Newtonian liquid; $\partial P/\partial z$, axial component of the pressure gradient; $I_2$, second invariant of the strain-rate tensor; F(V), functional to be minimized; $U(\chi_\alpha)$, an auxiliary function which is the solution of the Dirichlet problem for Poisson's equation in the region $\Omega$ under study; $\lambda(\chi_\alpha)$, an auxiliary functional depending on the form of the region $\Omega$ and the form of the rheological model; $C(\chi_\alpha)$, a constant contour line of $V(\chi_\alpha)$; dS, an element of arc; $\Gamma_1$, $\Gamma_2$, $\Gamma_3$, elements of the contour $\Gamma$; $\Gamma_0$, one of the lines of the orthogonal coordinate system; P, a point in $\Omega$, lying on one of the contour lines of $U(\chi_\alpha)$; $\tilde{P}$, $\tilde{P}_1$, points lying on $\Gamma_0$; $\dot{\gamma}(P, \Gamma_0)$, divergence of the contour lines; $P_1$, a point lying on the line from the second family of coordinate lines; $a$ and b, half-sides of the rectangle; $\varphi_0$, $\varphi_\infty$, fluidity of the liquid in the limits $\tau \to 0$ and $\tau \to \infty$; $\tau$, intensity of the tangential shear stresses; $\tau_1$, $\theta$, limit and measure of the structural stability of the liquid; n, rheological parameter; $\varepsilon$, fixed error of the iteration method; V, average flow rate of the flow; R, radius of the circle of the semicircular channel; $\mu_0$, Newtonian viscosity; and $\mu_{-1}$, function inverse to $\mu$.

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# A FEATURE OF HEAT TRANSFER TO ORGANIC HEAT-TRANSFER MEDIA

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It is shown that the nature of the changes in the wall temperature during heat transfer to an organic heat-transfer medium accompanied by the formation of deposits depends strongly on the roughness of the surface.

Heat transfer to organic liquids at high temperatures of the surfaces cooled by them is accompanied by the formation of carbonaceous deposits [1]. These deposits have very poor thermal conductivities and even in thin layers, they cause a considerable overheating of the walls or heat exchangers and other equipment in which the organic liquids are used as heat-transfer media, coolants, or for other purposes. This problem is particularly important in nuclear reactors. The formation of deposits on the surfaces of fuel elements is one of the main reasons which limits the use of reactors with organic heat-transfer media [2. 3].

Usually the formation of deposits causes a continuous increase of the temperature of the surface being cooled. However, many investigators have observed "anomalous" temperature changes of the surfaces being cooled in some experiments during the formation of deposits on the walls: during the first few minutes when the formation of the deposit occurs most intensively the wall temperature decreases, i.e., heat transfer improves.

This phenomenon has been related to distortions of the experimental results caused by the special features of heating the fuel element by an electric current with a nonuniform formation of the deposit on the wall surface, to the unsteady-state nature of the heat transfer in the first minutes of the experiment, and to various other causes.

We have experimentally established that the nature of the temperature changes of the surface being cooled during the formation of solid deposits on it depends on its roughness. "Anomalous" temperature changes of the wall are observed only in the experiments in which fuel elements with smooth (polished) surfaces are used.

The experiments were carried out in a laboratory heat exchange apparatus, which consisted of a closed hydraulic loop of stainless steel piping. The liquid being investigated was

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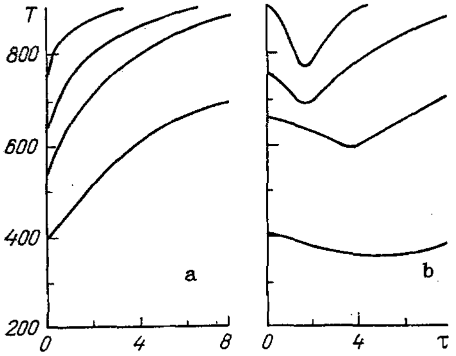

Fig. 1. Changes with time τ (min) of the temperature T (°C) of a surface being cooled as a result of the formation of a solid deposit on it: a) on rough surfaces; b) on smooth surfaces.

moved through the system by means of a gear pump. The working section of the apparatus was constructed in the form of an annular gap with a transparent outer wall (made of transparent plastic), which made it possible to observe the formation of the deposit during the time of the experiment and to examine the surface of the fuel element after the experiment. As the fuel element, use was made of an interchangable standard tube of 1Kh18N10T stainless steel of outside diameter 3 mm and wall thickness 0.5 mm, and a heated length of 60 mm. Heating of the fuel element was carried out by passing an electrical current through it. A description of this apparatus and the construction of the working section can be found in [4].

Below, the results are given of an experiment with kerosine T-1 with the following operating parameters: pressure, 45 bar; velocity of flow 3.75 m/sec; mass-average temperature 25-40°C.

The figure shows the results of experiments on fuel elements with natural roughness (transverse grooves of depth about 4 μm) with initial wall temperatures of 390, 540, 650, and 760°C and on fuel elements with smooth (polished) walls at initial wall temperatures of 400, 650, 750, and 900°C.

As can be seen from the figure, the formation of the deposit on the surface of a fuel element with a naturally rough surface caused a smooth increase in the wall temperature. On the fuel elements with polished surfaces the nature of the temperature change was quite different: in the first period, the formation of the deposit caused a decrease in the wall temperature, and then the wall temperature increased. It must be pointed out that the intensity of the formation of the solid deposit on the fuel elements with smooth and rough surfaces was the same. Such results have been observed not only in the experiments with kerosine T-1, but also with other organic liquids: toluene, n-heptane, di-isopropyl, cyclohexane, etc.

It is our view that the results which have been obtained can be explained as follows. The solid deposit causes roughness on the smooth surfaces, which improves the heat transfer and consequently leads to a reduction in the wall temperature of the heated surface. However, the deposits also have a poor thermal conductivity, and give rise to an additional thermal resistance, which causes the heat transfer to deteriorate. The interaction of these two factors therefore causes the complex dependence of the wall temperature on the time, as shown in the figure.

If the surface which is being cooled already has roughness elements in its initial state then the solid deposit cannot lead to an improvement of the heat transfer, and on the contrary, the deposit is formed primarily in the depressions of the roughness elements, which contributes additionally to the deterioration in heat transfer.

If standard tubes are used for the fuel elements, and no attention is paid to their roughnesses, then for the same operating conditions it is possible to find quite different characteristics for the change of temperature of the surface being cooled with time, as a result of the formation of the deposit.

The roughnesses of the tubes from which fuel elements are made are not regulated by All-Union State Standards, and may be different on different parts of the tubes. We have encountered tubes with roughnesses in the form of longitudinal grooves which could not be distinguished from smooth tubes in the experiments, as well as tubes with transverse grooves, analogous to roughness elements.

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# VELOCITY OF ULTRASOUND PROPAGATION IN SOLUTIONS OF HELIUM IN CRYOGENIC LIQUIDS

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The speed of ultrasound propagation is measured in neon–helium solutions. The effect of a helium impurity on ultrasound propagation speed in cryogenic liquids is analyzed.

The propagation speed of ultrasound in the low-frequency region where dispersion is absent is a purely thermodynamic quantity which relates compressibility and specific heat. Since, as a rule, the caloric properties of low-temperature liquids can be measured only with insignificant uncertainties, one can obtain the most complete information on equilibrium volume properties of such systems by using results of ultrasound velocity measurements together with the equation of state. It is also possible to use such data to verify theoretical models at a level significantly higher than is possible with the equation of state.

The solubility of helium in argon, and at sufficiently low temperature and pressure, in neon and hydrogen as well, is relatively low. This fact allows treating the general problem of describing the change in speed of ultrasound in solutions of He in Ar, Ne, and $H_2$ (for definiteness, $pH_2$) as one in which the He concentration is a small parameter. This problem has been solved within the framework of a model based on the method of distribution functions in the statistical physics of mixtures of simple liquids.

Experimental Results. Studies of ultrasound speed in Ne–He solutions were performed by the impulsive method at a frequency of 5 MHz along five isotherms at T = 26.95, 29.91, 32.89, 35.9, and 38.88°K at pressures up to 150 atm. The range of He concentration in the liquid Ne then comprised $x_2$ = 0-27 mol.%. The measurement technique and experimental equipment were described by the present authors in [1, 2]. The uncertainty in the ultrasound speed measurements was no greater than 0.1%. The experimental results are presented in Table 1. The He concentration in the solutions was determined from equilibrium phase diagrams [3]. The gaseous impurity (He) reduces the speed of ultrasound in Ne–He solutions as compared to the pure solvent (Ne), as in Ar–He [4] and $pH_2$–He [2], studied previously by the present authors. The higher the temperature, the higher the solubility of He in liquid Ne [3] and the more intense the reduction in ultrasound speed in the solution. Thus, at T = 26.95°K and p = 60 atm $|\Delta(p)| = u - u_{11}$ (where $u_{11}$ is the speed of ultrasound in pure Ne, u, the speed in the Ne–He solution) comprises ∼10 m/sec, while at T = 38.88°K and the same pressure $|\Delta u| \simeq 46$ m/sec.

Using density values for the Ne–He solutions calculated from data on dielectric permittivity [5] the adiabatic compressibility $\beta_S = 1/\rho u^2$ was determined. As is evident from Fig. 1, the He impurity increases $\beta_S$ of liquid Ne.

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