LITERATURE CITED

1. R. A. Herringe and M. R. Davis, J. Fluid Mech., 73, Part 1, 97-123 (1976).
2. V. P. Sevast'yanov, B. P. Golubev, and E. P. Svistunov, Teploénergetika, No. 12, 58-60 (1984).
3. L. Z. Shenderov, A. G. Kvashnin, and V. V. Dil'man, Inzh.-Fiz. Zh., 38, No. 6, 1005-1010 (1980).
4. B. P. Golubev, S. N. Smirnov, Yu. M. Lukashov, and E. P. Svistunov, Electrophysical Methods of Studying the Properties of Heat-Transfer Agents [in Russian], Moscow (1985).
5. E. P. Svistunov, N. B. Éskin, V. P. Sevast'yanov, and A. S. Grigor'ev, Teploénergetika, No. 11, 40-43 (1984).
6. M. A. Styrikovich, O. I. Martynova, and Z. L. Miropol'skii, Steam Generation Processes in Electric Power Plants [in Russian], Moscow (1969).

MAXIMUM THICKNESS OF A TWO-PHASE LAYER DURING BOILING ON A FLAT HORIZONTAL SURFACE TURNED DOWNWARD

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UDC 536.248.2.001.5

A study is made of the effect of the thermal load and pressure on the thickness of the two-phase layer in the boiling of water and nitrogen.

The boiling of liquid on a flat heating surface turned downward is characterized by low values of the critical thermal load and the heat-transfer coefficient in the sheet boiling regime [1]. A theory of heat transfer for such a heater orientation has yet to be developed; to construct such a theory, it will be necessary to have information on the dynamics of the vapor phase during boiling. Éskin, Kirichenko et al. [2] obtained data on the form and dimensions individual bubbles; it was found in particular that their thickness δ may not exceed a certain limiting value $\delta_{\ell m}$ associated with the capillary constant b and the contact angle α (at $\alpha \to 0°$, $\delta_{\ell m} \approx 2b$). In the nucleate boiling regime, growing and moving bubbles form a two-phase layer of the thickness δ_{tp}. In sheet boiling, the thickness of the vapor film depends to a considerable extent on the heat-transfer rate. Data on the thickness of the two-phase layer or film is very valuable for constructing a model of the heat-transfer crisis during sheet boiling However, the literature does not contain any such data.

The present study reports results of an investigation of the dependence of the maximum thickness of the two-phase layer δ_{tp} on pressure, the type of liquid, and the heat flux q at different stages of boiling. Tests were conducted with boiling water (atmospheric pressure) and nitrogen (pressure from 0.02 to 0.9 MPa) in the saturated state. The method used to photograph the process was described in detail in [2]. We took 3-5 photographs for each value of q. We used pictures enlarged fourfold to determine the maximum thickness of the vapor phase, i.e., the maximum distance of this phase from the heating surface. We then found the arithmetic mean of δ_{tp} from individual frames and a series of frames. We also determined the standard deviation, which turned out to be equal to 10-15%.

The error of determination of the maximum thickness by the simple method we employed was also no greater than 10% at acceptably low values of q.

For clarity, Fig. 1 compares the data on heat flux in fractions of its critical value q_{cr1} ($q_{cr1} = 2.87 \cdot 10^5$ W/m² for water and $6.07 \cdot 10^4$ W/m² for nitrogen). In the case of developed boiling ($q/q_{cr1} \geq 0.1$-0.2), the value of δ_{tp} is nearly independent of q. It can be seen from the figure that the thickness of the two-phase layer even decreases somewhat with the onset of the crisis ($q/q_{cr1} = 1$). In the photographs, sheet boiling appears as a single

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Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 55, No. 5, pp. 800-803, November, 1988. Original article submitted July 7, 1987.

0022-0841/88/5505-1272$12.50

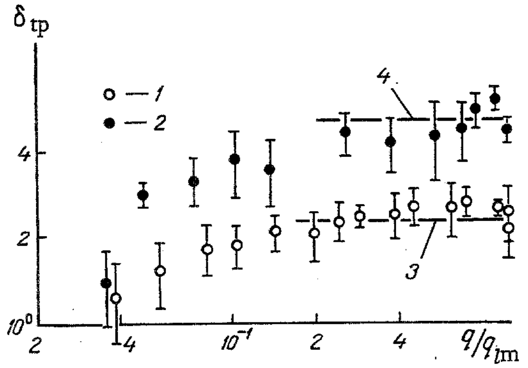

Fig. 1

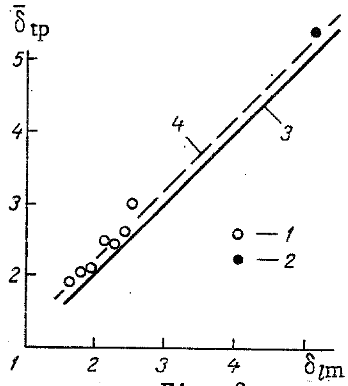

Fig. 2

Fig. 1. Dependence of the maximum thickness of the two-phase layer on the relative thermal load at atmospheric pressure. Nitrogen: 1) test data; 3) $\delta_{\ell m}$ from [2]; water: 2) test data; 4) $\delta_{\ell m}$ from [2]. δ_{tp}, mm.

Fig. 2. Dependence of the maximum thickness of the two-phase layer in developed boiling on the limiting thickness of the vapor bubble: 1) nitrogen (from right to left, the points correspond to the values 0.02, 0.05, 0.1, 0.2, 0.4, 0.6, 0.9 MPa); 2) water at atmospheric pressure; 3) $\bar{\delta}_{tp} = \delta_{\ell m}$; 4) $\bar{\delta}_{tp} = \delta_{\ell m} + 0.2$ mm. $\bar{\delta}_{tp}$; $\delta_{\ell m}$, mm.

large "bubble" covering the heater. This bubble has a relatively smooth bottom surface. In the nucleate regime, the surface of the two-phase layer has a very uneven profile. It must be noted that the thickness of the vapor film during the boiling of water in our experiments was considerably greater than the thickness found theoretically in [3] (1.0-2.5 mm); the form of the profile of the film also differs from that calculated in [3], where thickness was minimal at the center of the surface and maximal at the edges. Conversely, in the pictures of the sheet boiling of water and nitrogen, the film thickens at the edges of the heating surface in connection with the escape of vapor from under the heater.

Figure 1 shows lines corresponding to theoretical values of $\delta_{\ell m}$ for individual bubbles (in accordance with the results in [2], we took $\alpha = 20°$ for water and $\alpha = 10°$ for nitrogen). It is evident that the experimental data agrees quite well with the calculation in the region of developed nucleate boiling. The same result is obtained at pressures differing from atmospheric.

Another feature of the resulting relations $\delta_{tp}(q)$ is the presence of a section where the maximum thickness of the two-phase layer increases with an increase in q from the value corresponding to the onset of boiling. This section is characterized by the presence of individual spherical or slightly flattened bubbles. The bubbles have dimensions greater than the values of the separation diameter in the case of boiling on upward-turned surfaces ($D = 2.5$ mm for water and $D \approx 0.4$-0.5 mm for nitrogen [4, 5]). It should be noted that the bubbles recorded in the photographs of undeveloped boiling cannot be divided into still-growing bubbles in contact with the surface and bubbles which have already separated and are sliding along the surface over a liquid interlayer. The latter bubbles are undoubtedly able to grow during this displacement as well. Here, the growth is more rapid, the greater the value of q. Developed boiling is characterized more by the growth of individual deformed (flattened) bubbles as a result of the absorption of smaller neighboring bubbles. Thus, in this case there are only a small number of bubbles of considerable dimensions (in undeveloped boiling, there are many small bubbles); at the limit, with the transition to sheet boiling, there is a single "bubble" that occupies the entire surface.

The reasons for the separation of bubbles growing on the downward-turned surface and pressing against the latter as a result of buoyancy may include convective currents of liquid, a change in the sign of the inertial force of the reaction of the liquid when bubble growth slows, and the effect of a growing bubble on neighboring bubbles as it "parts" the liquid along the surface.

To compare our data on the maximum thickness of the two-phase layer in developed boiling with data on the limiting thickness of an individual bubble $\delta_{\ell m}$, we averaged values of δ_{tp} over q on sections of the relation $\delta_{tp}(q)$ and found the values of $\overline{\delta}_{tp}$ shown in Fig. 2. Values of $\delta_{\ell m}$ calculated by the method in [2] are plotted off the horizontal axis. It is evident that on the average the quantity $\overline{\delta}_{tp}$, changing in proportion to $\delta_{\ell m}$, somewhat exceeds the latter; as a first approximation, $\overline{\delta}_{tp} = \delta_{\ell m} + 0.2$ mm.

Thus, it can be concluded on the basis of the completed tests that in the developed nucleate boiling of liquids on a downward-turned horizontal surface, the maximum thickness of the two-phase layer may not be significantly greater than double the capillary constant and will be independent of the heat flux. In the case of sheet boiling, this conclusion is valid for the thickness of the vapor film which covers the heating surface.

LITERATURE CITED

1. N. Saki, S. Fukusako, and K. Torikosi, Teploperedacha, 100, No. 4, 67-72 (1978).
2. Yu. A. Kirichenko, K. V. Rusanov, and E. G. Tyurina, Inzh.-Fiz. Zh., 51, No. 5, 709-715 (1986).
3. M. M. Farahat and E. E. Madbouly, Int. J. Heat Mass Transfer, 20, No. 3, 269-277 (1977).
4. V. I. Tolubinskii, Heat Transfer during Boiling [in Russian], Kiev (1980).
5. Yu. A. Kirichenko, V. V. Tsybul'skii, M. L. Dolgoi, et al., Inzh.-Fiz. Zh., 28, No. 4, 581-588 (1975).

THEORETICAL STUDY OF THE STABILITY OF NUCLEATE BOILING AND PULSATIONS OF THE TEMPERATURE OF A WALL HEATED BY A HOT LIQUID

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UDC 536.2

An analysis is made of the mechanism of development of temperature pulsations and conditions of the disturbance of the heat balance of a wall.

The heat-transfer crisis associated with the transition from nucleate boiling to sheet boiling poses a serious hazard, since it is accompanied by a sharp increase in wall temperature and may lead to burning of the heating surface. The boiling regime which exists under conditions of free convection is unambiguously determined by the difference between the temperature of the wall and the saturation temperature ($\Theta = T - T_s$). Proceeding on the basis of this fact, the authors of [1, 2] hypothesized that the notions of the stability of the temperature field of a heating element are equivalent. A sudden change in the temperature field in the event of a change of boiling regimes can be regarded as the result of disturbance of the heat balance of the wall [3]. Thus, to evaluate the stability of the temperature field, it is sufficient to solve the nonsteady heat-conduction problem for the wall. An analysis of the heat balance of the wall makes it possible to determine the region of stable operation and determine the magnitude of the deviations that are causing the shift in boiling regime.

Along with the heat-transfer crisis, danger is also presented by pulsation of the temperature of the wall. Such fluctuations may lead to fatigue failure of the wall material [4, 5]. As was shown in [4], analysis of the temperature field of a heating wall makes it possible to predict the conditions under which temperature fluctuations may be intensified.

The need for analysis of the temperature fields of walls has been noted in several other publications devoted to study of the stability of boiling regimes. For example, the

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Institute of High Temperatures, Academy of Sciences of the USSR, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 55, No. 5, pp. 803-810, November, 1988. Original article submitted June 11, 1987.

 0022-0841/88/5505-1274$12.50