BOILING OF A SUPERHEATED LIQUID IN THE PRESENCE OF A METALLIC SURFACE UNDER ISOTHERMAL CONDITIONS

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Measurements are made of the temperature dependences of the mean times before the boiling, at atmospheric pressure, of superheated n-pentane and n-hexane in a glass capillary tube, and with the introduction of a metal wire into the tube.

Under "pure" conditions, a large number of liquids of different chemical natures (water being an exception) can be superheated quasistatically up to the temperature of spontaneous boiling [1, 2]. Such conditions can be achieved in glass capillary tubes, as well as when the liquid is placed in another liquid which is electrically conductive [1, 2]. The temperatures reached in the superheatings of the liquids in this case agree with the results of calculation of the boundary of spontaneous boiling using formulas from the classical theory of homogeneous nucleation [3-5]. The discrepancy between experiment and theory, within 0.5-1.5°K, is almost within the experimental error and the error of the thermophysical parameters used in the calculation.

It is widely believed that contact with a metal surface prevents high superheatings of liquids. In fact, when a liquid is heated on a metal surface, the theoretical values of the spontaneous boiling temperature are reached only by resort to the pulse method, whereby the heating is done very rapidly ($t \leqslant 1$ msec) [6]. In this case, boiling of the liquid at ready vaporization nuclei cannot prevent heating of the main mass of the boundary layer of the liquid to the temperature of intensive fluctuational nucleation.

In the quasistatic heating of metallic surfaces (wires, tubes, plates) immersed in a liquid [7-12], the empirically observed values of superheating are always considerably lower than the attainable values predicted by the theory of homogeneous nucleation. The same situation holds in the superheating of liquid metals [13].

We conducted studies of the boiling of a superheated liquid during its contact with a metallic surface under isothermal conditions, i.e., in the absence of heat flows. The tests were conducted in a "clean" bubble chamber using the method of measurement of the mean lifetime of the superheated liquid [1, 2]. The liquid was superheated in a thermostatted glass capillary tube with $d_{in} \simeq 1.0$ mm by decreasing the pressure from $P > P_s$ to atmospheric pressure. The length of the working section of the tube $l = 8$ cm, while the superheated volume $V = 0.06$ cm^3. We determined the mean time before the boiling of the liquid $\bar{\tau}$ at different temperatures close to the boundary of achievable superheating. The relation $\bar{\tau}(T)_p$ was first determined for a "clean" cell and then after the introduction of a metal wire. The wire received no special preliminary treatment (except for washing in the test liquid). Figure 1 shows, in semilogarithmic coordinates, the results of tests with n-pentane (nickel wire with $d \simeq 0.1$ mm) and n-hexane (platinum wire with $d \simeq 0.2$ mm). The vertical lines show the statistical error of the mean time τ for 20-50 tests. Here the lifetime $\bar{\tau}$ of the superheated liquid is distributed randomly according to the Poisson law, with a probability density

$$\omega(\tau) = \frac{1}{\bar{\tau}} \exp\left(-\frac{\tau}{\bar{\tau}}\right).$$

With insertion of the wire, the probability of boiling at first increases markedly, although the time before boiling is still quite long (much longer than the time of boiling). Point A in Fig. 1b is the average of 50 tests ($\bar{\tau} = 6.8$ sec). The surface is "run in" after 100-150 measurements and the mean time before boiling nearly reaches the "background" values in the "clean" cell. It is also interesting to note that the presence of the metal wire

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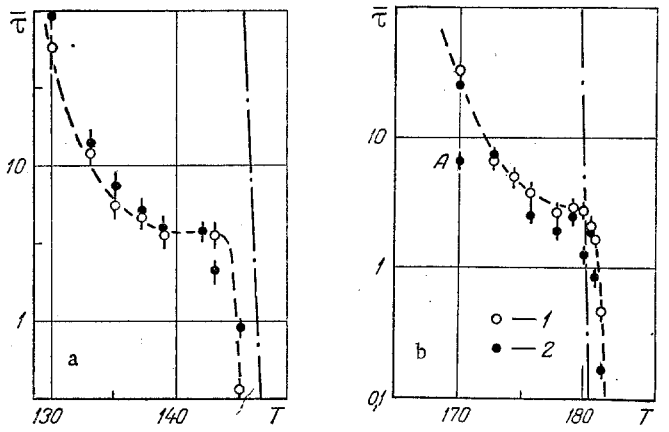

Fig. 1. Temperature dependence of mean lifetime of superheated n-pentane (a) and n-hexane (b) at atmospheric pressure: a) 1) "clean" cell; 2) cell with nickel wire; T_s = 35°C; b) 1) "clean" cell; 2) cell with platinum wire; T_s = 68°C. $\bar{\tau}$, sec; T, °C.

does not significantly shift the boundary of attainable superheating of the liquids (the sections of sharp reduction in $\bar{\tau}$ with an increase in temperature). The dot-dash lines in Fig. 1 show the results of calculation of $\bar{\tau}$ from the classical theory of nucleation [1]. Here we used the relation $JV\bar{\tau} = 1$, which accounts for the fact that boiling takes place with the appearance of the first viable vapor bubble.

The question of the effect of the rate of temperature increase in the system and of the heat flux on the walls on the superheating of liquids has been discussed in the literature [12, 13]. One feature of the method we used is that it permits determination of the probability of boiling of a liquid under given conditions (P, T) at zero values of both of these factors. Without presently going into the mechanism of activation of boiling nuclei on the metal surface, we will note that the relations $\bar{\tau}(T)_p$ shown in Fig. 1 qualitatively explain the effect of the heating rate on the values of superheating observed in the tests. Of course, the higher the heating rate, the lower the probability that conditions leading to boiling up of the liquid will occur, and the greater the observed superheating. At the same time, the probabilistic nature of the activation of boiling centers explains the large spread in the liquid boiling temperatures normally observed in heating on metal surfaces.

In conclusion, we should also note that the achievement of high superheatings of a liquid in contact with a metal surface expands the possibilities for experimentally studying the properties of superheated liquids.

NOTATION

t, time; d, diameter; l, length; P, pressure in the liquid; P_s, saturation pressure; τ, time in the metastable state; $\bar{\tau}$, mean lifetime; J, frequency of nucleation; ω, probability density; V, volume of the system; T, temperature.

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ENTRANCE SECTION OF A PLANAR TURBULENT JET IN TRANSVERSE FLOW

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The author presents a solution for the entrance section of a planar turbulent jet in a carrier stream, accounting for additional ejection of liquid in the upstream mixing zone.

Reference [1] examined a solution of the problem of the entrance section of a planar turbulent jet generated in a transverse flow, using an integral method. The system of jet boundary layer equations, written in curvilinear coordinates fixed to the jet axis, is closed by means of the Prandtl formula for the shear stresses in which curvature is not accounted for. For high carrier stream speeds this solution does not agree well with experimental data.

Figure 1 shows the experimentally obtained width of the mixing zone, as described in [1], for jet to flow velocity ratios of $u_0/V_\infty = 9.35$, 4.83, 3.23. The broken lines are the width of the mixing zone for the ordinary immersed jet ($V_\infty = 0$). It can be seen from Fig. 1 that the upstream mixing zone is wider than the downstream one, and the difference between them increases with increase of the carrier stream velocity. The jet in the upstream mixing zone seems to eject additional mass, compared with the ejection into the mixing zone of the ordinary immersed jet and into the downstream mixing zone. The apparent cause is the influence of jet curvature, which can be quite large in the entrance section, on the intensity of mixing. It is known (see, e.g., [2]) that mixing proceeds with greater intensity in a stream flowing along a curved convex wall where the velocity falls with increasing distance from the wall, since centrifugal force ejects fast particles along the radius from the center of curvature with greater intensity than slow particles, and therefore the thickness of the mixing zone must be larger than when there are no centrifugal forces. The presence of a centrifugal force is linked to curvature of the jet, and the centrifugal force is greater, the greater is the component of carrier stream velocity normal to the axis. An increase of the speed of the carrier stream for a given initial jet speed leads to an increase of jet curvature, of the carrier stream velocity component normal to its axis, and of the centrifugal force. This in turn must lead to an increase in the additional mass coupled to the forward part of the jet. The jet curves with increasing distance form the source, the angle between the axis and the carrier stream is reduced, and therefore the normal flow velocity component is reduced and tends to zero in the limit. Therefore, the added ejection should not be taken into account in calculating the main section. But in the development of the entrance section, the added ejection into the upstream mixing zone of the jet must play an important role.

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