A cavitation model of formation of vapor films in transition boiling is proposed; this model reveals the main features that determine the superheats at critical heat fluxes.

In [1] the relation $q(\Delta T)$ in liquid boiling was clearly determined for the first time and the existence of two extrema was discovered. The maximum heat flux (point C in Fig. 1) corresponds to the cessation of the intense heat transfer characteristic of nucleate boiling and is called the first critical heat flux. The minimum at point E corresponds to the onset of developed film boiling. Transition boiling (curve CE) is characterized by a space–time alternation of nucleate and film boiling on the given heating surface. The portion DF of the single-phase convection curve corresponds to the heat fluxes and, accordingly, to the superheats at which vapor-phase formation after single-phase convection leads to the formation of a stable vapor film on the heat-exchange surface, i.e., to the degeneration of nucleate boiling. The portion CD of the transition-boiling curve ($q_{*} < q_{cru} < q_{crr}, \Delta T_{cru} < \Delta T_{crr} < \Delta T_{s}$) corresponds to the critical heat fluxes for unstable boiling on surfaces depleted of nucleation sites, which were experimentally investigated in [2, 3]. Here $q_{*}$ and $\Delta T_{s}$ are the minimum heat flux and superheat at which single-phase convection can change directly to film boiling, bypassing the nucleate boiling regime.

According to the hydrodynamic theory of heat-transfer crises [4], the transition from nucleate to film boiling (point C) is due to radical alteration of the hydrodynamics of the two-phase boundary layer, leading to a change in the heat-removal mechanism. The stability criterion obtained for the critical heat flux in this paper satisfactorily describes the experiments and allows the prediction of previously unknown effects.

Another important parameter of the heat-transfer crisis in boiling liquids is the heating-surface superheat relative to the saturation temperature $\Delta T_{cr1}$ at which a stable vapor film is formed after nucleate boiling. The factors determining the value of this quantity have not yet been determined.

Kutateladze [5] found that developed nucleate boiling, which is characterized by rapid increase in the heat-transfer coefficient with increase in heat-flux density, is followed by a special subcritical boiling regime in which the heat-transfer rate is practically constant. In Fig. 1 the corresponding portion of the $q(\Delta T)$ curve lies between the points B and C. The existence of a regime with a practically constant heat-transfer rate was subsequently discovered in experiments on the bubbling of gas into a liquid through a microporous surface [6].

Thus, the first heat-transfer crisis in boiling occurs when the law governing the heat-transfer rate differs from that which operates in developed nucleate boiling and, hence, the true wall superheat when $q = q_{cr1}$ is greater than in developed nucleate boiling. Consequently, the method of calculating $\Delta T_{cr1}$ [7] based on the use of the equations for heat transfer in developed nucleate boiling and the critical heat flux does not always
give correct results. Estimates of $\Delta T_{CR1}$ for the high-pressure region were made on the basis of a thermodynamic model of the boiling crisis in [8] and on the basis of a thermal model in [9].

Below we present a model of vapor-film formation in transition boiling, based on the decisive role of hydrodynamic disturbances in the boiling superheated layer of liquid near the wall.

Experiments on boiling on surfaces with a greatly reduced number of nucleation sites [3] allowed these investigations to be made in the region of superheats corresponding to transition boiling. The investigations showed that the mechanism of vapor-film formation in this regime is of a cavitational nature. There is avalanche-like production of microbubbles in the vicinity of the heater, due to disturbances introduced into the metastable superheated layer of liquid by vapor bubbles, and the subsequent formation of a vapor film.

Since the boiling crises are the boundary values of the transition-boiling curve we can naturally assume that the cavitational mechanism of vapor-film formation operates in the immediate vicinity of the first heat-transfer crisis in the boiling liquid (approach to crisis from the transition boiling side of the curve).

We consider an arbitrary volume $V_*$ of superheated liquid in a boiling wall layer. We estimate the mean kinetic energy of pulsational motion of the liquid in this volume as $p'V_*/V_*$. Let $n$ nucleation sites be formed in the considered volume of liquid. The work of their formation is then equal to $n\sigma R_*^6$ in order of magnitude.

As a criterion of vapor-film formation when $q = q_{CR1}, \Delta T = \Delta T_{CR1}$, we introduce the quantity

$$n\sigma R_*^6(p'V_*/V_*) = \text{const.} \quad (1)$$

On the basis of Hsu's hypothesis [10] of a relation between the sizes of the nuclei and the mean thickness of the boundary layer, we estimate the radius of the nucleus for developed boiling conditions as

$$R_* \sim \delta. \quad (2)$$

Using the results of [11], we write

$$\delta \sim v/v_*, \quad v_* \sim \Delta T_{CR1}^6/(\alpha T). \quad (3)$$

It is obvious that the number of nucleation sites $n$ is directly proportional to the volume $V_*$. Since in the present model vapor-film formation is related to the formation of vapor bubbles within the superheated wall layer the number of nuclei per unit volume $n/V_*$ can be determined in terms of the strength characteristics of the liquid. Such a characteristic is the critical cavitation nucleus which, as distinct from the vaporization nucleus $R_*$, is not a function of the superheat. Taking the radius of the critical cavitation nucleus (Fisher [12]) as a linear scale, we can write

$$n/V_* \sim \alpha/[(kT^* \ln (NK^* T^*/h))]^{3/2}. \quad (5)$$

![Fig. 2. Correlation of experimental data by Eq. (6). $H_2O$: 1) [13]; 2) [16]; 3) [15]; 4) [17]. $C_3H_6O$: 5) [18]; 6) [8]; 7) author's data. $C_3H_8$: 9) [13]; 10) [18]; 11) author's data. $CCl_4$: 12) author's data; 13) [13]. $N_2$: 14) [19]; 15) [20]; 16) [21]; 17) [22]; 18) [23]. $O_2$: 19) [19]; 20) [24]; 21) [25]. $H_2$: 22) [22]. $C_2F_3Cl$: 23) [14]. $C_3H_{12}$: 24) [8]. $C = \Delta T_{CR1}/\left(\frac{\sigma}{kT^* \ln (NK^* T^*/h)}\right)^{3/16}$.](image)

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