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TRANSITION TO FILM BOILING OF HELIUM UNDER STEPPED THERMAL LOADING

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The results of an experimental investigation of the transition to film boiling of helium under stepped thermal loading, obtained in a wide range of pressures, are presented.

The critical point of heat transfer accompanying nonstationary boiling of helium does not appear immediately after thermal loading, but rather after some time τ_{cr}, during which the intensity of the heat transfer remains quite high [1-4]. The length of time indicated is of considerable interest for calculations of the stability of superconducting magnets under pulsed thermal loads [5].

In this work we studied the effect of a heat flow q and saturation pressure p on the value of τ_{cr} during boiling of liquid helium in a large volume under conditions of a jump in the intensity of heat efflux from the heated wall. As a test element we used a 65 × 4 × 0.05 mm working section of a brass foil described in [6]. The experiments were performed under the saturation pressure of helium 40-200 kPa with different orientation of the heat transfer from the surface in the field of gravity.

The value of τ_{cr} was determined from the oscillograms of the nonstationary thermal process (Fig. 1), on which the change in the working current of the heater I and the overheating of the wall of the test element ΔT were recorded simultaneously. The onset of film boiling was conditionally taken as the time when the overheating of the wall became 30% higher than the value corresponding to nonstationary bubble boiling of helium. As is evident from Fig. 1, in the course of almost the entire time τ_{cr} the temperature of the wall remains practically constant, with the exception of small intervals of time at the beginning of the transient process and prior to the onset of film boiling. Thus, within the time τ_{cr} the amount of heat expended on heating the working section can be ignored, and the heat flux density on the heat-exchange surface can be defined as $q \approx Q/F$.

The experiments showed that τ_{cr} depends in a complicated manner on the thermal load, pressure, and orientation of the heating surface. Figure 2 shows in the $q-\tau_{cr}$ plane the experimental data, obtained with different angles of inclination of the heating surface to the horizontal under pressures close to atmospheric pressure. Analogous results were also ob-

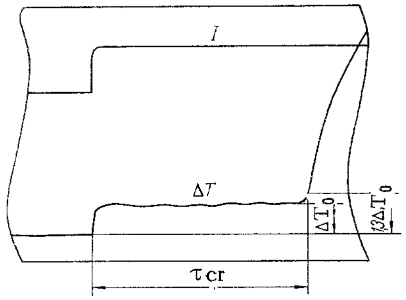

Fig. 1. Oscillogram of the nonstationary thermal process.

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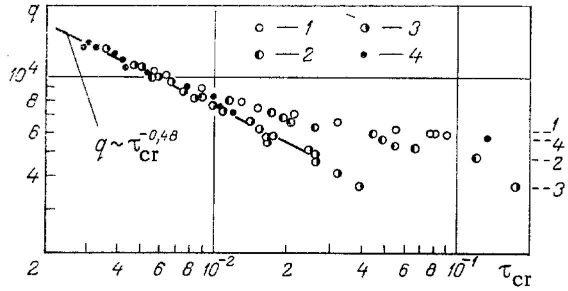

Fig. 2

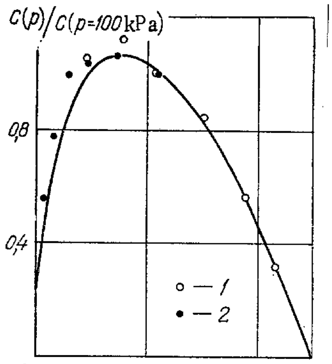

Fig. 3

Fig. 2. Effect of heat flow on length of time from the moment of thermal loading to the onset of film boiling of helium. Experimental data for atmospheric pressure and different orientations of the heating element: horizontal orientation of the 65-mm side (the heating surface is oriented upwards (1), vertically (2), downward (3), and vertically (4). q, W/m²; τ_{cr}, sec.

Fig. 3. Relative change in the coefficient of proportionality C in formula (1) accompanying an increase in reduced pressure p/p_{cr}: 1) experimental data from this work; 2) data from [3]; the curve shows calculations using formula (2).

tained with other helium saturation pressures. The broken lines on the right side of the figure mark the values of the critical heat flow $q_{cr,st}$ for different orientations of the working section, measured under conditions of a slowly increasing thermal load. As shown in [6], in the range of helium saturation pressures studied the quantity $q_{cr,st}$ is for all practical purposes the same as $q_{cr,nst}$.

It is evident from Fig. 2 that as the thermal load is increased, near $q = (1-2)q_{cr}$, the value of τ_{cr} decreases sharply. At the same time, the absolute value of τ_{cr} is strongly affected by the orientation of the heating surface. The values of τ_{cr} are maximum for a horizontally oriented test element, whose heating surface is oriented upward. When q is further increased, the effect of the orientation is not observed and the relationship of q to τ_{cr} can be described by a simple power-law function

$$q = C\tau_{cr}^{-n}, \tag{1}$$

where the exponent n for different pressures remains virtually constant in the range from 0.43 to 0.48. The value of n obtained agrees well with the data in [1, 2, 4] and the experiments in [3]: $n \simeq 0.35$-0.4.

The coefficient of proportionality C in the formula (1) depends on the pressure. The substantial differences in the experimental conditions did not make it possible to compare our data with the data in [1-4] on the absolute magnitude. In relative coordinates C(p)/C(p = 100 kPa) — p/p_{cr} (Fig. 3), however, the results of this work are in satisfactory agreement with [3]. The curve in Fig. 3 corresponds to the dependence [7]

$$\frac{C(p)}{C(p=100\ \text{kPa})} = 0.28 + 7.52\left(\frac{p}{p_{cr}}\right) - 27.1\left(\frac{p}{p_{cr}}\right)^2 + 47.6\left(\frac{p}{p_{cr}}\right)^3 - 44.0\left(\frac{p}{p_{cr}}\right)^4 + 15.7\left(\frac{p}{p_{cr}}\right)^5, \tag{2}$$

which describes the change in the stationary critical heat flow $q_{cr,st}$ as a function of the boiling pressure of helium in a large volume. As evident from Fig. 3, the use of the dependence (2) permits calculating, to within 20%, for a known value of C for atmospheric pressure the values of C for other pressures.

NOTATION

C, coefficient of proportionality; F, area of the heating surface, m²; I, current, A; q, heat flux, W/m²; $q_{cr,st}$ and $q_{cr,nst}$, stationary and nonstationary critical heat fluxes, W/m²; Q, intensity of the jump in the heating, W; n, exponent; p, pressure, Pa; p_{cr}, critical pressure, Pa; ΔT, overheating of the wall, °K; τ_{cr}, time interval from the moment that the thermal load is applied to the onset of film boiling, sec; ΔT_0, overheating of the working section in the presence of nonstationary bubble boiling, °K.

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INFLUENCE OF PARTICLES ON THE TURBULENT HEAT-TRANSFER INTENSITY

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The influence of particles on the intensity of turbulent heat transfer by a gas-suspension is investigated on the basis of a system of equations of the second single-point moments of the carrier phase velocity and temperature fluctuations.

A study of the regularities of particle influence on the turbulent transfer of momentum and heat of dusty flows is of great interest for analyzing the operation of installations in which the flows of gas suspensions are used as heat carrier [1]. The majority of experimental and theoretical researches on the heat elimination of dusty flows is devoted to a study of the influence of the particle size and concentration on the heat transfer [1-3]. At the same time experimental investigations of the relative heat elimination of dusty gases show that the magnitude of the solid phase contribution to the heat transfer depends substantially on the ratio between the specific heats of the particle and gas materials and not only on the particle size [1, 2]. Equations are obtained in this paper that describe the turbulent heat diffusion and the intensity of the temperature fluctuations of a carrier gas with particles and a qualitative analysis is performed of the influence of the particle concentration, size and specific heat on the turbulent heat flux, the temperature fluctuation intensity, and the turbulent Prandtl number.

1. The heat-transfer equations for a gas with particles and solid phase have the form

$$\frac{\partial \Theta_1}{\partial t} + U_k \frac{\partial \Theta_1}{\partial x_k} = \chi_1 \frac{\partial^2 \Theta_1}{\partial x_k \partial x_k} - \frac{c_2}{c_1} \Phi \frac{1}{\tau_\theta} (\Theta_1 - \Theta_2), \tag{1}$$

$$\frac{\partial \Theta_2}{\partial t} + V_k \frac{\partial \Theta_2}{\partial x_k} = \frac{1}{\tau_\theta} (\Theta_1 - \Theta_2), \tag{2}$$

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