EFFECT OF THE PLATE POSITION ON THE RATE OF THE HEAT TRANSFER DURING THE BOILING OF FREON-113

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Experimental data are presented on the heat transfer from a horizontal plate to boiling Freon-113, with the heater surface of that plate turned either up or down.

Tests were performed with Freon-113 boiling under atmospheric pressure in a conventional setup. The liquid was at its boiling temperature. A cylindrical glass container 100 mm in diameter and 160 mm high served as the boiler with a condenser coil mounted on top.

The heater was made up as a horizontal plate of metal-clad glass-filled Textolite sheet. In the center portion of this plate, on the glass-filled Textolite side, a groove was cut with a 0.2 mm thin wall left to separate it from the metal foil and with a thermocouple installed in it. The groove was then filled with epoxy resin. An insulating 5.5 mm thick plain Textolite plate was glued to the glass-filled Textolite above the buried thermocouple. The 0.05 mm thick copper foil on top was used as the heating surface. The heat flux on the test plate was determined from the electric current and the resistance. The thermocouple emf was measured with a P-306 potentiometer matched to a normal Class 0.2 element and to an M17/1 mirror galvanometer, while the Freon temperature was measured on a laboratory thermometer with 0.1°C divisions.

The surface roughness of the plate, as determined on an MIS-1 profilometer, was $R_z = 3\ \mu$. The test plate is shown schematically in Fig. 1.

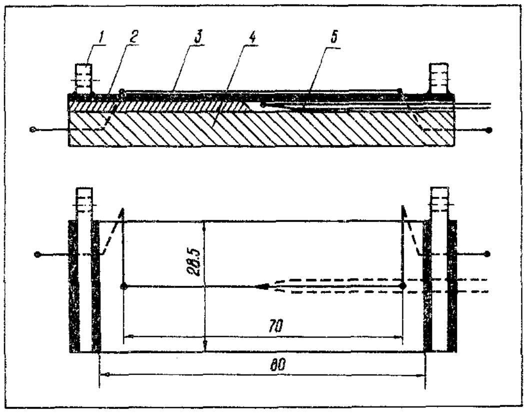

Fig. 1

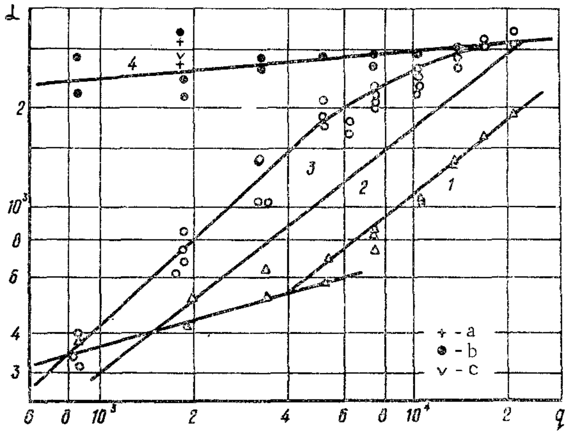

Fig. 2

Fig. 1. Schematic representation of the test plate: 1) current carrying busbars; 2) heater plate; 3) constantan wire (bubble generator); 4) Textolite cover; 5) thermocouple.

Fig. 2. Test results: 1) plate in the heater-side-up position; 2) tube with an $R_z = 58\ \mu$ [1] surface finish; 3) plate in the heater-side-down position; 4) plate in the heater-side-down position, with generation of vapor bubbles at the wire; a) 1 W; b) 2 W; c) 4 W. α, W/m²·°C; q, W/m².

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After the plate had been washed with dichloroethane, it was suspended in technically pure Freon-113 filling the boiler. The height of the liquid level remained 40 mm above the heater plate.

Tests were performed with the load increasing from $q = 900\ W/m^2$ to $q = 21{,}000\ W/m^2$ and then decreasing in the reverse sequence. The horizontal plate was first positioned with the heater side facing upward and then, by a 180° rotation, with the heater side facing downward.

With the heater side turned down, furthermore, two series of tests were performed on the plate during the heating of a constantan wire immersed in the boiler underneath the plate. The wire, 0.15 mm in diameter and 70 mm long, served as a generator of vapor bubbles for the test plate. During these tests the distance between wire and plate was either 1.5 mm or 5.0 mm. All the test data are shown in Fig. 2. An analysis of the results shows that, within the range $q = 1000\text{-}15000\ W/m^2$, the heat-transfer coefficients for the horizontal plate with the heater side turned down increase relative to the α values for the horizontal plate with the heater surface turned up by a factor of 2-3, and they are somewhat better than the heat-transfer coefficients for a tube with an $R_z = 58\ \mu$ surface finish [1].

A still higher rate of heat transfer (at $q < 10{,}000\ W/m^2$) is observed when vapor bubbles are generated with the aid of the hot wire underneath the plate. Varying the quantity of generated vapor within the range corresponding to a heater wire power of 1-4 W does not indicate a significant effect on the heat transfer.

Visual observations of the boiling process have shown that at the heater surface, when it is turned up, the boiling does not in any way differ from the boiling commonly observed. At the plate with the heater side turned down, however, an emerging bubble is initially spherical in shape and then grows until it combines with adjoining bubbles into oblate spheroids which slowly slide along the surface. As they slide toward the plate edges, they separate as large irregularly shaped vapor masses. With additional generation of vapor at the wire, this pattern prevails, but the bubbles separating from the plate become smaller as the surface becomes saturated with them.

When the vapor generator wire was located at a distance of 1.5 mm from the heater surface, the bubbles forming at the wire touched the heater surface after having fully grown and their separation from the wire did not occur. As a bubble was approaching the plate surface, a considerable increase of its dimensions and a merger with adjoining bubbles were observed. At discrete instants of time the wire was completely surrounded by a vapor phase.

When the wire was located at a distance of 5.0 mm from the plate, the bubbles that formed separated and hit the plate surface. As is seen in Fig. 2, the values of α are the same for different distances between wire and heater plate.

These results can be interpreted as follows.

The small differences in temperature observed under identical heat flux when the heater surface of the plate faces upward or downward are a consequence of different conditions of bubble growth.

At the upper side of the plate, during boiling, the fraction of a bubble which adheres to the surface and through which heat transfer occurs most intensively decreases as the bubble grows.

The vapor bubble emerging at the plate with the heater surface turned downward is pressed against it by the force of buoyancy and expands horizontally. As a consequence, the fraction of the area across which heat is carried intensively increases as the bubble grows.

The dimensions of vapor formations leaving the heater surface are, moreover, much larger than the diameters of bubbles which separate during boiling. Therefore, interaction between vapor phase and heater surface (through the boundary layer) takes place over a larger area and for a longer time during boiling at the lower surface than during boiling at the upper surface of the plate. Consequently, the rate of liquid evaporation, the rate of heater cooling, and the heat-transfer coefficients are higher at the heater surface in the first case than in the second case (at equal and small values of q).

As the heat flux increases, the evaporation rate in the liquid layer adjacent to the heater surface also increases and during boiling, therefore, part of the plate surface on the lower side can find itself in direct contact with the vapor phase. Consequently, the value of the heat-transfer coefficient is less affected by the magnitude of q. As q increases, at the same time, the number of vapor bubbles forming at the plate with the heater side turned up increases and this causes the heat to be carried away from it at a higher rate. For large values of q, then, the values of α for both plate positions come closer together.

Bubbles arrive at the plate from the hot wire with dimensions corresponding to the bubble diameter at separation. For the plate with the heater side turned down these bubbles become a new kind of vapor generating centers with radii curvature of larger than those of ordinary nucleations. Therefore, the formation of such bubbles will occur at smaller values of Δt.

In the presence of a vapor generator, furthermore, the number of bubbles simultaneously existing on the plate increases and so increases the surface of the phase separating boundary toward which heat is carried from the heater at a high rate and toward which evaporation proceeds. All these circumstances lead to more intensive heat transfer than in the case of a plate without a vapor generator.

With the same power dissipated in the wire, the number of bubbles generated by it remains constant, their mean dimensions are the same, and the heat transfer at the plate is almost independent of q (curve 4 in Fig. 2). At high values of q the number of bubbles forming at the plate itself becomes comparable to the number of bubbles coming from the wire, while the values of α at the plate without and with vapor generation tend to become equal.

The data presented here allow one to consider that, within the range of small temperature differences Δt and under low pressures characteristic of refrigerating apparatus operation, the rate of heat transfer can be increased by the use of oval tubes and also by the generation of vapor with the aid of some special devices. On the basis of these data, we conclude that the heat-transfer coefficient is higher for a bundle of tubes than for a single tube not only because of turbulization and an increased convective heat transfer component but also because of the additional evaporation of liquid at the upper tubes into bubbles rising up from the lower tubes.

LITERATURE CITED

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