THE EFFECT OF NON-STATIONARY HEAT TRANSFER FEATURES ON THE BEHAVIOR OF THE CHANGE BOUNDARY BETWEEN BOILING REGIMES

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The development of one-dimensional (1D) and two-dimensional (2D) sites of film boiling has been studied numerically. While describing the dynamics of the front of boiling regime change in the simulation model, the non-stationary character of heat transfer within different zones at the front of regime change was taken into account. Calculations of stability zones for the film boiling sites depending on their initial sizes and dynamic characteristics of development are presented for different levels of heat flux. The influence of frequency, amplitude and linear size of the zone of pulsation intensity of heat transfer in the areas of nucleate and transitional boiling on the average propagation velocity of film boiling is shown quantitatively. Data on thermal stability and dynamics of succession development for the local film boiling sites was obtained in the framework of simulation model. It is shown that consideration of high-intensive evaporation in local zones of liquid meniscuses near the boundaries of interacting «dry» spots drastically decreases formation probability for enlarged stable sites of film boiling.

Usually, in calculations describing the process of dynamic transition from one boiling regime to another, different authors use the boiling curve obtained at quasi-stationary heat release and averaged experimentally for some certain scales in time and along the heat-releasing surface. In the current work, the non-stationary boundary conditions were used for the calculation of heat transfer intensity in various zones of the front of boiling regime change. The alteration areas for dimensionless parameters ε, $\tilde{\omega}$, β, $\tilde{R}_1$ were determined, and the use of quasi-stationary boiling curve for description of dynamic change of boiling regimes in these areas is not correct. Some calculation results on the significant effect of non-stationarity in the local zones of high-efficient heat transfer in the front of boiling regime change are presented in Fig. 1. It is clear that for pulsating heat flux, removed into the liquid, propagation of the front has non-monotonous, pulsating in time character. Regimes with a considerable oscillation amplitude of regime boundaries near the state of equilibrium, shown in Fig. 1, were experimentally observed by the authors on heat-releasing surfaces in cryogenic liquids[1-4]. To reveal the effect of non-stationary heat transfer in the zone of transitional boiling caused by hydrodynamic instability of the interface, accompanied by longitudinal oscillations of the wetting boundary, we carried out corresponding calculations, whose results are shown in Fig. 2. It is clear according to Fig. 2 that with an increase in the level of relative pulsation of the heat transfer coefficient in the area of β~0.5-1, the average propagation velocity of the film boiling boundary increases significantly. Only a weak influence is observed of the non-stationary heat transfer character in bubble boiling regime in the frame of three-zone boiling curve (curve 3). After processing of some experimental results[5-7], the dependency for calculation of the temperature difference, which corresponds to the maximal density of the heat flux, removed into the liquid in the front of regime change and averaged by time on typical frequencies, was suggested:

$$\Delta T_{bound}^{max} = \Delta T_{cr.1} + \frac{\Delta T_{lim} - \Delta T_{cr.1}}{1 + m \cdot \varepsilon^{n}},$$

where m=0.8; n=0.4 at $0.09 < \varepsilon < 2.9$.

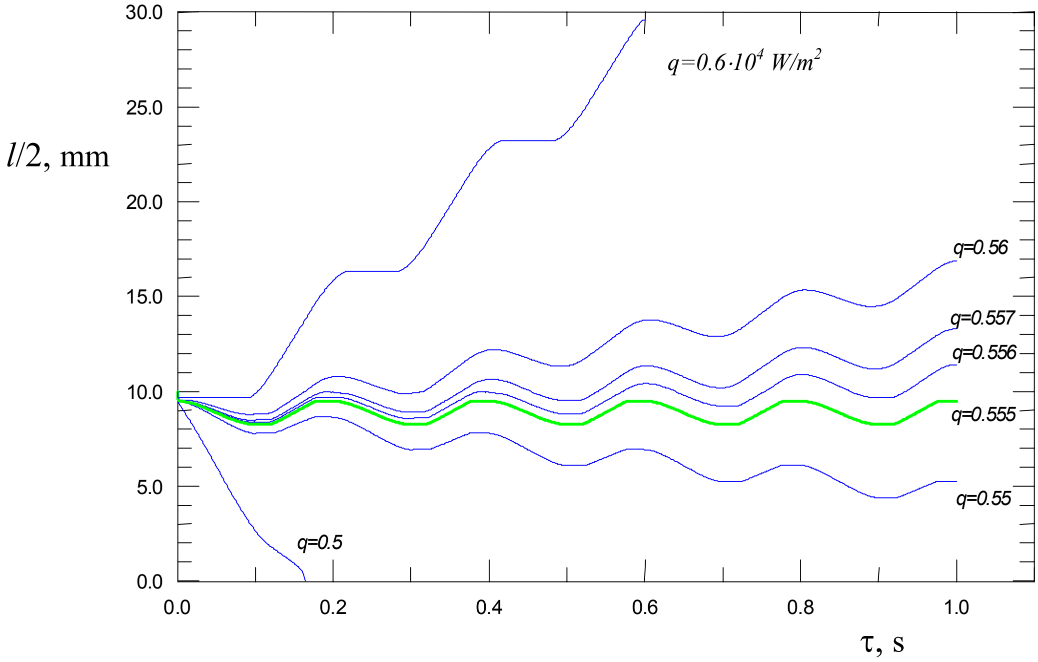

Fig. 1. Behavior dynamics of the boiling regime change. Helium. The heater – stainless steel. The three-zone model of the boiling curve with extremums in points $T_{bound.1}=T_{lim}$ and $T_{bound.2}=T_{cr.2}$; δ_h=0.125mm (ε=0.088), P/P_{cr}=0.23, $R_{1,bub}$=1 mm ($\widetilde{R}_{1,bub}=R_{1,bub}/\delta_{char.1}=31.25$).The model with pulsation of the heat flux density in the zone of nucleate boiling near the boundary of regime change (β=1). $\omega_{bub}=5$ s^{-1} ($\widetilde{\omega}_{bub}=0.068\cdot10^{-3}$).

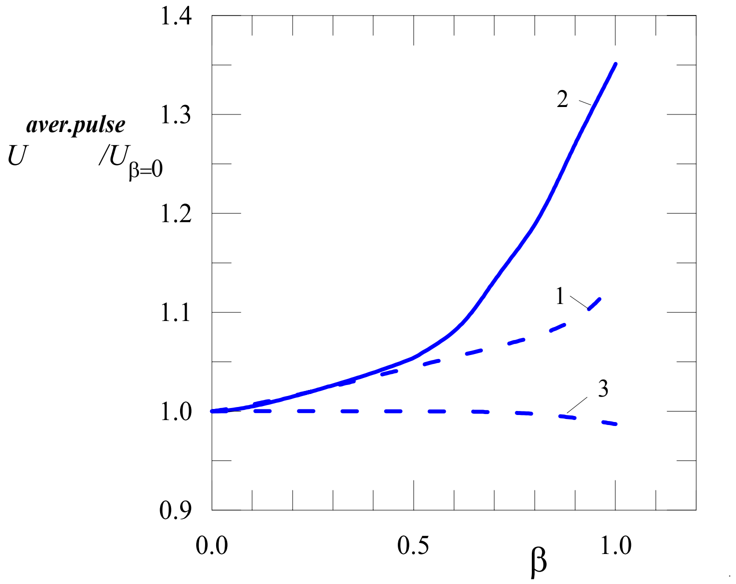

Fig. 2. The effect of the average propagation velocity of the film boiling zone vs. pulsation level β. $\delta_h=0.125\times10^{-3}$ m. Liquid nitrogen. Stainless steel. $\widetilde{q}=q/q_{eq}=2.24$, $\widetilde{R}_{1,trans}=\widetilde{R}_{1,bub}=6.13$, $\widetilde{\omega}_{trans}=\widetilde{\omega}_{bub}=0.063$, 1 - pulsation in the zone of transitional boiling for three-zone boiling curve ($q=7.52\times10^{4}$ W/m^2, $R_{1,\,trans}=1.8\times10^{-3}$ m, $\omega_{trans}=3$ s^{-1}), 2, 3 – pulsation in the zone of bubble boiling ($R_{1,bub}=10^{-3}$ m, $\omega_{bub}=10$ s^{-1}) for two-zone boiling curve with $T_{bound}=T_{\lim}\sim T_{cr.2}$ (2 - $q=15\times10^{4}$ W/m^2) and three-zone boiling curve with two characteristic points $T_{cr.1}$ and $T_{\lim}\sim T_{cr.2}$ (3 - $q=7.52\times10^{4}$ W/m^2).

CONCLUSION

On the basis of numerical analysis, a considerable effect is shown of the non-stationary boundary conditions at the front between boiling regimes on the development of the dynamics and the stability of the local film boiling sites. It is further shown that the use of a quasistationary boiling curve for the heat–releasing surfaces within $\varepsilon<1$ can lead to a significant understatement of the equilibrium heat flux and a change in propagation velocity of the local film boiling sites. According to the modelling results, thermophysical properties and thickness of the heater are of particular importance for the dynamic propagation characteristics and equilibrium heat flux for the local sites with a small initial size. Consideration of zones with non-stationary high-efficiency heat transfer in the front allowed quantitative description of the experimental results on propagation velocity of the film boiling sites and equilibrium heat flux in various liquids over a wide alteration range of relative pressure. The obtained calculation dependencies can be used for new approaches for the description of nucleate boiling crisis with consideration of thermal-physical properties and geometrical parameters of a heat-transmitting wall. This work was financially supported by the Russian Foundation for Basic Research (Grants No. 02-02-16230-a and No. 02-02-06220-mas).

NOMENCLATURE

l –size of film boiling site, m;
$\tilde{q}$ - non-dimensional equilibrium heat flux density, W/m^2;
U – velocity, m/s;
$\Delta T_{cr.1}$ – the first critical temperature difference, K;
ΔT_{lim} - temperature difference at liquid limited overheating, K;
ε - dimensionless parameter, characterizing the ratio between the width of the temperature front along the heater to the characteristic size of capillary force action;
$\tilde{\omega}$, β, $\tilde{R}_1$ - non-dimensional frequency, amplitude and linear scale of heat transfer pulsation, respectively.

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