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INFLUENCE OF THE "COEFFICIENT OF THERMAL ACTIVITY" OF A WALL ON HEAT TRANSFER IN TRANSIENT BOILING

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A simple method for calculation of heat transfer in transient boiling of liquids on a wall with a finite "coefficient of thermal activity" is suggested on the basis of model concepts available in the literature and also by an earlier developed method for analysis of processes.

An analysis of modern concepts of transient boiling of liquids is given in [1, 2]. A consistent physical model of this phenomenon that is based on study of the periodic temporal structure of the process is developed in [3]. According to [3] a complete cycle of the process of transient boiling includes the following two basic stages: evaporation of a liquid film in the base of a vapor cluster up to cessation of the contact between the liquid and wall ("active" period); direct contact of the vapor volume with the wall up to the "burst" of a next portion of cold liquid to the wall ("passive" period). In this case the duration of the "active" stage is much smaller than that of the "passive" stage. In accordance with the analysis of [4-6], the strong thermal effect of the wall on the mean coefficient of heat transfer α_m should be expected for these processes of heat transfer with periodic discontinuous pulsations of intensity and an extended passive period

$$\alpha_m = \frac{q}{\Delta T}. \tag{1}$$

Here q, ΔT are the values of heat flux density and temperature difference averaged over the total period of heat transfer τ_0.

According to [3], all the heat is transferred from the wall to the liquid during the stage of liquid film evaporation, so an "active" coefficient of heat transfer α_+ can be introduced

$$\alpha_+ = \frac{q_+}{\Delta T_+}, \tag{2}$$

where q_+, ΔT_+ are the corresponding values mean over the "active" period of heat transfer τ_+. The mentioned discontinuous type of temporal pulsations of heat transfer intensity is studied in [6]. The following results were obtained.

A. The quantity α_+, which determines heat transfer during the active period, remains constant with variation of the thermophysical properties of the wall. Therefore, for heat transfer processes characterized by dependence of the coefficient of heat transfer on the temperature difference (such as nucleate and transient boiling) we can prescribe a dependence of the active coefficient of heat transfer α_+ on the heat flux density q which is universal with respect to the thermal effect of the wall

$$\alpha_+ = \alpha_+(q). \tag{3}$$

The universal character of a similar dependence for an active temperature difference ΔT_+

$$\Delta T_+ = \Delta T_+(q). \tag{4}$$

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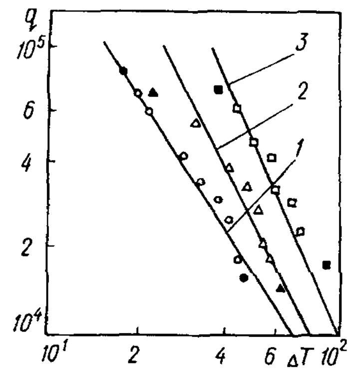

Fig. 1. Comparison of the results of calculation by (8) (lines) with the experimental data of [7] (dots) on heat transfer in nitrogen transient boiling on walls made of copper (1), nickel (2), and stainless steel (3). Black dots correspond to boiling crises. q, W/m^2; ΔT, K.

also follows from (2), (3).

B. The quantity $\varphi \equiv \Delta T/\Delta T_+$, which is the ratio of temperature differences averaged over the total τ_0 and active τ_+ periods of heat transfer, is a measure of the wall thermal effect on heat transfer

$$\psi = 1 + \frac{\alpha_+ \tau_+^{1/2}}{\sqrt{2}\, B}. \tag{5}$$

Here $B \equiv (\lambda_w c_w \rho_w)$ is the "coefficient of thermal activity" of the wall, λ_w, c_w, ρ_w are the thermal conductivity, specific heat capacity, and density of the wall material, respectively.

According to [3], heat is transferred from the wall by heat conduction through an evaporating liquid film with thickness $\delta(\tau)$

$$\alpha_+ (\tau) = \frac{\lambda}{\delta (\tau)}. \tag{6}$$

The duration of the "active" period τ_+ is found from the condition of complete evaporation of the liquid film

$$\tau = \tau_+ : \ \delta = 0. \tag{7}$$

From (6) and (7) we obtain an expression for the parameter of the thermal effect of the wall on heat transfer in transient boiling:

$$\varphi = 1 + \frac{\sqrt{2}}{B} \frac{r\lambda\rho}{\Delta T_+}. \tag{8}$$

Combined use of relations (3), (4), (8) makes it possible to calculate the mean temperature difference ΔT for various values of the "coefficient of thermal activity" of the wall B at q = idem. In the limiting case $B \to \infty$ we obtain $\varphi = 1$, which corresponds to the minimum possible value $\Delta T = \Delta T_+$. Here we have a decay of the thermal effect of the wall with its infinite "thermal activity." For final values of the parameter B we have $\Delta T > \Delta T_+$, with ΔT increasing with a decrease in B. Thus, to calculate ΔT at finite B (and at q = idem) it is enough to assign its corresponding (minimum) value $\Delta T = \Delta T_+$ when $B \to \infty$. Strictly speaking, for this purpose the corresponding theoretical model of the type of [3] should be used. It is known [1-3], however, that the process of transient boiling strongly depends on such difficult-to-control factors as surface roughness and surface wettability by liquid, which makes, according to the estimate of the author of [3], the problem of the creation of a universal model of the process practically impossible. Therefore, it seems reasonable for each experimentally studied case to restrict ourselves to the following relative method of calculation. At the first stage the universal dependence $\Delta T_+(q)$ obtained experimentally for the largest value of B is determined. At the second stage the corresponding values of ΔT for the remaining (smaller) values of B are calculated for a fixed value of q by formula (8). In this case at the first stage even at a large (but finite) value of B the parameter φ in (8) will be higher than unity. Therefore, at the third stage the universal dependence $\Delta T_+(q)$ should be recalculated by formula (8). The suggested simple procedure lasts till the moment when the difference between the last two results becomes smaller than the error of the considered experiment.

Figure 1 presents a comparison of the results of calculation by the suggested procedure with the experimental data of [7] on transient boiling of nitrogen on walls made of copper, nickel, and stainless steel. Here, due to the great difference between the corresponding "coefficients of thermal activity" the first iteration itself gives acceptable results.

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NOTATION

τ, time; τ_0, total period of heat transfer; τ_+, active period of heat transfer; α_m, mean coefficient of heat transfer; q, ΔT, heat flux density and "wall–liquid" temperature difference averaged over the total period of heat transfer τ_0, respectively; q_+, ΔT_+, heat flux density and "wall–liquid" temperature difference averaged over the active period of heat transfer τ_+, respectively; $\varphi = \Delta T/\Delta T_+$, ratio of temperature differences averaged over the total τ_0 and active τ_+ periods of heat transfer; λ_w, c_w, ρ_w, thermal conductivity, specific heat capacity, and density of the wall material, respectively; $B = (\lambda_w c_w \rho_w)^{1/2}$, coefficient of thermal activity of the wall; δ, thickness of the evaporating liquid film. Subscripts: 0, total period; +, active period; w, wall; m, mean over the period.

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