VARIATION IN NUMBER OF ACTIVE VAPORIZATION SITES AS A FUNCTION OF HEIGHT OF FLUID LAYER

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A study was made of the variation in the number of active vaporization sites as a function of the height of a layer of boiling fluid above a heat-releasing surface. An explanation of the results is given.

The number z ($1/m^2$) of active vaporization sites is one of the basic factors determining the intensity of heat transfer during bubbling boiling of fluids. As has been shown [1], however, a unique relation between the coefficient of heat transfer during boiling and the number z does not hold in all cases, since the process also significantly involves the mean separation diameter d_0 of the vapor bubbles, their separation frequency f, and the coefficient of bubble growth ε within the volume of the fluid, which, in general, depend on the height H of the layer of boiling fluid.

The dependence of the density of vaporization sites on various factors was studied in a number of papers which are reviewed in detail in [2, 3]. In these papers, however, the question of the effect of the height of the layer of boiling fluid on z was not discussed. Existing information on this question is extremely limited and contradictory.

As far back as Jakob [4], a rise in the number of sites was noted as the height of the fluid layer above a horizontal heat-transfer surface decreased. In this case, a rise in the coefficient of heat transfer was not observed, but even some reduction accompanied by a small increase (by ~5%) in the temperature of the heating surface.

Extremely sparse data on the dependence of the number of active vaporization sites on the height of the fluid layer were also presented in [5, 6], in which the increase in z associated with a change in the thickness of the layer was accompanied by a considerable drop in the temperature of the wall in contrast to [4].

The sparseness and contradictory nature of the experimental data and the absence of a basis for the dependence of the number of active vaporization sites on the height of a fluid layer established the advisability of further experimental study of this problem of fundamental and practical interest.

The experiments were performed with distilled water at atmospheric pressure. The water was poured into a vessel 100 mm in diameter. In this case, the initial height of the fluid layer was 65 mm. Reduction in the thickness of the layer occurred as water evaporated from the vessel. The number of vaporization sites was counted visually through the lid of the vessel which was made of two quartz glasses with a gap between into which hot air was fed in order to prevent fogging. The thickness of the layer was measured with a ruler to ±0.5 mm. The number of sites was determined in an area bounded by a circle 60 mm in diameter.

Three Chromel—Alumel thermocouples were imbedded in the body of the heater in order to determine thermal flux and surface temperature. Thermal flux density was estimated from the temperature gradient along the body of the heater and was kept constant. The heat-transfer surface was made of M1 quality copper. Observations were made on freshly machined surfaces with correspondingly slightly increased heat-transfer coefficients.

Experiments with such equipment were concluded when the thickness of the water film was approximately 3 mm. For smaller thicknesses, the experiments were performed on apparatus which made it possible

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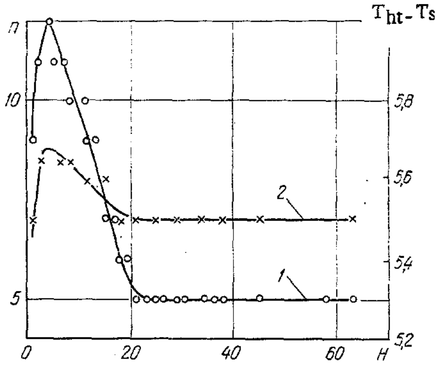

Fig. 1

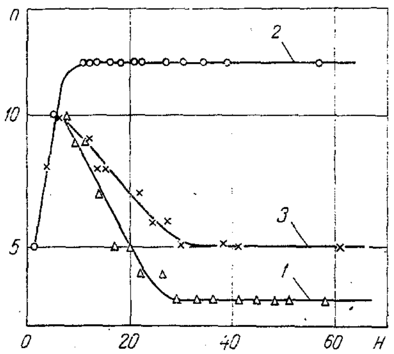

Fig. 2

Fig. 1. Dependence of the number of active vaporization sites and of the superheat of the heat-transfer surface (°K) on thickness of fluid layer (mm) for a thermal flux density of 28 kW/m^2: 1) number of vaporization sites; 2) superheat of heat-transfer surface.

Fig. 2. Dependence of number of active vaporization sites on thickness of water layer (mm) for a thermal flux density of 10 kW/m^2: 1) surface deficient in vaporization sites (polished surface); 2) surface artificially saturated with sites; 3) technically rough surface (class 4-5, All-Union State Standard 2.309-68).

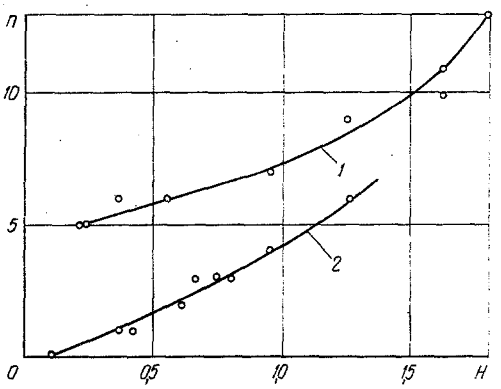

Fig. 3. Dependence of number of active vaporization sites on thickness of water film (mm): 1) thermal flux density, 120 kW/m^2; 2) 23 kW/m^2.

to control film thickness during an experiment by additional feed of fluid or discharge of fluid from the vessel. Boiling took place on the face of a copper rod 28 mm in diameter. Thickness of the film was determined by means of a contact needle to ±0.01 mm.

Figure 1 shows the change in the number n of active vaporization sites functioning on a surface bounded by a circle 60 mm in diameter and the change in the value of the superheat of the heat-transfer surface with respect to saturation temperature as functions of the thickness of the fluid layer for a thermal flux density of 28 kW/m^2. The experiments showed that the temperature of the surface remained constant at such (low) thermal flux densities over a rather broad range of layer thicknesses and increased insignificantly only at small thicknesses of the layer (less than 10-20 mm). The rise in surface temperature was accompanied by an increase in the number of active vaporization sites, which agrees qualitatively with the data of [4].

This can be explained in the following manner. As the height of the fluid layer decreases, the fraction of vapor produced because of vaporization of superheated fluid in surfacing bubbles begins to decrease markedly at some point in time and the coefficient of vapor-bubble growth ε within the volume of the fluid decreases correspondingly [1]. Because of this, the average temperature of the fluid and, correspondingly, the wall temperature increase as the height of the layer decreases.

Thus, with a constant heat supply to the heating surface and, consequently, with an unchanged total amount of vapor formed, the product $d_0^3 z f$ must increase according to the consideration advanced in [1]. From our observations, the average separation diameter d_0 of vapor bubbles remains practically constant as the layer thickness decreases. Consequently, the number z of active vaporization sites and the frequency f of vapor-bubble separation must increase.

The increase in z predominates when there is a small population of active sites on the heating surface. An increase in the number of active sites can only occur as the result of an increase in surface temperature to a value corresponding to the temperature for activation of new sites. In fact, as shown by our observations (Fig. 1), the increase in the number of active vaporization sites is accompanied by a rise in the temperature of the heat-transfer surface when there is a reduction in the fluid level.

If one artificially creates a surface saturated by a large number of active sites, a considerable fraction of them will function with reduced output and, correspondingly, decreased frequency. Under these conditions, few new sites can be activated when the level is lowered, but the frequency of bubble separation is markedly increased at previously "sluggish" sites.

Figure 2 shows the dependence of the number of active vaporization sites on height of fluid layer for three heating surfaces treated in different ways. The plot makes it clear that a rise in the number of active vaporization sites is not observed as the level decreases in the case of surface 2. Only an increase in separation frequency occurs for some bubbles in this case. The increase in the number of sites is relatively less for surface 3 than for surface 1. Thus, the data obtained qualitatively confirm the considerations presented above.

When the height of the fluid layer is less than 1-2 mm, a decrease in the temperature of the heat-transfer surface starts which is associated with an increase in that fraction of the heat that is transmitted by thermal conductivity and convection into the gaps between vaporization sites. In this case, the drop in temperature of the surface leads to a reduction in the number of vaporization sites. Boiling may be completely absent in a very thin film where all supplied heat can be transferred by thermal conductivity.

Figure 3 shows the dependence of the number of active vaporization sites at atmospheric pressure for thin films of water (less than 2 mm). A considerable drop in the number of active vaporization sites is observed at a thermal flux density of 120 $\mathrm{kW/m^2}$ (curve 1). There is not complete suppression of boiling at this thermal flux, since the fluid film is broken down by thermocapillary forces until a thickness is reached for which all supplied heat can be transferred by thermal conductivity. For a thermal flux density of 23 $\mathrm{kW/m^2}$ (curve 2), vaporization sites vanish in water films 0.1-0.2 mm thick and boiling of the fluid ceases.

Thus, an increase in the number of vaporization sites with unchanged thermal flux density is not always accompanied by an increase in the intensity of heat transfer. On the contrary, some worsening of heat transfer can even be observed under certain conditions, for example, when there is a reduction in the thickness of the layer of boiling fluid. Such a conclusion is of practical interest for thin-film heat-exchangers. The use of water films with thicknesses greater than 1-2 mm in them is inadvisable because of the reduction in the coefficient of heat transfer in comparison with the large volume.

NOTATION

z, number of vaporization sites per square meter of heat-transfer surface; d_0, mean separation diameter of vapor bubble; f, frequency of vapor-bubble separation; $\varepsilon = v/v_0$, coefficient of vapor-bubble growth within fluid volume; v, v_0, volumes of vapor bubble (instantaneous and at separation); H, height of liquid layer; n, number of active vaporization sites on entire heat-transfer surface; T_{ht}, T_s, temperature of heat-transfer surface and saturation temperature.

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