Int. J. Heat Mass Transfer. Vol. 11, pp. 347–351. Pergamon Press 1968. Printed in Great Britain

THE INFLUENCE OF THE STATE OF HEATING SURFACE ON HEAT TRANSFER AT BOILING

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(*Received* 9 *January* 1967)

Аннотация—В работе приводятся результаты исследования влияния состояния теплоотдающей поверхности на теплообмен при кипении ряда органических жидкостей (дифенила, моноизопропилдифенила, бензола и этанола), которые значительно лучше воды смачивают поверхность. Когда жидкость полностью смачивает поверхность, влияние изменения смачиваемости на механизм кипения исключается и, следовательно, в этом случае можно выявить влияние других факторов, вызывающих изменение теплоотдающих свойств поверхности со временем.

At PRESENT vast experimental material is stored on heat transfer at boiling under conditions of both free convection and forced movement of liquid. Despite this, many problems related to the boiling mechanism have not been sufficiently studied. There are especially many uncertainties concerning the mechanism of the effect of the state of the heating surface upon heat transfer in boiling. It has been established by numerous investigations that thermal properties of the surface are changing with time. The most comprehensive data concerning the change in surface properties are obtained from the study of the critical heat flux q_{cr}. Thus, the authors of [1, 2, 3] have shown that in water boiling on a new smooth surface, the critical heat flux is considerably smaller than it is after several hours of surface work under the conditions of boiling. The increase of q_{cr} is attributed to better moistening caused by deposition on the heat transfer-surface of mineral compounds, that are always present even in distilled water.

The studies of heat-transfer coefficients α have revealed different effects caused by the change in surface properties on the heat-transfer rate. Thus, according to [4, 5, 6] the heat-transfer coefficients on new surfaces are higher than those already used for boiling. An exactly opposite result has been obtained [7, 8], and the authors of [9], who studied water boiling on nickel-plated copper surface at atmospheric pressure, have found that at the beginning of the test the heat-transfer coefficient decreases, attains its minimum in about 4 h and then, increasing gradually, approaches a constant value.

In all the studies mentioned above, the working fluid was water, whose moistening properties considerably depend on the state of the surface. It is of interest to experiment on liquids whose thermal properties are different from water and to see whether a similar phenomenon does in fact take place. The results of such work are described in the present paper. Tests were made with certain organic liquids (diphenyl, monoisopropyldiphenyl, benzol and ethanol) which moisten the surface much better than water. When liquid completely moistens the surface, the influence of changes in moistening properties on the mechanism of boiling is eliminated and, therefore, in such a case the effect can be revealed of other factors which cause time-dependent changes in heat-transfer properties of the surface.

First of all, the influence of the operation time on the value q_{cr} has been studied in diphenyl boiling on a polished stainless steel surface. The experiment was carried out on the apparatus described in [10]. Tested was a horizontal plate of stainless steel 5-mm high and 1-mm thick.

The tests were carried out at a pressure of 11 bar and temperature equal to that of saturation. Before the experiment, total deaeration of diphenyl was carried out, after which two values of the critical heat flux were determined on a new polished plate. They appeared to be 552 . 10^3 W/m^2. Then at a given pressure the heat flux was kept equal to 450 . 10^3 W/m^2 (which was 80 per cent the critical heat flux) and from time to time (not less than two to three times an hour), the values of the critical heat flux were again determined. All the data obtained coincided within ±2·5 per cent (Fig. 1).

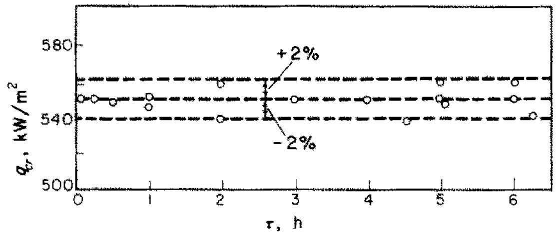

FIG. 1. The influence of boiling time on q_{cr} at diphenyl pool boiling.

Separate experiments were carried out on polished plates covered with a thin layer of engine oil, and the results obtained were similar to the results of the experiments with the surface degreased by benzol.

In some cases the heat flux was kept for a long time 5 per cent below the critical. However, the crisis here did not appear spontaneously. This indicates that transition to film boiling takes place with sufficiently constant values of heat flux, i.e. under constant regime conditions the process is rather stable even when near the crisis.

As pointed out above, a number of investigators have noticed that in water boiling exists a considerable dependence of q_{cr} on the time of preliminary boiling on the heat-transfer surface. What is the reason for the absence of this phenomenon in boiling of high-boiling organic heat carriers?

The following tests have been conducted to answer this question. For a long time the tested sample was boiled in one liquid and then the dependence of heat transfer and critical heat flux on the time of boiling was experimented in another liquid whose properties are different from those of the first one. After the stable values of α and q_{cr} have been achieved, the test was repeated with the liquid in which the experimental section had initially been boiled.

The test was carried out on the apparatus similar to that described in [10]. All the parts of the apparatus were made of stainless steel. To eliminate the influence of contamination, before the experiment the apparatus was thoroughly cleaned and washed with benzol. In the experiment chemically pure substances were mainly used. The values of α and q_{cr} were determined during boiling of liquids heated up to the saturation temperature at atmospheric pressure.

The experimental section was a smooth horizontal nickel tube 2·5 mm in diameter with the wall 0·1-mm thick. The temperature of heat-transfer surface was measured by two chromel–copper thermocouples mounted inside the tube and connected with the potentiometer P.2/1. Boiling proceeded on the outer tube surface.

First α and q_{cr} were determined in boiling of chemically pure benzol on the new experimental surface. The stable values of α and q_{cr} were achieved only after some hours of boiling [with heat flux 100 kW/m^2. Figs. 2(a) and 3(a)]. Here during the starting period the heat-transfer coefficient and critical heat flux increases with time.

After the stable values of α and q_{cr} had been achieved, the load was switched off, the liquid poured out, and the apparatus opened and dried. Then, distilled water was poured into the newly assembled apparatus (the time between disassembly and assembly did not exceed 10 min), and the influence of time of boiling on heat transfer and critical heat fluxes was studied for this liquid. Water boiling proceeded with heat flux 200 kW/m^2. In about 3·5 h when stable values of α and q_{cr} were achieved, the water was poured out and the experiment was continued with benzol (boiling proceeded at q = 100 kW/m^2). The results of these experiments are given in Figs. 2(b, c) and 3(b, c). It is seen from the figures that preliminary boiling of the heat-transfer surface in benzol produces an increase of α and q_{cr} in the subsequent boiling, and conversely, boiling water decreases α and q_{cr} when benzol is boiling.

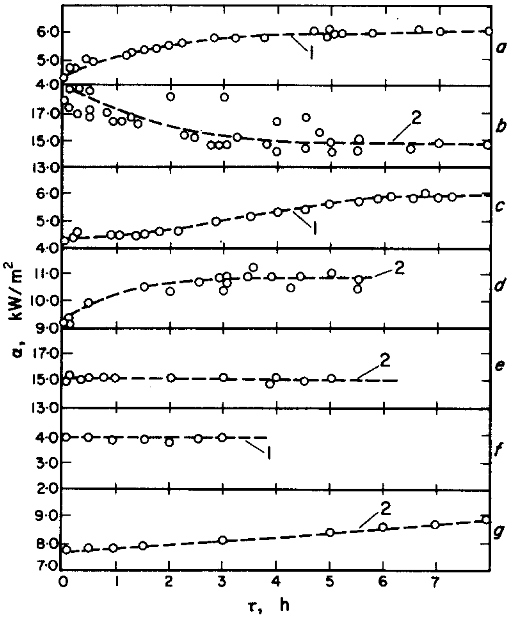

FIG. 2. Time dependence of heat-transfer coefficient for various kinds of liquid filling the microslits. 1—q = 100 kW/m^2; 2—q = 200 kW/m^2.

Figure	Liquid under test	Liquid in which experimental surface sample has been preliminarily boiled
a	benzol	new experimental sample
b	water	benzol
c	benzol	water
d	ethyl alcohol	water
e	water	ethyl alcohol
f	monoisopropyldiphenyl	benzol
g	benzol	monoisopropyldiphenyl

Such experiments were repeated several times. The agreement between the repeated data is sufficiently good. According to visual observations the surface remained clean throughout all the experiments. When preliminary boiling proceeded with higher heat fluxes, the stable values of α and q_{cr} were achieved for a shorter time.

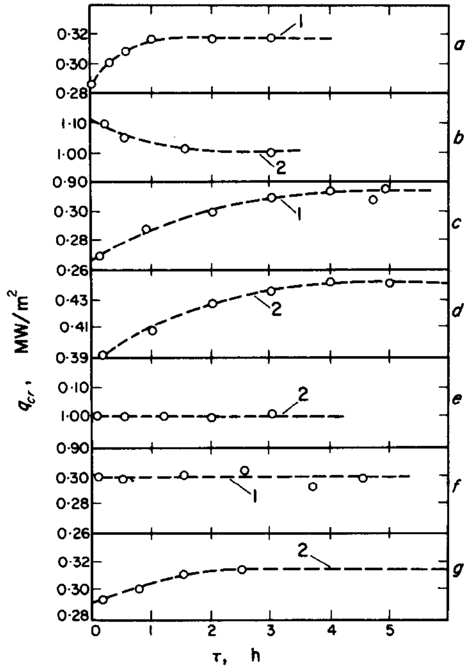

FIG. 3. The value of the critical heat flux vs. the kind of liquid filling the microslits. (Legends the same as in Fig. 2.)

In water boiling on the surface which has been working in benzol for a long time, the intensification of heat-transfer process is evidently caused by the fact that at a temperature equal to the boiling point of water the benzol in microslits becomes highly overheated and when evaporating provides additional vapour generation centres.

Benzol and water are two unmixed liquids and their presence in microslits can therefore effect moistening with these liquids. It is of interest to explain the influence of the above effect on α and q_{cr} when intersoluble liquids are boiling. To this end similar experiments were carried out on water and ethyl alcohol, benzol and monoisopropyldiphenyl. The experimental results are also presented in Figs. 2 and 3. It is seen from the figures that preliminary boiling of heat exchanging surface in a liquid whose boiling point exceeds that of the medium under study, decreases the heat-transfer coefficients and critical heat fluxes. The greater the difference between the saturation temperatures of the liquid filling the microslits and the liquid boiling in the vessel, the longer time is required to achieve the stable values of α and q_{cr}.

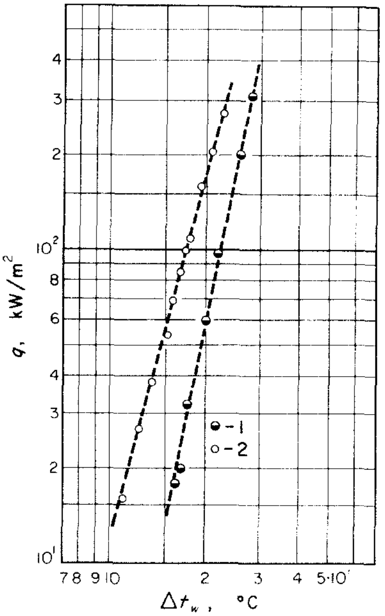

FIG. 4. The dependence $q = f(\Delta t_w)$ in boiling of benzol on the surface preliminarily working in monoisopropyldiphenyl. 1—$\tau = 0$; 2—$\tau = 8$ h.

No influence of preliminary boiling in ethyl alcohol on heat transfer in water boiling is observed. Thanks to good solubility in water, ethanol is apparently quickly removed out of microslits at a temperature of surface noticeably exceeding its boiling point. For this very reason no change of α and q_{cr} is found in boiling of monoisopropyldiphenyl on the surface working in benzol.

Also the boiling curve $q = f(\Delta t_w)$ (where Δt_w is the wall temperature excess over the saturation temperature) was determined for all the liquids under test at the beginning and at the end of the test. Figure 4 shows typical relations obtained in boiling of benzol on the surface previously boiled in monoisopropyldiphenyl just after the benzol has been poured into the apparatus ($\tau = 0$) and after 8 h of boiling ($\tau = 8$ h). It is seen from the figure that the character dependence of α on the time of boiling is the same for all heat fluxes. Thus, the experiments carried out revealed the conditions under which one or another type of dependence of the heat-transfer coefficient and critical heat flux on the time of surface work should be expected and explained the reason of the absence of the boiling time influence upon α and q_{cr} at boiling of high-boiling organic liquids.

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Abstract—In the paper the results are reported on the influence of the state of the heat-transfer surface upon the heat transfer in boiling of a number of organic liquids (diphenyl, monoisopropyldiphenyl, benzol and ethanol) which moisten the surface better than water. When liquid completely moistens the surface, the influence of change in moistening is neglected and, hence, in this case the effect of other factors can be revealed which cause a time change in heat-transfer properties of the surface.

Résumé—On rapporte les résultats de l'influence de l'état de la surface transmettant la chaleur sur le transport de chaleur par ébullition de plusieurs liquides organiques (diphényle, monosopropyldiphényle, benzol et éthanol) qui mouillent la surface mieux que l'eau. Lorsque le liquide mouille complètement la surface, l'influence du changement du mouillage est négligé et, de ce fait, l'effet dans ce cas d'autres facteurs peut être révélé ce qui provoque un changement dans le temps des propriétés de transmission de la chaleur à partir de la surface.

Zusammenfassung—In der vorliegenden Arbeit werden Versuchsergebnisse über den Einfluss des Zustands der Heizfläche auf den Wärmeübergang beim Sieden von einer Reihe von organischen Flüssigkeiten (Diphenyl, Moinoisopropyldiphenyl, Benzol, Äthanol), die die Oberfläche besser als Wasser benetzen, wiedergegeben. Wenn die Flüssigkeit die Oberfläche vollständig benetzt, wird der Einfluss einer Änderung der Benetzung vernachlässigt und in diesem Fall kann deshalb der Einfluss anderer Faktoren erkannt werden, die eine Änderung der Wärmeübergangseigenschaften der Oberfläche mit der Zeit verursachen.