EXPERIMENTAL STUDY OF THE MECHANISMS OF THE ACTIVE CENTERS OF BOILING

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The article presents the results of experimental studies of the mechanisms of operation of the active centers of vaporization when water boils under different temperature conditions.

Authors dealing with the quantitative description of the process of heat exchange in nucleate boiling usually concentrate on parameters of this phase transformation, such as frequency of detachment f, the mean detachment diameter D_0, the product fD_0 (usually called the "growth rate" of the bubbles on the heating surface), and also the density n of the active centers [1]. It is deemed self-evident that "the mean productivity of the center of vaporization under conditions of developed boiling is a practically constant magnitude" [2]. In other words, most researchers believe that during boiling the process of bubble formation in each active center is stable.

However, it follows from our previously developed notions [3-5] on the mechanism of the origin, growth, and detachment of bubbles from depressions in the heater surface that the regime of vaporization is by no means always steady. Moreover, in dependence on the conditions of boiling, there are bound to exist different unsteady regimes of operation of the active centers.

The present article briefly explains the results of the experimental study of the mechanisms of the bubble generating action of depressions in a heater when water boils under different temperature conditions.

For filming the processes occurring inside the center of vaporization, we used three-layered transparent surfaces of boiling. With a special scalpel a fine notch was made in the rib of the central layer, and this notch then served as vaporization center. The depths of the pores thus made varied from 0.3 to 1.0 mm, and the width of the mouth from 0.05 to 0.12 mm. Then the layers were carefully glued together and thermostated. Particular care was taken to ensure that no gas inclusions remained between the layers because they would distort the pattern of the center's operation. The obtained surface was glued to a nickel foil that had been heated by electric current. The finished heater was heat-insulated from below with glass-fiber reinforced textolite so that the heat was released predominantly through the surface of boiling. The temperature gradient was measured with the aid of a copper–constantan thermocouple, and the temperature within the liquid by a mercury thermometer with a scale division of 0.1°K.

The process of boiling was filmed with a high-speed film camera SKS-1M with a telescope lens TLA. The filming was done in transmitted light at the rate of $2 \cdot 10^3$-$3.5 \cdot 10^3$ frames per sec.

An analysis of the obtained films provided the basis for revealing the following regimes of vaporization.

1. Steady regime. It is encountered with saturated boiling of the liquid on the heating surface with large temperature gradient ΔT (in our experiments, $\Delta T > 5°K$). A characteristic of this regime is that, during the time of boiling, the vapor phase fills the entire space of the depression, and this depression grows monotonically above the mouth of the pore from some smallest volume V_0 to the maximum V^*; at that instant a rapidly narrowing neck forms on the contour of the protruding part of the bubble, and the upper spheroidal region (with the volume $V^* - V_0$) becomes detached and comes to the surface. In the depression there remains a bubble separated from the liquid by a protruding segmentlike cupola (Fig. 1).

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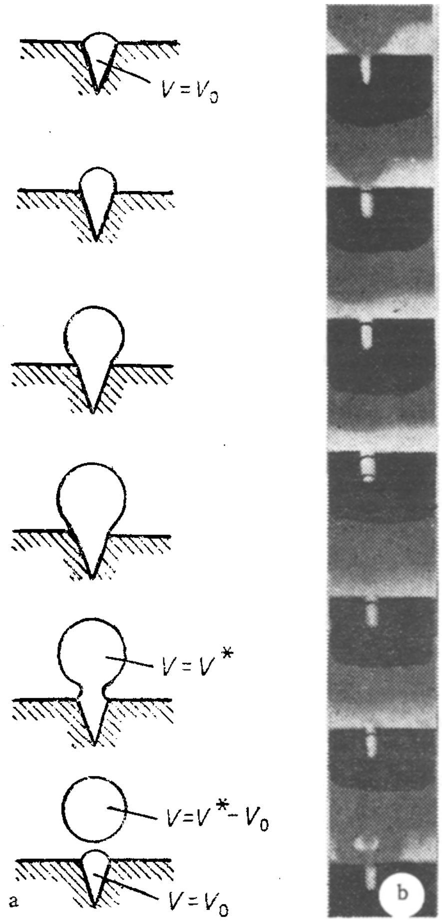

Fig. 1

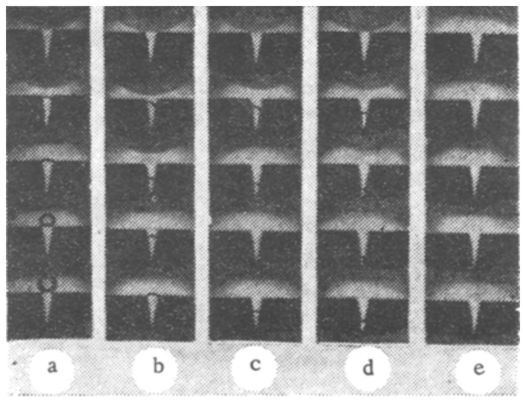

Fig. 2

Fig. 1. Steady operating regime of the active center: a) process of growth and detachment of bubble from a pore; b) cine film showing that with this regime liquid does not penetrate into the pore after detachment of the bubble.

Fig. 2. Regime of decreasing activity of the center of boiling. The cine films a–e were made at intervals of 2 h of continuous boiling with constant temperature gradient $\Delta T = 4°K$. Visible on the films a–d is the monotonic decrease in time of the volume of the residual bubble until it disappears completely (e) and operation of the center ceases.

After this the bubble increases again monotonically to the volume V^* in the course of time τ which is characteristic of the geometry of the center and the magnitude of the gradient ΔT.

With invariable conditions, the frequency of bubble detachment remains constant and equal to $f = 1/\tau$.

2. The regime of decreasing activity of the center of vaporization is encountered with saturated boiling on heaters with a small temperature gradient (in our experiments with $\Delta T < 5°K$). With this regime, after each detachment of the upper part of the vapor region, the liquid penetrates into the depth of the pore and compresses the bubble in it to V_1 (Fig. 2), and there maintains for a long time $\tau' > \tau$ the mechanical equilibrium with the liquid phase. Not until time τ' has passed does the bubble in the depression begin again to grow to the volume of detachment V^*. After detachment the liquid penetrates again into the pore and compresses the bubble to the volume V_1' which is smaller than that taken up by the preceding bubble, i.e., $V'_1 < V_1$. Here, the corresponding time of expectation τ'_1, after which the bubble in the pore begins to grow, is found to be longer than τ'.

Thus, in this regime, the bubbles become detached increasingly rarely, until the center ceases to act and becomes passive (Fig. 2e).

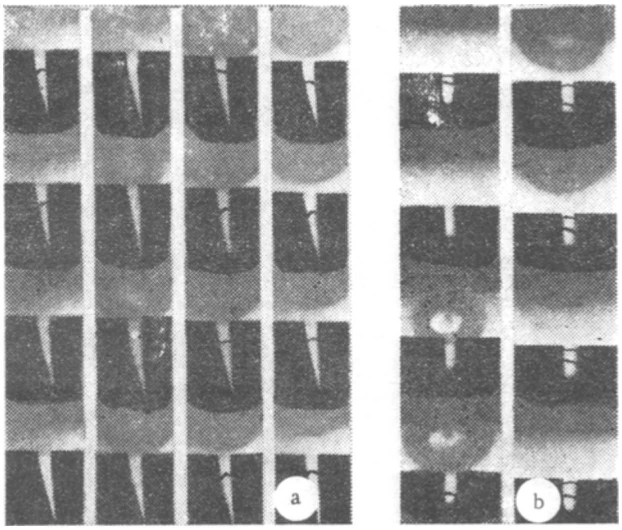

Fig. 3. Combined operating regime of the active center: a) formation of a liquid interlayer separating the bubble growing above the surface of boiling from the vapor cavity in a conical pore; b) the same in a cylindrical depression.

3. The regime of periodic activity is associated with unsaturated boiling on the heating surface with moderate temperature gradient. In this regime the vapor bubbles grow out of the depressions and become detached after time intervals $\bar{\tau}$, which are fairly long but on an average unchanging, and $\bar{\tau}$ is several tens of times longer than the time of bubble growth τ. After each detachment, cold liquid penetrates into the pore, and this compresses the residual bubble to microscopic size. The subsequent growth of a bubble begins after the heat from the deep layers of the heater has reached the pore walls.

4. We found the combined regime of vaporization in the depression when liquid not heated to saturation boils on a surface whose temperature is substantially higher than T_s. Under these conditions the bubble grows in the pore, expels the liquid, and forms a rapidly growing vapor cavity above the pore. The intense evaporation of the near-wall layer of liquid promoting this accelerated growth of the new phase, leads to such abrupt cooling of the section of the surface adjacent to the mouth that in the pore mouth the vapor begins to condense. It can be seen from Fig. 3 that this entails the rapid growth of the outer part of the bubble, whereas the inner part (in the depression) decreases as a consequence of the thickening of the liquid film dividing the vapor region into two independent parts.

The upper spheroidal vapor region, resting on the horizontal plane near the mouth, continues to grow until it rises to the surface. After some period of compression, the bubble in the depression gradually begins to grow, thereby expelling the liquid from the pore and again forming a rapidly growing vapor cavity above the pore mouth, i.e., the entire pattern repeats itself periodically.

In conclusion, we point out that there are grounds for assuming that, in addition to the described regimes upon change of the conditions of boiling, there are also other regimes of action of the centers of vaporization. We intend to continue investigating along these lines.

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