STUDY OF THE CRITICAL HEAT FLUX UNDER TRANSIENT CONDITIONS

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The results of an experimental study of the critical thermal flux under transient conditions when a liquid boils in a large volume are presented.

The appearance of various new engineering systems with high thermal stresses at the hot surfaces has stimulated interest in the critical boiling mode under transient conditions. Dynamic effects of changes in the mode of heat transfer should be felt especially during an instantaneous increase in the heat load.

Critical boiling during a sharp increase of heat load has been studied by several authors [1, 2]. Experimental results with organic liquids have been reported in [1], but no consideration was given there to the thickness of the heating element. Subsequent reports were published in [2] on similar experiments with water, but the authors there conclude that the critical heat flux in a large volume is the same under steady and transient conditions of heat transfer. Our studies have shown that such a conclusion can be valid only for a heating element the wall thickness of which exceeds a certain minimum.

Our experiments were performed on an apparatus the electrical part of which is shown schematically in Fig. 1. The test element was a shaped plate of Kh18N9T steel with three lugs, for measuring the voltage drop across the active segment and for switching on the automatic control device. The active segment of the test element had an area of 30 × 10 mm with the active surface turned up. Its underside was thermally insulated by means of the Textolite segment 200 mm in radius over which the test element had been spread. Both were separated by a thin (0.2 mm thick) Teflon-4 sealing pad; owing to the water repellant qualities of the latter, the possibility of water oozing under the active surface was thus eliminated. The test element, together with the entire assembly, was placed in a vessel with a double wall containing doubly

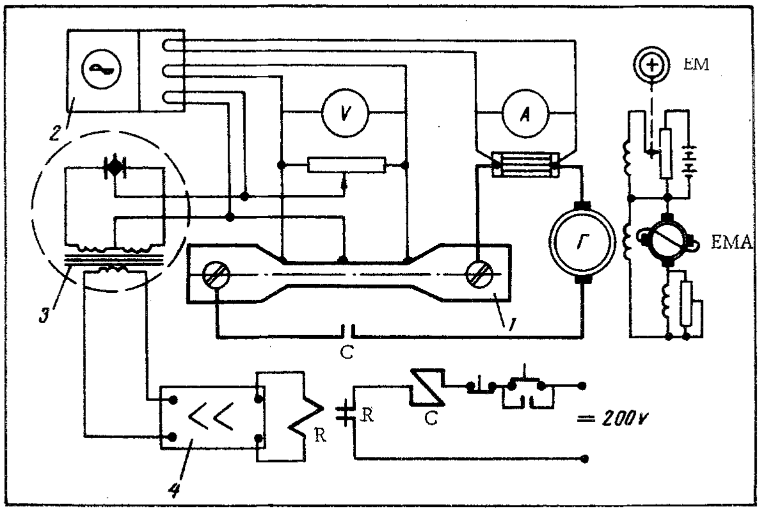

Fig. 1. Basic electric circuit of the test apparatus: 1) active segment; 2) oscillograph; 3) vibrator; 4) amplifier.

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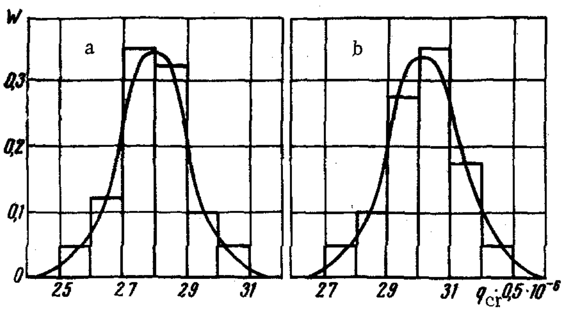

Fig.2

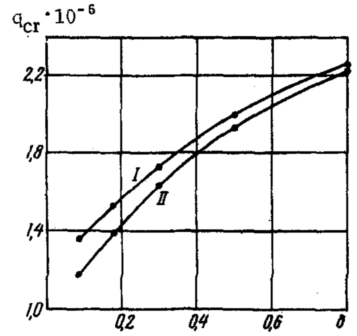

Fig.3

Fig.2. Histogram and smoothing curve which represent the distribution of transient (a) and steady-state (b) critical heat fluxes: $q_{cr}\cdot 0.5\cdot 10^{-6}$ W/m^2.

Fig.3. Graphs representing the steady-state (I) and the transient (II) critical heat flux q_{cr} (W/m^2) as functions of the wall thickness δ, mm.

distilled water. The space between the two wall sections was also filled with water. The water was maintained at the boiling temperature by means of a control heater. A heat load was applied to the active part of the element by passing through it a direct electric current. All tests were performed under atmospheric pressure in water which had been heated up to saturation temperature.

Preliminary tests had shown that, in determining the magnitude of the critical heat flux at the instant when the plate overheats, even under carefully maintained constant conditions the scatter of experimental points is too great. In order to synchronize exactly the onset of critical boiling and the interruption of electric current flow, we used an automatic control device operating on the principle of a balanced dc bridge with the work piece connected into two of its arms as shown in Fig.1.

The onset of critical boiling was detected by an unbalancing of the bridge and the appearance of a signal across its output diagonal. This signal was converted to an ac signal by means of a vibrator and, after amplification, was applied to relay R, the normally-closed contacts of which had been connected in series with the coil of power contactor C.

The load was removed 0.25-0.35 sec after the onset of critical boiling. The current, the voltage across the active segment, and also the instant at which critical boiling began were recorded on the strip chart of a type N-700 loop oscillograph.

The magnitude of the steady-state critical heat flux was determined by the following procedure: after the load had reached a level corresponding to 40-50% of the critical heat flux, the electric motor which drove the potentiometer in the amplidyne excitation circuit (Fig.1) was started; in this way, the load was increased monotonically until the onset of critical boiling and at that instant the generator was switched off by the automatic device; the instant at which critical boiling had begun was then read on the oscillogram along with the electric power, and from the latter the magnitude of the critical heat flux was now calculated.

The magnitude of the transient critical heat flux when electric power was instantaneously switched on was determined.

The load was increased gradually until the automatic device began to operate, after which it was decreased gradually until the automatic device ceased to operate. The magnitude of the heat flux corresponding to the switch-off point was taken as that of the transient critical heat flux.

We conducted five series of tests on plates 0.09, 0.18, 0.30, 0.050, and 0.80 mm thick. In each series we obtained 50 steady-state and 50 transient test points. A statistical distribution of critical heat flux values for the 0.18 mm plate is shown in Fig.2. It has been assumed here that this is a normal distribution. A χ^2 (Pearson) test has shown that our hypothesis agrees with the experiment at probability level of at least 70%. A similar analysis was performed for all the remaining test series.

Average values on the basis of all test series have been plotted in Fig.3, according to which the critical heat flux is greater under steady than under transient conditions. For the 0.09 mm plate the difference between them amounts to over 12%. This difference decreases as the plate thickness increases and is only 1.5% for the 0.8 mm plate. A comparison between our results pertaining to the transient critical heat flux for water and the results obtained in [2] for ethyl alcohol indicates qualitative agreement. In our case, however, the relation $q_{cr.tr} \approx \delta^{0.27}$ reflects a stronger dependence on the thickness than the relation $q_{cr.tr} \approx \delta^{0.2}$ in [2].

NOTATION

δ	is the thickness of the heating surface;
q_{cr}	is the steady-state critical heat flux;
$q_{cr.tr}$	is the transient critical heat flux.

LITERATURE CITED

1. V.M. Borishanskii and B.S. Fokin, Trudy TsKTI, No. 58, 58-64 (1965).
2. V.M. Borishanskii and B.S. Fokin, Trudy TsKTI, No. 78, 31-62 (1967).