUCTION OF HYDRODYNAMIC DRAG AND SIZE OF POLYMER PARTICLES

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UDC 532.5.013.12

The influence of the size of polymer particles and their number in the deformed fluid volume on the Thoms effect is examined in an example of biopolymers of surface extractions of water animals.

The reduction of turbulent fluid drag upon the insertion of admixtures of certain polymers is of national-economic interest. However, despite the numerous attempts of researchers, there is no theory of this phenomenon at this time [1], and the physicochemical aspects of both the mechanism of the action and the nature of the particles — the hydrodynamic activity carriers — have been inadequately studied. The clarification of the fundamental aspects of the mechanism of the process, of the most important parameters governing the hydrodynamic activity of macromolecular admixtures, is needed for a practical application of parameters in order to reduce the hydrodynamic drag of liquid media.

Since the hydrodynamic activity of polymers can be considered as the result of polymer particle interaction with turbulent formations of the medium, one of the fundamental parameters governing its interaction is the size of these particles.

T. G. Shevchenko Kiev State University. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 39, No. 5, pp. 815-819, November, 1980. Original article submitted November 23, 1979.

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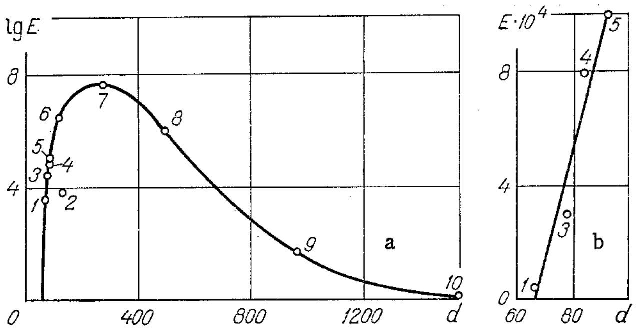

Fig. 1. Dependence of the hydrodynamic activity of surface excreta of water animals on the particle diameter: [a) curve with a smooth maximum; b) straight-line section of the curve]: 1) afaline skin excreta; 2) porpoise skin excreta; 3) smare mucus; 4) lascir mucus; 5) blue runner mucus; 6) gray mullet mucus; 7) afaline "tears"; 8) macromolecular smare fraction; 9) blue runner mucus after 6-h storage at room temperature; 10) blue runner mucus after 24-h storage at room temperature; d, nm.

Attempts were undertaken earlier to relate the mechanism of hydrodynamic drag reduction by polymer admixtures to the magnitude of the radius of supermolecular formations in polymer solutions [2, 3]. However, it was not taken into account that an increase in the particle size for a constant concentration of the polymer admixture would inevitably imply a diminution in their number. This resulted in a representation about the subordinate role of the particles.

This paper is devoted to a clarification of the role of the particle size in the capacity of polymer admixtures to reduce hydrodynamic drag with the concentration of these particles taken into account in the deformable fluid volume.

We showed earlier [4, 5] that surface excreta of fast-swimming water animals have a hydrodynamic function, where some of them exceed the best of the known synthetic polymers. Consequently, the slimy coverings of fish (gray mullet, blue runner [stavridy], smare [smaridy], lascir [laskirya]) and the surface excreta of dolphins (afaliny) were the objects of investigation.

The capacity of the surface excreta to reduce the hydrodynamic drag was measured in a flow-through apparatus with thin walls [6], and the hydrodynamic activity was estimated as the flow referred to unit concentration of admixture for the greatest value of the drag reduction effect:

$$E=\frac{H}{C_{\mathrm{opt}}}, \tag{1}$$

$$H=\frac{\eta_0-\eta}{\eta}\cdot 100\%. \tag{2}$$

The size of the polymer particles was determined by the method of the turbidity spectrum [7] by taking supermolecular particles as the dispersed phase and the true polymer solution as the dispersion medium

$$r=\frac{\alpha\lambda\mathrm{m}}{2\pi\mu_0}. \tag{3}$$

The wave exponential is found by investigating the spectrum dependence of the optical density of polymer solutions on the wavelength of light. The optical density was measured on an SF-16A spectrophotometer in the 400-500-nm wavelength band, where according to the data of tests specially performed, the substances under investigation have no intrinsic absorption bands.

Since the characteristic light-scattering functions depend on the relative refractive index of the particles $m = \mu/\mu_0$, this latter is found from the dependence

$$\rho=\frac{4\pi r(m-1)\mu_0}{\lambda\mathrm{m}}. \tag{4}$$

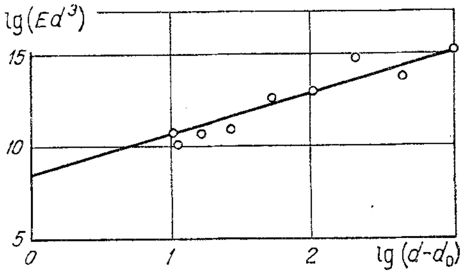

Fig. 2. Dependence of $\log(Ed^3)$ on $\log(d - d_0)$.

TABLE 1. Particle Size and Number for Biopolymers Located after the Maximum on the Curve of the Dependence of Hydrodynamic Activity on Particle Size

Mucous material	d, nm	N, cm^{-3}
Afaline "tears"	276	$6{,}47 \cdot 10^{10}$
Macromolecular fraction of blue runners	496	$4{,}19 \cdot 10^{8}$
Blue Runner mucus:		
after 6 h	966	$1{,}82 \cdot 10^{8}$
after 24 h	1538	$5{,}4 \cdot 10^{7}$

The radius was determined by an electron-microscope method. The magnitudes obtained for ρ lie in the limits 1.076-1.049, which is close to the quantity 1.04 found for bacteria [9].

The number of particles in the solution was determined by the equation

$$N = 1.26 \cdot 10^{17} \frac{\tau}{(\lambda')^2 K(\alpha, m)\alpha^2} \ [\mathrm{cm}^{-3}]. \tag{5}$$

The hydrodynamic activity of bipolymers of surface excreta varies as the particle size increases according to a curve with a smooth maximum in the 200-400-nm range (Fig. 1a). The ascending branch of the curve has a straight-line section that permits extrapolation to $E = 0$ and finding the minimum particle size $d_0 = 67$ nm (Fig. 1b) when the capacity to reduce the hydrodynamic drag can already appear for bipolymers.

As the particles coarsen above $d = d_0$, the hydrodynamic activity is raised despite the fact that the number of activity carriers N diminishes. Since tests are conducted for a constant concentration, we assume that the volume fraction φ of polymer particles in the excreta solutions is also constant:

$$\varphi = N \frac{\pi d^3}{6}. \tag{6}$$

Then the contribution of one particle in the hydrodynamic drag reduction effect ω is

$$\omega = \frac{E}{N} = K' \frac{1}{d^3}. \tag{7}$$

As follows from the data presented in Fig. 1, the hydrodynamic activity increases as the effective particle size grows $d_e = d - d_0$. This affords a foundation for seeking the dependence $\omega = f(d)$ by starting from the general form of a curve typical for the exponential

$$Ed^3 = 3.00 \cdot 10^8 (d - d_0)^{2.26}. \tag{8}$$

The experimental points (Fig. 2) in the logarithmic coordinates of (8) lie satisfactorily on a common line, where the correlation coefficient is 0.93.

The optimal particle size is found from the equation $dE/d(d) = 0$. The roots of (8) in differential form are $d_1 = 0$, $d_2 = d_0$, $d_3 = 4.05d_0$. Only d_3 has physical meaning, which yields the optimal particle-size value of $d_{opt} = 270$ nm.

The most important factors of polymer hydrodynamic activity are the particle size and particle concentration. The activity grows as the polymer particle diameter increases exponentially; however, coarsening of the particles above a specific limit results in so substantial a diminution in their number (see Table 1) that the total effect is reduced to definite values.

Therefore, we have established the hydrodynamic activity parameters of macromolecular admixtures, which are minimal and optimal for these measurement conditions for the particle size d_0/d_{opt} and their number per unit volume N.

NOTATION

H, relative reduction in the flow resistance; C_{opt}, concentration, %, at which the maximum value of H is achieved; η, resistance to fluid flow through the tube; r, particle radius; d, particle diameter; η_m, middle of the wavelength band of the straight-line section of the construction log D — log λ; μ_0, μ, refractive index of the medium and substance respectively; α, dimensionless quantity found from tables on the value of the wave exponent [8]; ρ, K(α, m), parameters found in tables [8]; τ, turbidity of the polymer solution; E, hydrodynamic activity; f, function; D, optical density.

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