CRITICAL HEAT FLUX AS A FUNCTION OF HEATER SIZE FOR A LIQUID BOILING IN A LARGE ENCLOSURE

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Results are presented of an experimental investigation to determine q_* for ethanol boiling under free convection on surfaces insulated on both sides.

This work is a continuation of experiments published in [1, 2], and its objective is to broaden the range of the test parameters. The experiments were carried out with ethyl alcohol at saturation temperature on flat horizontal plates whose width varied from 5 to 50 mm and for a pressure variation $(1-52) \cdot 10^{-5}$ N/m^2.

Two limiting and directly opposite situations were examined. a) The first case is that of a plate thermally insulated on its lower side, which corresponds to the situation analyzed theoretically in [3, 4], where the hydrodynamic nature of the critical heat flux was considered. Only the top surface of the plate generates heat.

b) In the second case the plate is thermally insulated on its top side, and only the lower surface emits heat.

Separate experiments were reported in [6-12] to determine the critical heat fluxes during boiling of various liquids on inclined thermally insulated surfaces. A review of this work was given in [13, 14]. The author of [13] attempted to calculate the influence of the angle of the heat-generating surface to the horizontal and proposed an empirical relation to modify the equation in [3].

In [15, 16] the relations obtained in [1, 2] for the variation of critical heat flux with variation in diameter of the heating element were described analytically. In these papers it was suggested that the stability criterion is determined in the end result by the nature of variation of the separated size of the bubble which grows on the curved surface of cylindrical heaters of different size. In [17, 18] relations were given for the stability parameter as a function of the viscosity of the heat-transfer agent.

Our tests were carried out on a piece of equipment which has been described in [5]. The single difference, in principle, in the present investigation is that a working volume of appreciably larger size was used. The working sections were flat horizontal stainless-steel plates, of thickness 0.5 mm, length 150 mm, and width b = 5, 10, 20, 30, and 50 mm (Fig. 1). The heat-generating plate was attached to an insulating spacer which was attached, in turn, to a textolite block of practically the same width as the experimental section. The textolite

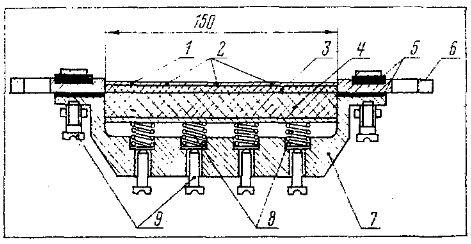

Fig. 1. Experimental section: 1) heat-generating surface; 2) thermocouples; 3) insulator; 4) textolite; 5) electrical insulation; 6) current terminal; 7) steel body; 8) springs; 9) screws.

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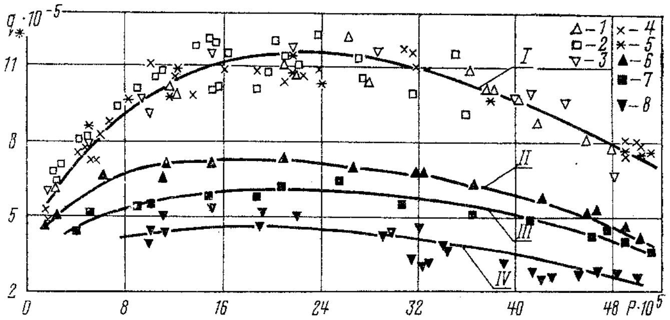

Fig. 2. q_* as a function of P (reference t = t"): I) plates insulated below or held in place at a narrow edge; 1) b = 5.0; 2) 10; 3) 20; 4) 30; 5) 50 mm; II-IV) plates thermally insulated on the top surface; 6) b = 5.0; 7) 10; 8) 20 mm.

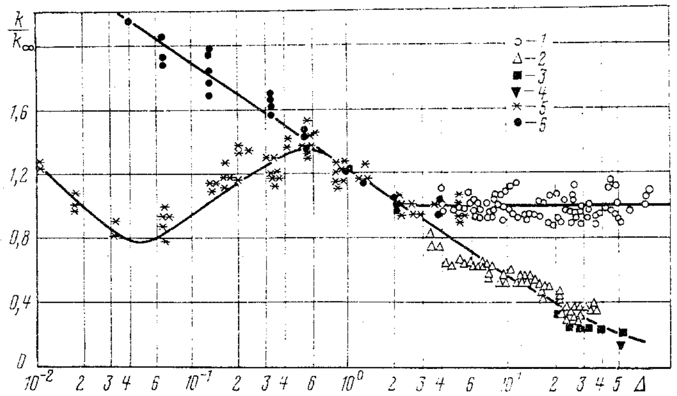

Fig. 3. Correlation of the experimental data using the coordinates of Eq. (1): 1,2) ethanol, 1) plates insulated below, 2) insulated above; 3,4) helium, 3) plates insulated above [7], 4) insulated below [9]; 5) cylindrical heaters t = t" [1], ethanol; 6) the same, z ≥ 18 [2], ethanol.

block was held down on the experimental plate by springs attached to the steel body. Three thermocouples, connected in a circuit which would cut the heating when critical boiling occurred, were located below the plate at different points along its length.

In the tests with the heat-generating surface facing downward and insulated on the top side, it is very important that the plate be strictly horizontal in both directions for reproducibility of the data. The working volume had viewing windows so that one could observe the boiling process and the location of the working section. The working section was heated by an alternating current from a power transformer, connected to a controller. In each section 5-10 measurements of the critical heat flux were taken at different pressures and then a new section was set up.

Figure 2 shows the experimental results in q_*–P coordinates. It can be seen (line I) that all the experimental points for the plates insulated on the bottom side are independent of the plate width and fall around a single line with a scatter of ± 15%. By averaging the test data we constructed a line using the relation proposed in [3], with k = 0.145. Here we have 24 measured values of q_* at various pressures with b = 30 and 50 mm with no thermal insulation, held on a narrow edge with respect to the gravitational force (slope angle 90°). The results of these tests also coincide with data for plates thermally insulated on the lower side.

Curves II-IV show the results of the measurements of q_* obtained for plates of various widths, thermally insulated on the top side. The increase in plate width leads to a considerable reduction in the heat flux. This rapid decrease in q_* is due to the fact that it is difficult for vapor to escape from the lower surface. Conditions are favorable for vapor bubbles to coalesce and for a vapor film to form, which substantially reduces the heat flux.

The results of our experiments have been expressed in terms of the coordinates

$$q_*/q_{*\infty} \equiv k/k_\infty = f(\Delta) \quad (1)$$

and are shown in Fig. 3, where $\Delta = b\left(\frac{\gamma' - \gamma''}{\sigma}\right)^{1/2}$ is the Weber number; q_*, $q_{*\infty}$ are the critical heat flux (in W/m^2) and the critical heat flux on the plate thermally insulated on its lower side, other conditions being equal; and k and k_∞ are the stability criteria for the above conditions.

In the general case, according to our data presented in [2]

$$q_{*\infty} = q_{*0}\left[1 + 0.09\,\frac{c\vartheta}{r}\left(\frac{\gamma'}{\gamma''}\right)^{3/4}\right], \quad (2)$$

where $z = \frac{c\vartheta}{r}\left(\frac{\gamma'}{\gamma''}\right)^{3/4}$ is a parameter which takes into account the underheating of the liquid up to the saturation temperature; and q_{*0} (W/m^2) is the critical heat flux at the saturation temperature on a flat thermally insulated plate.

All the experimental points are grouped around two lines. One line is a rather good correlation of the experiment for plates insulated below and indicates that the stability parameter does not change; this agrees with the conclusion derived theoretically from the hydrodynamics of the heat crisis [3, 4]. Similar experiments, described in [6, 7, 9, 10] and conducted with different heat-transfer agents, agree quantitatively to a satisfactory degree with our data, in the coordinates used. The results of this work have been generalized in detail in [14].

The second line correlates the results of tests where the plate is insulated on the top. The relative value of the stability parameter decreases sharply. Figure 3 shows the data of [7, 9], where the heat crisis was determined during boiling of helium on disks insulated on the top. These data agree satisfactorily with our results. To complete the picture of q_* as a function of heating element size, Fig. 3 shows our earlier published data from [1, 2] for boiling of ethanol.

The present investigation has expanded the range of variation of the Weber number by more than an order of magnitude (from 6 to 75). From the results we can state that the Weber number must be taken into account in calculating q_* in actual experiments where its value exceeds 3.0.

The lines which we have shown are limit boundaries for calculating q_*, between which the critical heat fluxes fall for heat-generating surfaces of different geometries and orientations.

NOTATION

q_*, critical heat flux, W/m^2; $q_{*\infty}$, critical heat flux on a plate insulated on its lower side, W/m^2; q_{*0}, critical heat flux at the saturation temperature, W/m^2; P, pressure, N/m^2; b, width of the experimental section, m; γ', γ'', specific weight of the liquid and the vapor, kg/m^3; σ, surface-tension coefficient, N/m^2; c, specific heat of the liquid, kJ/kg·deg; $\vartheta = t'' - t$, volume average of the underheating of the liquid up to the saturation temperature, °C; t'', temperature of the saturated vapor, °C; k and k_∞, stability criteria, determined experimentally for an arbitrary section and for a plate insulated below, other conditions being equal.

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HEAT TRANSFER IN A LAYER OF LIQUID ON A ROTATING ARCHIMEDES SPIRAL TAKING ACCOUNT OF THE ENTRANCE REGION

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The effect of the entrance region on the hydrodynamics and heat transfer in a layer of liquid on a rotating surface is studied.

Hydrodynamics and mass transfer in a layer of liquid on a rotating Archimedes spiral in the absence of wave formation were investigated earlier [1] by the integral relations method. In the present article we use the work method [2] to study heat transfer in a laminar liquid film on an Archimedes spiral rotating with a constant angular velocity ω, taking account of the entrance region.

We choose the origin of coordinates in the plane of the outlet, the x axis along the flow, and the y axis normal to it. The x, y coordinate system is fixed with respect to the streamlined solid surface. It is assumed that the pressure gradient in the liquid layer is produced by the rotation of the spiral apparatus and that the longitudinal rate of change of the flow parameters is much smaller than the transverse. We assume that the thermophysical parameters are constant and that the equation of the Archimedes spiral in polar coordinates is $r = A\theta$, where $A > 0$. Under these assumptions the hydrodynamics and energy equations take the form

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = F_x - \frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\frac{\partial^2 u}{\partial y^2},$$

$$-\frac{u^2}{R(x)} = F_y - \frac{1}{\rho}\frac{\partial p}{\partial y}, \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = a\frac{\partial^2 T}{\partial y^2}, \tag{2}$$

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