

NOTATION

Fr_m , modified Froude number, characterizing the action of centrifugal forces on the flow; Nu , local Nusselt number; \bar{Nu} , locally averaged Nusselt number; Re , Reynolds number; Pr , Prandtl number; T_w , temperature of the wall; T_f , flow temperature; u_{mm} , mean mass velocity; d_e , equivalent diameter; S , pitch of the tube coil; d , maximum size of the oval; ρ , density; μ , viscosity; δ , effective thickness of the near-wall layer; x , longitudinal coordinate, measured from the flow inlet into the bundle of tubes; l is the longitudinal coordinate, measured from the outlet of the bundle upwards along the flow; q_0 , specific heat flux; λ , thermal conductivity; $T_{m.f.}$, mean mass temperature of the flow; F , area of the throughput section of the bundle.

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HEAT TRANSFER TO AN EMULSION WITH HIGH SUPERHEATING OF ITS DISPERSE PHASE

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A method is described, and results presented, for measurement of the heat-transfer coefficient to an emulsion consisting of ether dispersed in glycerin.

In heat-treating metals, it is necessary to control the cooling rate. The latter depends on the dimensions and thermophysical properties of the specimen, as well as on the heat-transfer coefficient α . The value of α is determined by the velocity and properties of the coolant. If the specimen dimensions and material are given, then the coefficient α depends only on the properties of the coolant. Pure liquids and their mixtures, such as emulsions, are most frequently used at low temperatures. In this case, the cooling rate can be additionally controlled by changing the concentration of the components.

The present article attempts to measure the coefficient of heat transfer to an emulsion when droplets of the disperse phase are possibly superheated on the heat-emitting surface [1].

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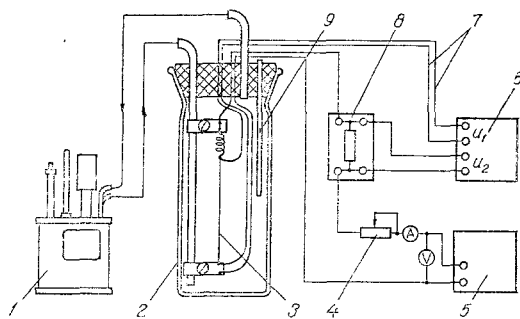


Fig. 1

Fig. 1. Experimental unit: 1) U-3 thermostat; 2) glass vessel; 3) wire-heater; 4) R314 resistance box; 5) VS-25 stabilized dc source; 6) R348 potentiometer; 7) potential leads from wire-heater; 8) standard R321 resistor; 9) thermocouple.

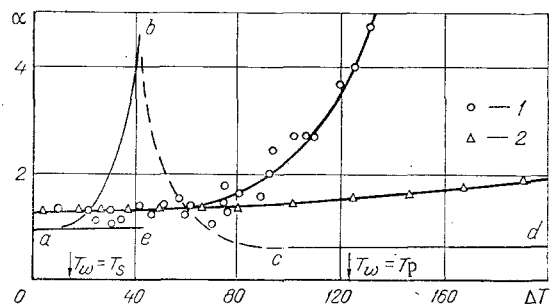


Fig. 2

Fig. 2. Dependence of heat-transfer coefficient α ($\text{kW}/\text{m}^2 \cdot \text{deg}$) on temperature difference $\Delta T = T_w - T$ ($^{\circ}\text{C}$): 1) emulsion of ether in glycerin; 2) glycerin; abcd) ether. Temperature of coolant $T = 20^{\circ}\text{C}$. The arrows denote the values of ΔT at which the temperature of the heating surface T_w was equal to T_s or T_p for the ether.

Figure 1 shows a diagram of the experimental unit. In the tests we cooled the surface of a platinum wire 3. The wire was 0.20 mm in diameter and 72 mm long. Working with a platinum wire, we may simultaneously determine both the power produced on its surface and its temperature. The power was determined from the voltage U and current I . For this purpose, we provided potential leads 7 and a standard R321 resistor 8. The current was established by means of an R321 resistance box 4 and was measured from the voltage drop on the potential leads of the resistor. The temperature of the surface of the wire was assumed to be equal to the temperature on its axis and was determined from its resistance. The wire was installed in a glass cylinder 2 through which the test liquid was pumped. The tests were conducted with analytically pure glycerin and pre-distilled anesthesia-grade ether, and with an emulsion prepared with these two substances. The test liquids were poured into the thermostat 1, thermostatted, and pumped through the cylinder 2. Their temperature was measured in the cylinder with a thermocouple 9. The emulsion was prepared in thermostat 1 by intensive mixing of the starting liquids with a paddle stirrer fitted onto the axis of the rotor of the thermostat pump.

The tests were begun with temperature calibration of the wire with a standard platinum resistance thermometer. The calibration was done in glycerin in the temperature range $20\text{--}280^{\circ}\text{C}$ with a current of 1 mA passed through the wire. The maximum calibration error was $\pm 0.05^{\circ}\text{C}$ at the highest temperature and was due mainly to fluctuations in the temperature of the glycerin in the cylinder 2.

After the calibration, a new batch of glycerin was poured into the thermostat 1, since the prolonged heating of the liquid to 280°C altered its composition. This was evidenced by its color change.

The heat-transfer coefficient was measured with the glycerin at a temperature of 20°C . The glycerin was pumped through the cylinder 2 at a velocity of roughly 0.01 m/sec. This velocity was chosen because, first, there was no marked increase in temperature in the cylinder 2 and, second, the heat-transfer coefficients with and without pumping differed little from each other. This was important for comparison of the resulting data with the data obtained in [2-6].

After work was completed with the pure glycerin, we conducted tests with the emulsion of ether in glycerin. This emulsion was chosen on the basis of considerations having to do with convenience in conducting the experiment. The concentration of ether was always 10 vol. %. The emulsion was prepared without emulsifiers to exclude effects associated with their use. Such emulsions are unstable and rapidly layer out. Thus, to prevent separation into layers, the emulsion was subjected to continuous intensive mixing in thermostat 1. There were no noticeable changes in the dispersion of the emulsion while it was present in cylinder 2. The dispersion of the emulsion was determined under a POLAM R-111 microscope. The mean volume diameter of the droplets [7, p. 157] was the same before and after the emulsion passed through cylinder 2 and was equal to roughly 0.005 mm. The temperature of the emulsion during all measurements was a constant 20.0°C .

The experiment results are shown in Fig. 2. The heat-transfer coefficient is shown in the form of its dependence on the difference in temperature $\Delta T = T_w - T$ between the wire T_w and the liquid in the volume. The heat-transfer coefficient α was calculated from the formula

$$\alpha = \frac{UI}{(T_w - T) \pi L d}$$

In the investigated temperature range, there is a slight increase in the heat-transfer coefficient to the glycerin (point 2 in Fig. 2) with an increase in the temperature difference ΔT . The character of the heat transfer in this case is similar to the heat transfer which occurs with free convection in a large volume [3, 4].

The character of heat transfer with the emulsion (points 1 and 2) changes appreciably with the transition from one temperature interval to another. The character of heat transfer at surface temperatures T_w below the temperature of saturated ether vapors T_s at atmospheric pressure is nearly the same as that observed with pure glycerin. An unstable heat-transfer regime, with fluctuations in the value of α , is seen in the interval from T_s to a temperature close to the achievable level of superheating of ether $T_p = 143^\circ\text{C}$ [8]. This interval is characterized either by unexpected, sudden boiling up of individual ether droplets on the surface or slow vaporization of the droplets. The probability of sudden boiling increases with approach of the attainable level of superheating of the ether. Sudden boiling is accompanied by an intensification of heat transfer, while slow vaporization is associated with a deterioration in heat transfer connected with insulation of the surface by the vapor which is formed. After a certain amount of time has elapsed, convective flows carry off the vapor and the rate of heat transfer increases. The amplitude of the fluctuations in heat-transfer rate may be judged from the spread of experimental points in the temperature intervals examined. This spread reaches 30% of the mean value of α .

A regime of stable heat transfer is seen in the temperature interval close to the temperature of attainable superheating of ether T_p . The heat-transfer coefficient is increased several times here. Ether droplets boil up explosively on the surface and there is intensive agitation of the boundary layer. The character of vapor formation in the emulsion is very similar to that in nucleate boiling in the pure liquid. For comparison, curve abcd in Fig. 2 shows the dependence of the heat transfer to the ether from a platinum wire of the same diameter with free convection ae, nucleate boiling ab, film boiling cd, and mixed boiling bc. A distinctive external characteristic of heat transfer to the emulsion is a substantial shift in the beginning of the sharp increase in heat transfer in the direction of higher temperatures. It was also noted that the maximum of the heat-transfer coefficient for boiling of the emulsion is located in the same temperature interval associated with the heat-transfer minimum for pure-ether boiling caused by the transition to film boiling.

Thus, using an emulsion as the coolant, it is possible to shift the maximum cooling rate in the direction of higher temperatures compared to cooling with a boiling pure liquid.

NOTATION

α , heat-transfer coefficient; $\Delta T = T_w - T$, difference between temperature of heat-emitting surface T_w and temperature of the liquid in the volume T ; U , voltage drop on the wire with the passage through it of an electrical current equal to I ; L and d , length and diameter of wire; T_s and T_p , temperatures of saturated vapors of ether and limiting superheating of ether at atmospheric pressure.

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