NOTATION

y, distance to the smooth plane wall; δ, boundary layer thickness; u_*, dynamic velocity; ν, fluid viscosity; ⟨u⟩, mean flow velocity in the boundary layer; U, outer flow velocity; $y^+ \equiv yu_*/\nu$, dimensionless coordinate; f_1, F_1, f_2, F_2, notation for the universal dimensionless functions of the dimensionless arguments y^+; $\eta \equiv y/\delta$; $\xi \equiv \delta u_*/\nu$; A_{kl}, B_{mn}, numerical factors; $c_f = 2u_*^2/U^2$, local drag coefficient; $Re = U\delta/\nu$, Reynolds number.

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INFLUENCE OF TEMPERATURE ON THE HYDRODYNAMIC RESISTANCE REDUCTION EFFECT

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The effect of temperature on hydrodynamic resistance of aqueous solutions of polyethylene oxide is established experimentally.

Of the large number of studies dedicated to reduction in hydrodynamic resistance by addition of polymers, only in a few cases has the temperature dependence of this phenomenon been considered [1-4]. Analysis of these studies leads to the conclusion that the question of the effect of temperature on the effectiveness of polymer additives is still far from solved. At the same time clarification of this matter is not only of great practical interest, but would also permit a refinement of certain aspects of the Toms effect and a more detailed description of the structure of polymer solutions.

The materials studied in the present study were true aqueous solutions of polyethylene oxide (PEO), prepared by the firm WDN Chemicals, Ltd (England), having a molecular mass of $3 \cdot 10^6$. The hydrodynamic resistance was measured with the pumpless apparatus of [11], having the following basic parameters: working volume, $700 \cdot 10^{-6}$ m^3; tube diameter, $2.68 \cdot 10^{-3}$ m; channel length, 1.876 m. Measurement accuracy was of the order of 2%.

In the present study PEO solutions with a mass concentration of 0.003% were examined, this being the optimum concentration level at 18°C. This was done because the resistance reduction effect is more sensitive to changes in external conditions at concentrations equal to or less than the optimum one [3].

The experimental results shown in Fig. 1 indicate a decrease in effectiveness of the PEO additive with increase in temperature. It is also evident from the figure that at all temperatures studied, the transition from laminar to turbulent flow regime occurs at the critical Reynolds number, i.e., no protracted maintenance of laminar flow was observed. At 18 and 38.5°C the polymer additive begins to act effectively even in the transition region. At higher temperatures, after the transition to the turbulent regime, there exists a Reynolds number range in which the additive has no effect on flow resistance. The resistance reduction effect at these temperatures appears only after attainment of a threshold Reynolds number, the value of which increases with increase in temperature.

Since the studies were performed at elevated temperatures, it could be suggested that thermal destruction of the macromolecules had a significant effect on effectivenss of the polymer additive. This effect could not be avoided completely, so to reduce the effects of thermal destruction and improve repeatability of the results the solutions were maintained at elevated temperatures for identical times of 30 min. The following experiment was per-

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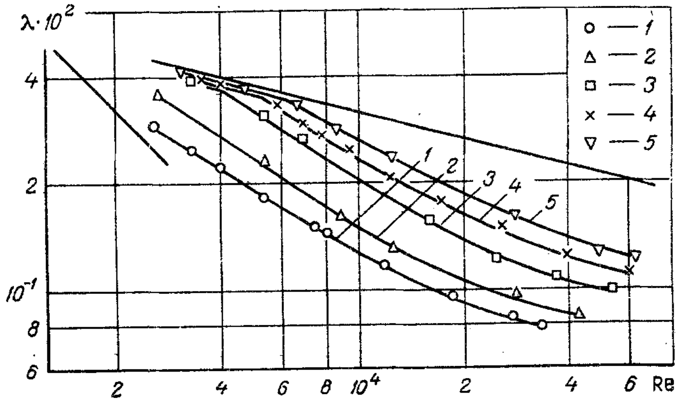

Fig. 1. Hydrodynamic resistance coefficient vs Reynolds number at various temperatures (°C): 1) 18; 2) 38.5; 3) 57; 4) 66; 5) 75.

formed to evaluate the effect of thermal destruction. A solution was maintained at 75°C for 30 min, then cooled rapidly to 18°C. Its effectiveness then proved to be 53%, as compared to 56% for a solution not subjected to heating. The resistance reduction effect at 75°C and the same Reynolds number Re = 8000 was 11%. From this it is evident that the reduced effectiveness of PEO solutions at elevated temperatures cannot be explained by thermal destruction.

It is generally accepted that resistance reduction is the result of the development of anisotropy in viscosity in a laminar sublayer, due to deformation and orientation of the polymer molecules. Therefore, for effective resistance reduction the macromolecules must have sufficiently large dimensions, by asymmetric, and oriented in the flow direction.

With increase in temperature the quality of water as a PEO solvent deteriorates [6]. This indicates an intensification of interaction between individual parts of the polymer macromolecules and an attenuation of the interaction between the polymer and the solvent [7], which should lead to a reduction in macromolecule dimensions. This is also indicated by the decrease in characteristic viscosity [8]. Moreover, increased solvent temperature intensifies Brownian motion, as a result of which macromolecule orientation along the flow is hindered. This all leads to an increase in hydrodynamic resistance.

According to the data of various authors [2, 9, 10] the effect begins to appear in aqueous solutions of PEO at temperatures of the order of 20°C after attainment of a threshold shear at the wall of $\tau_{\text{thr}} = 0.5\text{-}1.2$ N/m². In our experiment at t = 18°C in the transition region a shear stress of 3.5 N/m² was reached. Consequently, even while still in the laminar regime the macromolecules are oriented and deformed to a significant degree, and immediately after attainment of a turbulent flow regime effective reduction of hydrodynamic resistance occurs. With increase in temperature, the dimensions of the macromolecules decrease, and orientation is hindered. Thus, the effect begins to appear only after attainment of a threshold shear stress sufficient for the required deformation and orientation of the polymer molecules. With increase in temperature these threshold values increase. Thus at 57°C the threshold stress is 2.6 N/m², at 66°C, 3.2 N/m², and at 75°C it reaches 3.5 N/m².

The experimental results permit the following conclusions.

1. At constant Reynolds number, increase in temperature leads to a decrease in the hydrodynamic resistance reduction effect due to decrease in the dimensions of the PEO macromolecules and increased difficulty in orientation because of more intense thermal motion.

2. The hydrodynamic resistance reduction effect at elevated temperatures appears only after attainment of a threshold shear stress value on the wall, necessary for sufficient deformation and orientation of the macromolecules along the flow. With increase in temperature the value of this threshold shear stress increases.

NOTATION

Re, Reynolds number; τ_{thr}, threshold shear stress on tube wall, N/m²; λ, hydrodynamic resistance coefficient; t, temperature, °C.

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EXPERIMENTAL STUDY OF DYNAMIC EFFECTS IN BUBBLE BOILING OF LIQUIDS

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Results of an experimental study of the principles of the transient processes in vapor bubbles for a steplike increase in thermal load are presented.

In [1, 2] boiling was studied by use of a kinetic equation, the derivation of which was based upon consideration of the two-phase boiling layer as a set of gas bubbles, appearing and growing on the heating surface. The properties and evolution of the set of gas bubbles on the heat liberating surface were studied as a function of the conditions under which they appeared and the heat-exchange regime. It was found that in the solutions of the kinetic equations the sensitivity of parameters (mean values of current and separation radii, bubble frequency and distribution) were sensitive not only to external conditions, but also to the dynamics of change of these conditions. It develops that for a standard perturbation in the form of a steplike increase in thermal flux, the bubbles respond with a transition from an initial established state to a final one, which is not monotonic for all parameters. For example, the vapor content, which is an important characteristic of the boiling regime, passes through a maximum in the transition. The time at which maximum vapor content is achieved is related to the time at which the modal value of the separation radius is achieved by the expression

$$\tau(\varphi_{\max})/\tau_s = 3.5, \qquad (1)$$

in which the purely collective properties of the boiling process appear.

In calculating equipment operating with a boiling heat exchange liquid this effect is not considered. Nevertheless, one should not neglect the possible effects of flares in vapor content in transition regimes for heat-exchange devices which operate with high stresses on the heat-liberating surfaces. In particular, nonstationary heat liberation at the heated wall has been found to affect the value of the first critical thermal flux [1, 3, 4].

The purpose of the present study is an experimental verification of the theoretically predicted existence of a maximum in vapor content for steplike increase in thermal flux, quantitative measurement of the maximum parameters, and comparison with theoretical values.

The experimental technique used consisted of illuminating the layer of boiling liquid adjacent to the heat-liberating surface by a parallel light beam. With such illumination of the two-phase layer the attenuation of the light beam at the output due to intense scattering on bubbles is proportional to the total area of the projections of such bubbles intersecting the beam. If the size of the surface upon which boiling occurs is taken sufficiently small in the direction of light propagation, then mutual overlap of bubble projec-

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