THE NUMBER OF VAPOR-FORMATION CENTERS IN THE BOILING OF BINARY MIXTURES

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We describe the installation and method for the determination of the number of vapor-formation centers by a photography method. We present the curves showing the heat-transfer coefficient and the density of the vapor-formation centers as functions of the composition for four binary mixtures.

The results from a series of investigations demonstrate that the heat-transfer coefficients [1-5] and the critical heat flows [4-10] vary as a function of the composition of the binary mixtures, but not additively, rather exhibiting extremal values at intermediate concentrations.

Since the density of the active vapor-formation centers exerts great influence in boiling on heat transfer, to determine the mechanism involved in the boiling of binary mixtures we find considerable interest in the relationship between the density of these active centers and the composition of the mixture.

To the best of our knowledge, experimental research into the determination of the number of vapor-formation centers have been carried out, as a rule, with pure liquids or with mixtures for a limited interval of concentrations [11-13], which does not make it possible to judge the nature of the relationship between the number of vapor-formation centers and the composition of the mixture.

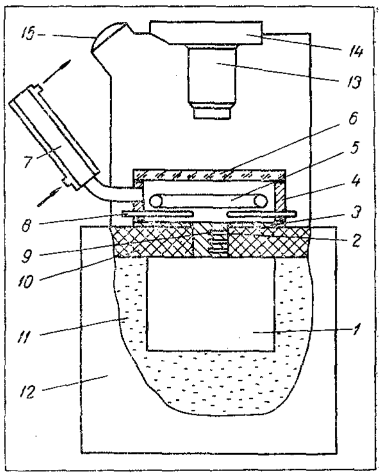

Fig. 1. Diagram of the experimental installation: 1) heater core; 2) core lead; 3) disc; 4) boiler; 5) refrigeration device; 6) glass; 7) condenser; 8) thermocouple sleeve; 9) holes for thermocouples; 10) asbestos cement; 11) glass wall; 12) casing; 13) adapter for macrophotography; 14) camera; 15) photoflash.

The purpose of this investigation was to determine the nature of the relationships between the number of vapor-formation centers and the composition of the mixture. For this we chose four binary mixtures with components that mix completely in the liquid phase: ethanol–water; acetone–water; acetone–butanol; benzene–toluene.

It was the function of the experimental portion of this project to derive the experimental data on the density of the active centers on a flat surface by means of photography (with simultaneous determination of the heat-transfer coefficients). The experiments were carried out at atmospheric pressure.

Figure 1 shows a diagram of the installation. The heat source is a nichrome-strip spiral positioned in the slot of the copper core 1. The heat is transmitted by the boiling liquid through cylindrical projection 2 with a diameter of 24 mm, whose end served as the heating surface. The junctions of three thermocouples were placed into the 1.5 millimeter holes 9 of projection 2; the emf of these thermocouples was measured by means of a semiautomatic R2/1 potentiometer.

The millimeter disc 3 made of stainless steel and soldered with a silver flux to the edge of the projection 2 served as the bottom of the boiling unit. The ends of the disc and of the projection, in one and the same plane, were galvanically coated with a thin chrome layer, thus protecting the heating surface from oxidation during the course

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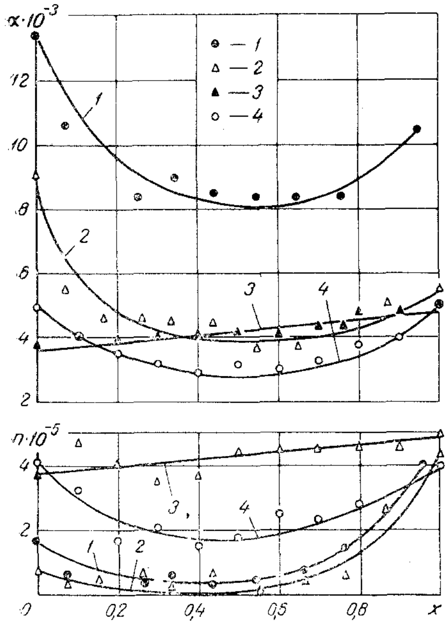

Fig. 2. Heat transfer coefficient α (W/m$^2\cdot$deg) and the density n (1/m^2) of the active vapor-formation centers as functions of the concentration x of the low-boiling component (in weight fractions): 1) ethanol–water; 2) acetone–water; 3) benzene–toluene; 4) acetone–butanol.

of the experiment and made it possible to regard the surface finish as constant. The surface finish corresponded to class 7-8.

The boiler housing 4, made of stainless steel, had an inside diameter of 80 mm and it was 30 mm in height. It contained brass refrigeration units 5, condenser 7, and sleeve 8 for the thermocouples measuring the temperature of the liquid in the boiling unit. The lid of the boiling unit was made up by a flat piece of glass 6 through which it was possible to carry out the photography. The seals were Teflon spacers. The limited height of the heater made it possible to photograph the heating surface at a close distance, with precise focusing.

All of the thermocouples used in the installation were made of Chromel–Copel wire 0.3 mm in diameter. The thermocouple calibration accuracy was 0.1°C.

The mixtures were composed of boiled organic liquids and distilled water.

Prior to the start of each series of experiments the heating surface was stabilized by the boiling of distilled water for 2 h at a load of $250\cdot10^3$ W/m^2. Moreover, prior to each experiment the heating surface was polished with acetone, distilled water, ethanol and, finally, with the liquid being investigated.

During the test the installation was inclined at an angle of 45° to enable the vapor to enter the condenser, and the rising bubbles thus did not cover the glass to prevent the taking of high-quality photographs. At the beginning of each experiment the load was set at $250\cdot10^3$ W/m^2. As soon as the saturation temperature was reached, the load was reduced to its operational levels. The heat flow was controlled by means of an autotransformer. Determination of the number of centers was accomplished for three mixtures with a specific heat flow of $100\cdot10^3$ W/m^2, while for the ethanol–water mixture the determination of the number of centers was carried out at a load of $200\cdot10^3$ W/m^2. These loads made it possible to calculate the centers of vapor formation over the entire concentration interval.

As soon as the steady-state regime is achieved – and this was determined from the constancy of the emf of all of the thermocouples – the readings of the potentiometer were recorded.

The specific heat flow was calculated with the Fourier equation. The heating-surface temperature was found through extrapolation of the known temperatures at points 9. The heat-transfer coefficients were determined from the formula $\alpha = q/(t_W - t_S)$.

Since the heating surface is darkened by means of flash powders, to achieve their rapid condensation, the liquids were subcooled (20-30°). For this, immediately prior to the photography, cooling water was passed through refrigeration unit 5. Within 3-4 sec, when the separating bubbles disappeared (condensed), and the bubbles at the surface were clearly visible, the photography of the heating surface was undertaken. The exposure time was determined by the duration of the light pulse from the photoflash (0.0005 sec) whose light was incident on the heating surface at an angle of 20-30° at a distance of 15 cm. The image on the film was obtained in approximately natural size. The subsequent (second) photograph was taken with the cooling shut down, so that the temperature of the boiling liquid began to approach the saturation temperature, but the bubbles had not yet separated from the heating surface.

The photographs were projected on a white screen with a 10-fold magnification. In examining the images for purposes of counting the number of centers, we took into consideration those bubbles with a circular area 20 mm in diameter. The averaged result for two photographs was taken as the average value for the number of active vapor-formation centers.

In our opinion this method of experimentation is very similar to that described in [14], and it introduces no fundamental errors into the nature of the relationships investigated. Indeed, such factors as size, location, and heating-surface finish remain constant for all mixture compositions. Assuming the boiling process to be self-similar with respect to the size of the heating surface, we can assume the distribution of the bubbles over the surface to be uniform [15]. Of course, with a small number of bubbles the error in the determination of the density of vapor-formation centers increases, but nevertheless the over-all character of the relationship between the density of centers and the composition of the mixture, in our opinion, should not change.

The subcooling of the liquid apparently leads to a reduction in the thickness of the superheated liquid layer at the heating surface. Primarily this affects the bubble size, rather than their number. Considering the brevity of the subcooling effect, we can also assume that this factor does not significantly affect the nature of the variation in the density of the vapor-formation centers with a change in mixture concentration.

The results of the experiment are shown in Fig. 2. As was assumed in [1], for binary mixtures we observe a minimum number n of active centers for the same approximate concentrations at which the minimum heat-transfer coefficient is found. For benzene–toluene mixtures, which is close to an ideal solution, the deviations of $\alpha(x)$ and $n(x)$ from a straight-line (additive) relationship are slight. The great similarity between the $n(x)$ and $\alpha(x)$ curves confirms yet one more time the relationship between the intensity of heat transfer in boiling and the number of vapor-formation centers. The deviations in α and n from additivity are brought about apparently by the unique features encountered in the mechanism of mixture boiling.

NOTATION

n is the density of vapor-formation centers;
α is the heat-transfer coefficient;
q is the specific heat flow;
t_w is the temperature of the heating surface;
t_s is the boiling temperature;
x is the content in the liquid of a component with a lower boiling point.

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