ON CERTAIN CHARACTERISTICS OF BOUNDARY-LAYER TURBULENCE IN WATER STREAMS CONTAINING SOME MACROMOLECULAR SUBSTANCES

E. M. Khabakhpasheva and B. V. Perepelitsa

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The results are presented of an experimental study concerning certain characteristics of boundary-layer turbulence in water streams containing small amounts of polyethylene oxide and polyacrylamide. The stroboscopic method of observing the flow was used in the experiment.

In articles on this subject the question is extensively discussed as to what causes the reduced resistance to turbulent flow of water with a small content of certain macromolecular substances. A significant number of authors subscribes to the view that the reduced resistance is a result of a thicker viscous sublayer.

The method of stroboscopic flow observation developed at the Institute of Thermophysics, Siberian Branch, Academy of Sciences of the USSR [1] makes it possible now to study the character of the liquid flow not only throughout the channel cross section but also in the immediate vicinity of a wall. In their preceding articles [2] the authors have shown that an addition of substances results in a considerable increase of the transition flow region where the velocity profile becomes more sloped.

The last series of tests had been performed with weak solutions of polyethylene oxide (0.007%) and polyacrylamide (0.01-0.012%). The procedure applied here and the wealth of experimental data obtained made it possible not only to determine the profiles of average and of pulsating velocity over the channel cross section but also to construct pulsation histograms and to find the coefficients of spatial correlation for the longitudinal component of velocity.

Experience has shown that polyethylene oxide and polyacrylamide solutions break up considerably and fast when in motion. For this reason, measurements were made in closed circulation systems as well as in a high-capacity system behaving like an open one.

The profiles of average velocity obtained from these tests are shown in Fig. 1 in dimensionless coordinates. Curves 1 and 2 represent the flow of fresh polyethylene oxide and polyacrylamide solutions driven once through a 1 × 1 cm channel. The velocity profiles differ considerably from common turbulence profiles over the entire range of measurements ($y/H \leq 0.75$, $\eta \leq 340$).

Curves 3 and 4 represent the flow of solutions circulating for some time (several hours) through a closed system and largely broken up as a result. On these curves one can distinguish all three regions which characterize turbulent flow: the viscous sublayer, the transition region, and the region of developed turbulence where the slope of the velocity profile (the turbulence factor $\varkappa$) is the same as for common liquids. The transition region is much wider, however, and also the velocity has increased at the boundary with the turbulent core of the stream.

It is possible to calculate, on the basis of the plotted velocity profiles, the mixing length which appears in the Prandtl equation $\tau_T = \rho l^2 (dU/dy)^2$. These calculations are shown in Fig. 2. The mixing lengths in polyethylene oxide and in polyacrylamide solutions appear much shorter than in a water stream. The turbulence factor $\varkappa$ for the fresh polyethylene oxide solution is almost constant and about 0.075 over the entire measured region.

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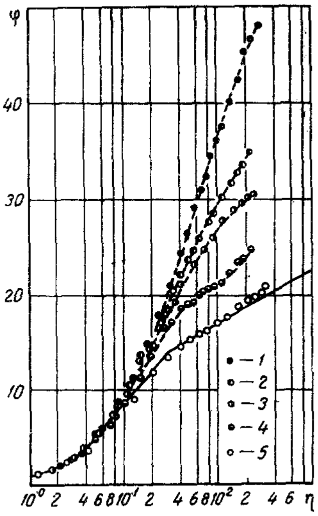

Fig. 1

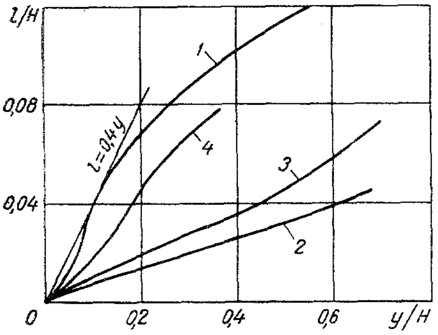

Fig. 2

Fig. 1. Velocity profiles in dimensionless coordinates: 1) 0.007% polyethylene oxide solution, Re = 27,000 (fresh solution); 2) 0.01% polyacrylamide solution, Re = 18,300 (fresh solution); 3) 0.02% polyacrylamide solution, Re = 9400 (after breakup); 4) 0.007% polyethylene oxide solution, Re = 13,200 (after breakup); 5) water, Re = 35,000.

Fig. 2. Distribution of mixing lengths over the channel cross section: 1) water; 2) polyethylene oxide solution; 3, 4) polyacrylamide solutions of various concentrations.

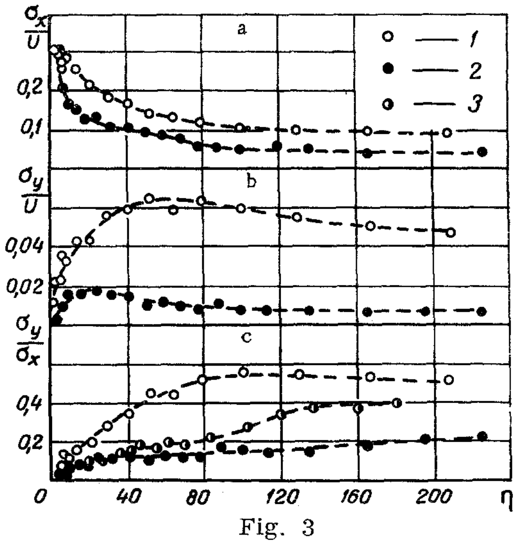

Fig. 3

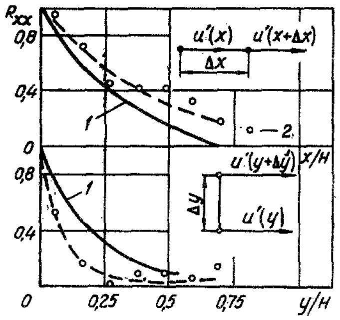

Fig. 4

Fig. 3. Relative mean-square values of longitudinal and transverse velocity pulsations: 1) water, Re = 35,000; 2) 0.007% polyethylene oxide solution, Re = 27,000; 3) 0.01% polyacrylamide solution, Re = 18,300.

Fig. 4. Spatial correlation for the velocity u as a function of x and y: 1) water; 2) 0.007% polyethylene oxide solution.

In Fig. 3 are shown the mean-square pulsations (longitudinal and transverse) measured in the same solutions and in pure water. It follows from the diagram in Fig. 3a and b that the relative magnitudes of pulsations (referred to the velocity at a given point) decrease as polymer material is added, the transverse pulsations decreasing much faster. While the turbulent velocity pulsations near the wall in a pure water stream are characterized by some degree of anisotropy, in solutions of polyacrylamide or especially of polyethylene oxide this anisotropy is much more pronounced and is maintained over a much greater distance from the wall (Fig. 3c).

In Fig. 4 are shown the coefficients of spatial correlation for the longitudinal component of pulsating velocity over a distance $y/H = 0.75$ ($\eta = 80$) from the wall. The measure of longitudinal vortices (along the x-axis) is much greater than of the transverse ones. As the authors' measurements have shown, this difference is also greater in the solutions studied here than in pure water streams.

One may postulate some relations between the properties of polyethylene oxide solutions and the character of turbulent pulsations in them.

It is well known that dissolved polyethylene oxide easily stretches into very thin and rather long fibers. If such fibers are formed in the stream under the influence of tangential stresses parallel to the direction of flow, these fibers can impede pulsations in the direction perpendicular to the fiber axes. The tangential stresses decrease as the distance from the wall increases and, therefore, this effect gradually weakens.

It must be emphasized, however, that the various polymers differ from one another with respect to their properties and that their flow pulsation levels are reduced by different mechanisms.

NOTATION

$\varphi = V/v^*$	is the dimensionless velocity;
$\eta = yv^*/\nu$	is the dimensionless coordinate;
l	is the mixing length;
σ_x, σ_y	are the mean-square pulsations of the longitudinal and of the transverse velocity component, respectively;
v^*	is the rate of shear stress at the wall;
U	is the average longitudinal velocity;
u'	is the instantaneous longitudinal velocity;
R_{xx}	is the correlation coefficient;
y	is the distance from the channel wall;
H	is the half-width of the channel;
Re	is the Reynolds number.

LITERATURE CITED

1. E. M. Khabakhpasheva, B. V. Perepelitsa, E. S. Mikhailova, V. V. Orlov, V. M. Karsten, and G. I. Efimenko, Heat and Mass Transfer [in Russian], Vol. 1, Énergiya, Moscow (1968), p. 165.
2. E. M. Khabakhpasheva and B. V. Perepelitsa, Inzh.-Fiz. Zh., 14, No. 4 (1968).