BUILDUP RATE OF VAPOR BUBBLES AT A HEATER SURFACE

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Various solutions are considered to the problem concerning the buildup rate of vapor bubbles at a heater surface. The applicability ranges of extremal solutions are established on the basis of the Jacob number.

One basic physical parameter which characterizes the heat transfer during boiling is the buildup rate of vapor bubbles at the heater surface. The buildup of a bubble is due to evaporation of superheated liquid adjacent to its surface. The rate of heat supply is determined by the hydrodynamic conditions around the bubble surface.

So far various physical models have been proposed to describe the buildup of vapor bubbles, and solutions to the problem have been obtained accordingly. Several authors [1-5] have derived appropriate relations which can be put in the form of the following equation:

$$\frac{dR}{d\tau} = \beta_1 \frac{a'}{R} \mathrm{Ja}^2. \tag{1}$$

Solution (1) is based on the concept of a vapor bubble building up inside the volume of superheated liquid due to an excess superheat enthalpy. Depending on the method of solution and on the precision with which various factors are accounted for (curvature of the heater surface, dynamic effects, etc.), the values of coefficient β_1 range from $8/9\pi$ to 2.

D. A. Labuntsov [6, 7] has developed new physical concepts about the buildup rate of vapor bubbles nucleating on the heater surface. According to his model, the principal evaporation zone comprises the areas near the bubble base. Moreover, the heat for evaporation enters directly from the heater surface, conducted through the layer of adjacent superheated liquid. Such a model of the mechanism has yielded the following solution:

$$\frac{dR}{d\tau} = \beta_2 \frac{a'}{R} \mathrm{Ja}. \tag{2}$$

It is quite evident that the basic difference between solutions (1) and (2) lies in the power of the Jakob modulus in the expression for the buildup rate. Inasmuch as the value of the Jakob modulus is determined by the thermal flux density and the saturation pressure, the buildup rate of a bubble is different according to (1) and (2) respectively, depending on the basic state parameters.

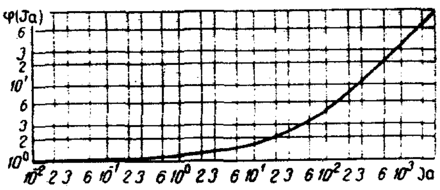

Fig. 1. Trend of function φ(Ja) according to Eq. (4).

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V. V. Yagov [8] has proposed a new model of bubble buildup on a heater surface. It is assumed in this model that evaporation of the liquid into a vapor bubble results from the heat transmitted through the liquid layer at the bubble base, directly from the heater surface, and the heat given off by the superheated liquid layer at the interphase boundary. The solution based on such a model will be written as

$$\frac{dR}{d\tau} = \beta_2 \frac{a'}{R} \mathrm{Ja} \left[1 + \frac{\beta_3^2}{\beta_2} \mathrm{Ja} + \frac{\beta_3}{\beta_2} \sqrt{2\beta_2 \mathrm{Ja} + (\beta_3 \mathrm{Ja})^2} \right]. \tag{3}$$

We introduce here

$$\varphi(\mathrm{Ja}) = \left[1 + \frac{\beta_3^2}{\beta_2} \mathrm{Ja} + \frac{\beta_3}{\beta_2} \sqrt{2\beta_2 \mathrm{Ja} + (\beta_3 \mathrm{Ja})^2} \right]. \tag{4}$$

With this notation, formula (3) becomes

$$\frac{dR}{d\tau} = \beta_2 \frac{a'}{R} \mathrm{Ja}\, \varphi(\mathrm{Ja}). \tag{5}$$

A comparison of formula (3) with numerous test data in [8] has shown that the agreement is closest when the geometrical factors are $\beta_3 = 0.3$ and $\beta_2 = 6$.

The calculation of $\varphi(\mathrm{Ja})$ is shown in Fig. 1 for Ja from 10^{-2} to 10^4, with $\beta_3 = 0.3$ and $\beta_2 = 6$.

For $10^{-2} \le \mathrm{Ja} \le 1.0$, according to the graph, it may be assumed that $\varphi(\mathrm{Ja}) = 1$. The mean relative error here is $\simeq 8\%$. When $\mathrm{Ja} \ge 600$, then $\varphi(\mathrm{Ja}) = 2(\beta_3^2/\beta_2)\mathrm{Ja}$. Thus, the range $10^{-2} \le \mathrm{Ja} \le 1.0$ may be regarded as the range of small Jakob modulus (high saturation pressure). Solution (2) is applicable to this range.

The range $\mathrm{Ja} \le 600$ may be regarded as the range of a large Jakob modulus (low saturation pressure). Here solution (1) is applicable.

For the range $1 < \mathrm{Ja} < 600$ it is necessary to use the general solution (3) in an analysis of bubble boiling. Calculations have shown that, for the determination of breakaway dimensions and frequency in the case of vapor bubbles [9], solution (3) yields a closer agreement with test data.

NOTATION

$\mathrm{Ja} = \rho' c' \Delta t / \rho'' r$ is the Jakob modulus;
ρ' is the density of the liquid;
ρ'' is the density of the vapor;
c' is the specific heat of the liquid;
$\Delta t = t_W - t_S$;
t_W is the temperature of the heater surface;
t_S is the saturation temperature;
r is the latent heat of evaporation;
a' is the thermal diffusivity of the liquid;
R is the bubble radius;
τ is the time.

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