INFLUENCE OF NUMBER OF ACTIVE VAPOR-FORMATION CENTERS ON HEAT TRANSFER INTENSITY DURING BUBBLE BOILING IN A LARGE VOLUME

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Results are presented of an experimental determination of the temperature difference between a heater surface and Freon-113 as a function of the heat flux and of the number of active vapor-formation centers.

Investigations conducted in recent years by a number of authors have shown that the intensity of heat transfer in bubble boiling is determined not only by the physical properties of the liquid, the pressure, and the heat flux (the temperature head), but also by the physical and chemical properties of the heater and its surface roughness. Of the Russian references here we may refer in the first place to [1–5].

A review of a number of foreign investigations devoted to this question has been given in [6].

From analysis of the results of these works, the conclusion may be drawn that the coefficient of heat transfer from a boiling liquid at the same pressure and given heat flux depends appreciably on the number of active vapor-formation centers on the heater surface. The latter is evidently determined by both the physical and chemical properties [4, 7–9], and the cleanness of mechanical preparation (roughness) of the heater surface [5, 10–14].

In the opinion of some investigators, the generally accepted relation for the heat transfer coefficient in the bubble boiling region,

$$\alpha = Aq^n = A^{1/(1-n)}\,\Delta t^{n/(n-1)}, \tag{1}$$

cannot describe the true picture of the process with sufficient completeness.

In some experiments involving change of surface roughness and of density of distribution of vapor-formation centers, the values not only of A, but also of the exponent n, have been varied [6, 12].

It had already been established in [1], that, other conditions being equal, we must have the proportionality

$$\alpha \sim (q/r\rho'')^{n_1}\,(z/F)^{n_2}. \tag{2}$$

An equation in the form

$$q = \text{const}\,\Delta t^{a}\,(z/F)^{b}, \tag{3}$$

including two parameters, the temperature head and the number of vapor-formation centers, was obtained by Tamagata et al [7]. From tests with liquids of different surface tensions they found $a = 1.5$ and $b = 0.25$.

A similar equation was obtained also, from examination of the boundary layer, by Zuber [6] and by Tien [15]. In the former case, $a = 2$ and $b = 0.25$, and in the latter $a = 1$, $b = 0.5$.

Zuber [6], as a result of study of the dynamics of the liquid flow created by the growing and separating bubbles, and of a generalization of the available experimental material, came to the conclusion that (3) was more general than (1) for the coefficient of heat transfer in bubble boiling of a saturated liquid. He obtained $a = 5/3$ and $b = 1/3$.

The results have been published in [14] of an experimental determination of the heat transfer coefficient during boiling of Freon-113 (FCl_2—$CClF_2$) in tubes of different roughness. The latter was achieved by processing the surfaces of the experimental tubes with abrasive cloth of different grades. Heating was achieved by means of low voltage alternating current passing through the tube wall. Before the tests the tube surface was rubbed down with dichloroethane. The tests were conducted at atmospheric pressure. In some of the tests, besides measurement of q and Δt, a determination was made of the number of active vapor-formation centers, the count being made visually. This could be done most accurately at small heat fluxes. The data of two observers usually agreed to an accuracy of 10–15%. An evaluation was made of the total number z of centers, this being permissible in a given case, if we assume that the dimensions of all the experimental tubes are identical.

Figure 1 shows the results of measurement of Δt as a function of z and q. Because the results given here were associated with tests to determine α, we did not arrange the data for strictly constant q in tubes of different roughness, and each of the curves of $\Delta t = f(z)$ shown in Fig. 1 relates to some region of variation of q, which possibly explains the large scatter of points on Fig. 1. Examination of Fig. 1 allows us to draw certain conclusions, one being that for the same heat flux the temperature head varies as a function of z. With increase of z, which corresponded in the tests to the surface with large roughness, Δt decreases. The greatest influence of the number of vapor-formation centers is in the small z region, when there is transition from free motion to bubble boiling. The dotted lines on Fig. 1 join the test data to points lying on the line z = 0. The values of Δt corresponding to these points were calculated for conditions of absence of boiling according to the formula $\Delta t = q^{0.75}/B$, where B was determined from the experimental formula for free motion, taking account of the test data in this region for the other Freons. With q = const, $\Delta t \sim z^{-1/3}$.

Figure 2 shows the relation $\Delta t z^{1/3} = f(q)$. Here, in addition to the data of Fig. 1, we have also shown test points which did not fall in the region of heat flux

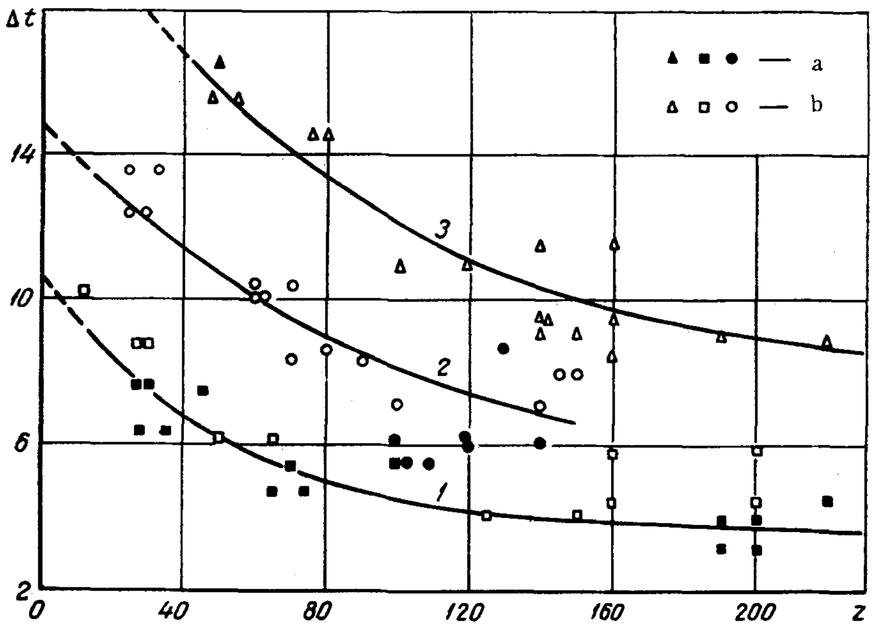

Fig. 1. The influence of q and z on the temperature head (°C) in boiling of Freon-113 in tubes of different roughness: a) for copper tubes; b) for steel: 1 – q = 2600–3500 W/m^2, 2 – 4400–4600; 3–8600–9200.

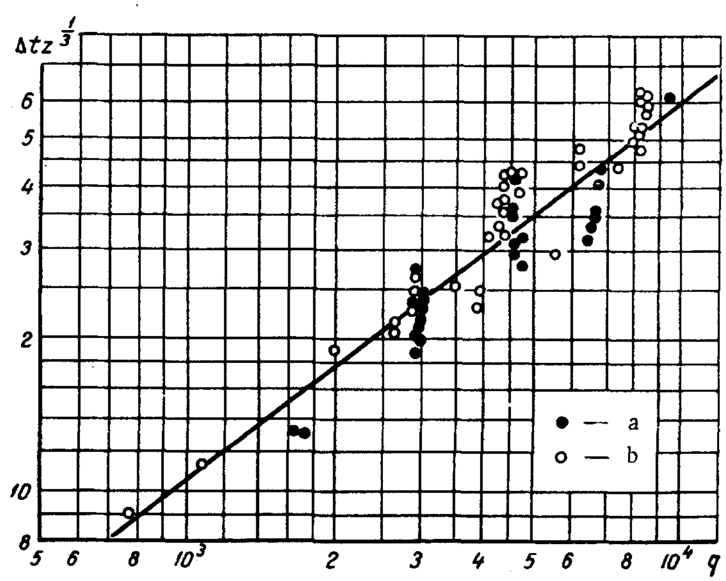

Fig. 2. Generalized relation between Δt, z, and q for boiling of Freon-113 at atmospheric pressure: a) for copper tubes; b) for steel.

represented on it. The straight line which approximates to the test points of Fig. 2 has a slope of $a = 3/4$.

Thus, for Freon-113 at atmospheric pressure,

$$\Delta t \sim q^{3/4} (z/F)^{-1/3},$$
$$q \sim \Delta t^{4/3} (z/F)^{4/9},$$
$$\alpha \sim q^{1/4} (z/F)^{1/3}. \quad (4)$$

According to Zuber, we have for water, as follows from the data cited above,

$$\Delta t \sim q^{3/5} (z/F)^{-1/5},$$
$$q \sim \Delta t^{5/3} (z/F)^{1/3},$$
$$\alpha \sim q^{2/5} (z/F)^{1/5}. \quad (5)$$

The data for Freon-113 and for water are qualitatively in agreement. The value b = 0.44 obtained for Freon-113 lies between the values 0.25 and 0.5 found with the aid of boundary layer theory [6, 15]. It follows from comparison of formulas (4) and (5) that the degree of influence of the number of vapor-formation centers on Δt and α for Freon-113 turns out to be greater than for water.

Observations [1, 16] show that the saturation pressure also influences the number of vapor-formation centers. Even if we suppose that at the same p the number z/F for Freon and water is the same, and that the degree of influence on z/F is also the same for them, then in accordance with (4) and (5), the variation of heat transfer coefficient with pressure proves to be larger in the first case than in the second. Taking into account the lower critical parameters of the Freons in comparison with water, we may expect a steeper influence of pressure on z for them than for water, and therefore a more substantial variation of heat transfer coefficient with increase of pressure.

This is evidently one of the causes of lack of agreement between experimental data for the Freons and a number of calculated criterial equations.

NOTATION

A and B are coefficients; F is the area of the heater surface; p is the pressure; q is the heat flux; r is the heat of vapor formation; Δt is the temperature difference between the heater surface and the saturated liquid; z is the number of vapor-formation centers; α is the heat transfer coefficient; ρ is the density of the dry saturated vapor.

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