INFLUENCE OF AN INDIVIDUAL VAPOR-PRODUCTION SITE AND THE RATE OF BREAKAWAY OF VAPOR BUBBLES ON WALL TEMPERATURE

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The wall temperature at an individual vapor-producing site has been measured. The presence of such a site on the heater wall causes a pronounced fall in T_W. Increase in the rate of breakaway of vapor bubbles also lowers T_W, but to a lesser extent.

It is known that the increase in the heat transfer coefficient during boiling is related to an increase in the number of active sites and the rate of breakaway of vapor bubbles from the heater surface, and that the production and breakaway of vapor bubbles, which make the boundary layer turbulent, play a decisive role in boiling heat transfer. However, the individual contributions of each of these two factors (the presence of an active site and the rate of bubble breakaway) to the lowering of the wall temperature are not known.

The answer to this question may be obtained by direct measurement of T_W under a vapor-producing site. Although the process of vapor bubble production at a fixed point of the heater surface is a poorly controlled one, we succeeded in measuring T_W at an individual vapor-producing site.

The measurements were carried out using an experimental setup (Fig. 1) consisting of a textolite container with two opposite walls made of glass. The base of the container consisted of two textolite plates, with a small metal box measuring 25 × 10 mm tightly sealed into the upper one. A nichrome wire heater was installed in the box, and the bottom of the box, which faced upwards, served as the heater surface. The tests were carried out on a stainless steel plate 0.7 mm thick.

A copper-constantan thermocouple was sealed into the middle of the plate. Its junction was brought through to the surface of the plate from below and peened flush with the surface. Underneath, the heater was insulated with mica and asbestos, and then the second textolite plate was rigidly clamped to the first and to the container itself by four bolts. In this way the thermal losses from the heater were minimized.

Results of Wall Temperature Measurements at an Individual Vapor-Producing Site

Heat flux density q, kW/m²	T_W, °K	Test conditions
Pure water (ν_0 = 32 sec^{-1})		
49.2	381.2	Vapor-producing site present
63.6	388.2	"
67.2	388.6	"
76.0	394.2	"
Solution of a surface-active agent (ν_0 = 51 sec^{-1})		
50.0	379.0	Vapor-producing site present
65.5	402.3	Vapor-producing site absent
66.7	388.6	Vapor-producing site present
63.0	402.2	Vapor-producing site absent
78.4	403.2	Vapor-producing site absent
79.5	393.4	Vapor-producing site present
56.4	383.0	Vapor-producing site present

In our case the method of sealing in the thermocouple was not quite correct for measurement of heater surface temperature, since the thermocouple junction was peened directly on the plate surface; this caused frequent production of vapor bubbles near the junction, so that the thermocouple did not indicate the true surface temperature. In our tests, however, the fact that vapor bubbles were produced at the thermocouple junction was used to investigate the influence of bubble production on T_W. It was more important for us to obtain the relative drop in surface temperature

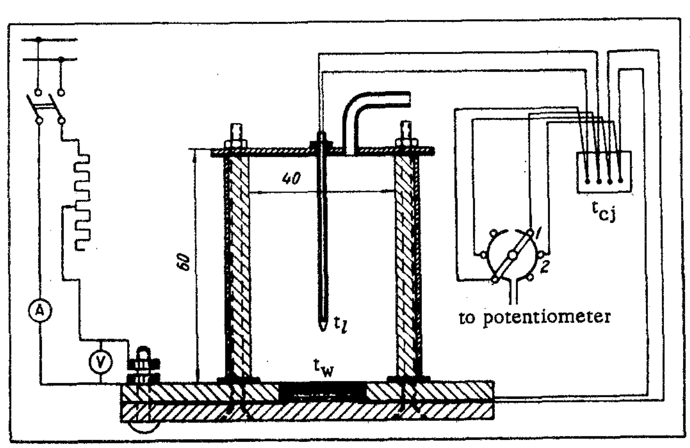

Fig. 1. Experimental setup.

in the presence of a vapor-producing site, and when the rate of vapor bubble breakaway was increased, than to obtain the true temperature of the surface as a whole.

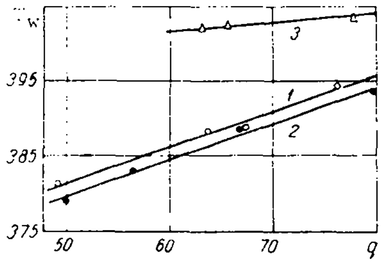

Fig. 2. Variation of wall temperature as a function of heat flux density: 1) with a vapor-producing site present; 2) at increased rate of vapor bubble breakaway; 3) without a vapor-producing site.

When the water boiled at the thermocouple junction, vapor bubbles were always formed at a single vapor-producing site. The rate with which they were formed was varied by adding a surface-active agent (OP-25) to the water. When the solution of surface-active agent boiled, the production of vapor bubbles sometimes ceased. In all cases we measured wall temperature, voltage drop, and current.

The results of the measurements are shown in Fig. 2 and in the table. Curve 1 relates to the boiling of water, when the formation of large vapor bubbles was observed, while curve 2 relates to the boiling of water with a 0.2% addition of surface-active agent, which lowers the surface tension of the water by 45%. There was then a noticeable increase in the rate of vapor bubble breakaway (confirmed by motion-picture photography), and T_w fell by approximately 2 degrees. When the vapor-producing site disappeared (boiling of solution of surface-active agent), a sharp increase in T_w (curve 3), averaging 12 degrees, was observed.

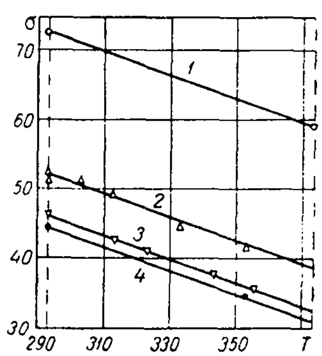

Fig. 3. Surface tension of liquid as a function of temperature for various concentrations of surface-active agent: 1) 0.0%; 2) 0.05%; 3) 0.1%; 4) 0.2%.

The motion-picture study of the rate of vapor bubble breakaway, corresponding to curves 1 and 2 of Fig. 3, was carried out in a special apparatus on a copper plate 100 mm in diameter, immersed in the liquid, at a constant value of the heat flux density q and two extreme values of the surface tension σ of the liquid (curve 1—59 mN/m at 373° K for pure water, and curve 2—31 mN/m for a 0.2% solution of OP-25).

The surface tension of the liquid was determined by the method of maximum bubble pressure. Measurements of the viscosity and density of the liquid showed that the addition of 0.2% of surface-active agent altered only the surface tension of the water. Since the latter does not affect the rate of convective heat transfer, the shift of the curves in Fig. 2 for identical values of q is due to a change in the boiling mechanism.

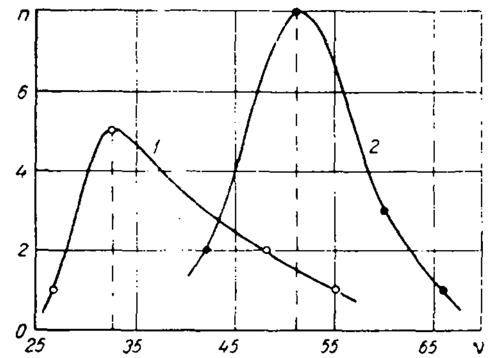

Fig. 4. Distribution of vapor bubbles according to rate of breakaway: 1) for pure water (σ = 59 mN/m); 2) for a 0.2% solution of surface-active agent (σ = 31 mN/m).

The results of the motion-picture investigation are shown in Fig. 4. The most probable of breakaway for water was $\nu_0 = 32$, and for the solution of surface-active agent $\nu_0 = 51$. This increase in the rate of production of vapor bubbles in the presence of a surface-active agent is due mainly to shortening of the period between the breakaway of one bubble and the growth of a fresh one. Thus, whereas when water boils, a bubble sits on the surface for $\tau_1 = 0.014$ sec, and the next bubble grows in $\tau_2 = 0.017$ sec, when the solution boils, $\tau_1 = 0.018$ sec and $\tau_2 = 0.0016$ sec, i.e., the interval between breakaway and the growth of a fresh bubble virtually disappears, which, of course, leads to an increase in the rate of vapor bubble production.

Thus, our investigation has shown that the presence of a vapor-producing site on the heating surface lowers the wall temperature appreciably; an increase in the rate of vapor bubble breakaway also lowers the wall temperature, but to a lesser extent. Hence it may be concluded that the number of active sites probably plays a decisive part, and the rate of breakaway of vapor bubbles a minor part, in boiling heat transfer.

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