STUDY OF THE TURBULENT FLOW OF SOLUTIONS OF SURFACE-ACTIVE MATERIALS BY MEANS OF A LASER ANEMOMETER

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The results of measurements carried out on the mean velocity profile in aqueous solutions of surface-active substances (SAS) are presented. It is shown that the introduction of SAS additives to a turbulent flow of liquid leads to a considerable change in the distribution of the mean-velocity profile over the whole flow cross section.

It is well known that, by analogy with high-polymer compounds, the incorporation of certain surface-active substances (SAS) into aqueous solutions tends to reduce the hydrodynamic resistance. The effect of SAS (as represented by a mixture of potassium stearate and sodium palmitate) on the hydrodynamic resistance was studied in [1], and a relationship was established between the hydrodynamic resistance and the critical concentration of micelle formation in SAS solutions. Nevertheless, there are still hardly any reliable experimental data regarding the mean velocity profile in flows containing SAS.

In this paper we shall present the results of some mean-velocity measurements in a turbulent flow of aqueous SAS solutions. The measurements were carried out by means of an optical Doppler velocity meter (laser anemometer). Owing to the contactless nature of the method and also its high resolving power, this procedure enabled us to study the flow structure up to within 0.5-0.1 mm of the solid wall. The operating principles of this instrument were based on the well-known Doppler effect.

After encountering moving optical inhomogeneities in SAS solutions, the frequency of the scattered radiation of an optical quantum generator (laser) receives a displacement proportional to the rate of flow, and this displacement constitutes a measure of the velocity.

For purposes of measurement we used a differential optical scheme analogous to that described in [2]. The light beam from an LG-56 source was passed through a prism and divided into two parallel beams, being focused by means of a lens at the point of the flow under consideration. If the refracting lens is situated a reasonably long way from the plane mirror of the laser, the parallel nature of the beams imparts self-adjusting properties to this system. The probing beams intersect in the region of the construction (cross-over) at which the transverse dimensions of the beam are at their smallest while the wave vectors are plane. The light scattered from the volume formed by the intersection of these two beams is collected by the objective on the photocathode of an FÉU-14 photoelectron multiplier and causes a photocurrent component at the Doppler frequency to appear. The Doppler signal was analyzed by means of a selective V6-1 voltmeter acting on the principle of a narrow-band filter.

In carrying out the experiments we used closed-cycle experimental apparatus. The mean-velocity profile of a flow containing SAS additives (methaupon, dithalan) was measured in a channel of 20 × 100 mm cross section at a distance of 80 diameters from its initial point. The pressure drop ΔP was determined with a liquid manometer in a section of channel 3 m long. The SAS solutions were circulated by means of a centrifugal pump. The resistance in the SAS solutions under test diminished on adding traces of electrolytes; the experiments were, accordingly, carried out with an optimum concentration of electrolyte (NaCl), C = 3 and 8% for dithalan and methaupon, respectively.

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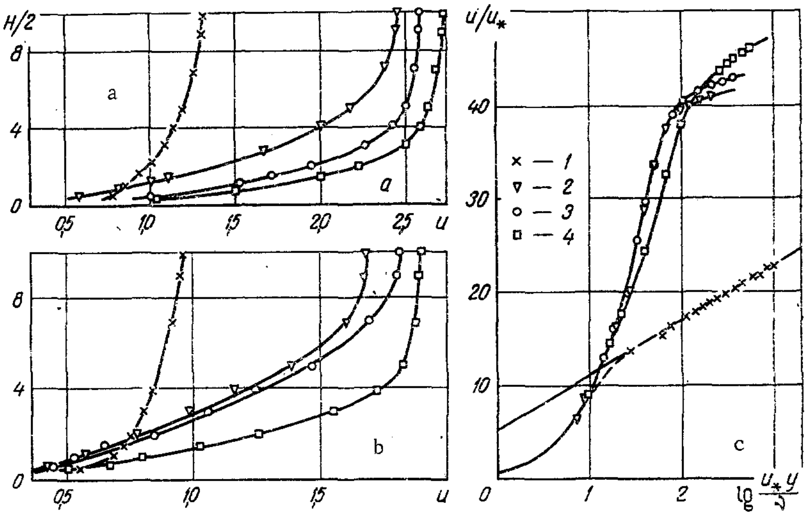

Fig. 1. Mean-velocity profile: a,c) $\Delta P = 73.6\ \mathrm{N/m^2}$; b) $\Delta P = 130.5\ \mathrm{N/m^2}$; 1) water; 2,3,4) methaupon concentration C = 0.45, 0.30, 0.15%, respectively; H/2, mm; u, m/sec.

A characteristic feature of SAS solutions is the fact that on passing through a pump they lose none of their hydrodynamic efficiency. This is evidently due to the fact that the SAS solutions have a micelle nature. A distinguishing feature of the structure and formation of micelles in solutions is that after mechanical breakdown as a result of "over-stress" the micelle structures are restored, i.e., a certain dynamic equilibrium is established in the flow between the breakdown and restoration of the micelles. Thus during a 7-h circulation of aqueous methaupon and dithalan solutions of constant concentrations in a closed circuit the reduction in resistance remained almost unaltered.

Measurements of the hydrodynamic resistance in aqueous methaupon solutions revealed that the reduction in resistance appeared at a concentration of C = 0.13%; then it rose sharply over a narrow range of concentration and reached a maximum value ($\Delta\lambda/\lambda = [(\lambda_1 - \lambda_2)/\lambda_1]100\% = 78\%$) at C = 0.15%. In the concentration range C = 0-0.15% there was a slight increase in the viscosity of the solution (from 1 to 1.18 cS). Further increasing the methaupon concentration leads to a sharp rise in viscosity (at C = 0.45% the viscosity of the solution equals 4.24 cS, while the reduction in hydrodynamic resistance is 62%). The mean velocity profiles were therefore measured at three methaupon concentrations: C = 0.15, 0.30, and 0.45%.

Figure 1a,b shows the mean-velocity profiles for the turbulent flow of aqueous methaupon solutions of various concentrations for two pressure drops. We see that the introduction of the methaupon additive leads to a substantial change in the mean-velocity-profile distribution over the cross section of the flow. With increasing methaupon concentration there is a tendency for the profile of the mean velocity to become laminar.

In Fig. 1c the experimental results are presented in universal coordinates. The dimensionless coordinate was calculated from the viscosity of the methaupon solution. We see that the velocity profiles in the transient zone vary far more sharply than the universal profile of water. With increasing concentration of methaupon the relative dimensions of the turbulent core of the flow decrease.

We may note that the velocity profiles in aqueous solutions of methaupon increase more rapidly than the velocity profiles in aqueous solutions of polymers [3, 4]. In other words, in aqueous solutions of SAS the tendency toward the laminarization of the velocity profile appears more sharply than in polymer solutions.

We also carried out some experiments with aqueous solutions of dithalan. The results showed that the optimum concentration of dithalan was higher than that of methaupon, and equalled 0.36%. The fall in resistance for this concentration was $\Delta\lambda/\lambda = 76\%$. However, we were unable to measure the mean-velocity profile in aqueous dithalan solutions at concentrations close to the optimum and higher, owing to the worsening of the optical transparency of the solution and hence the impossibility of separating the Doppler displacement frequency at the photocathode of the photomultiplier. Reliable results were only obtained for dithalan concentrations of C = 0.2% (the hydrodynamic resistance drop at C = 0.2% was $\Delta\lambda/\lambda$ = 32%). The measurements showed that the tendency occurred in the mean-velocity-profile distribution for aqueous dithalan solutions as for methaupon solutions.

Thus the foregoing experiments have shown that the optical Doppler velocity meter (laser anemometer) may be used for studying turbulent flows containing surface-active additives, provided that the solutions of these are sufficiently transparent.

NOTATION

u, mean longitudinal velocity component; u_*, dynamic velocity; $Re = u_* y/\nu$, Reynolds number; y, distance from wall; ν, kinematic viscosity; C, concentration; $\Delta\lambda/\lambda = [(\lambda_1 - \lambda_2)/\lambda_1] \cdot 100\%$, reduction in hydrodynamic resistance; λ_1, resistance for the flow of the pure solvent; λ_2, resistance for the flow of the solvent containing SAS additives; ΔP, pressure drop; h, height of channel.

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A SOLUTION METHOD FOR PROBLEMS OF FREE CONVECTIVE MOTION IN LIQUIDS

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The solution of the problem of free convective motion of liquids with high Prandtl and Schmidt numbers is obtained in the form of inner and outer asymptotic solutions which are joined together. Boundary conditions of the first or second kind are considered.

The interest in problems of free convection in liquids has definitely increased in recent years [1, 2]. This is due to the growing importance of liquids (Newtonian, as well as non-Newtonian) in chemical industry and power engineering. In the present article a solution method is described for the problem of free convective motion of liquids close to bodies immersed in the latter. The analysis is carried out by considering an example of a "power series" model of a liquid. In this case the dimensionless equations for stationary concentration thermally free convection in the boundary-layer approximation with the consistency coefficient dependence on heat taken into account are of the following form:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\partial}{\partial y}\left[\omega(\Theta_1)\left|\frac{\partial u}{\partial y}\right|^{n-1}\frac{\partial u}{\partial y}\right] + (\Theta_1 + K_1\Theta_2) M x^{\beta};$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0; \qquad (1)$$

$$u\frac{\partial \Theta_1}{\partial x} + v\frac{\partial \Theta_1}{\partial y} = \frac{1}{\mathrm{Pr}_1}\frac{\partial^2 \Theta_1}{\partial y^2},$$

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