MECHANISM OF BUBBLE SEPARATION FROM CYLINDRICAL PORES AFTER BUILDUP DURING THE BOILING OF A LIQUID

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The mechanism by which bubbles separate after buildup in cylindrical pores was studied with the aid of high-speed cinematography. The separation diameter of a bubble has been established, as a function of the pore dimensions at various thermal flux levels.

It is well known today that the basic form of active boiling centers on the heater surface are various kinds of depressions, cracks and pores, not completely filled with liquid [1-11]. It is evident, moreover, that the process of vapor bubble formation, buildup, and subsequent separation must depend substantially on the depression geometry, on the surface wettability, and also on the external pressure as well as on the original volume of the gaseous phase and on the temperature drop.

The effect of the critical wetting angle on the activity of cylindrical pores was examined in [3, 8], and the bubble forming ability of various shape cavities was studied in [9, 10]. The bubble formation in conical pores was analyzed theoretically in [11].

The authors will describe here the experiments performed in a study concerning the bubble separation from cylindrical pores, depending on the pore dimensions, on the magnitude of the thermal flux, and on the contact time between liquid and heater surface before the start of boiling.

High-speed cinematography (4500 frames/sec) was used for a study of saturation boiling of water, glycerine, and ethyl alcohol on silver, copper, and brass plates ($64 \times 3 \times 1.3$ mm) with prefabricated pores of various diameters and depths. The operating segment was heated electrically with direct current. The temperature of the liquid was measured with a thermometer having 0.1°C divisions on the scale, the mean surface temperature was measured by the compensation method with a copper-constantan thermocouple.

Furthermore, the boiling of water was observed visually on an electrically heated precisely ground metal plate of rather large dimensions ($170 \times 80 \times 16$ mm). Into the upper surface of this plate were fabricated 120 cylindrical pores differing in diameter and in depth.

In order to attain uniform wetting across the entire plate surface, the latter was pretreated by appropriate physicochemical techniques (for good wettability, it was smeared with diamond paste and then a weak solution of sodium sulfate; for poor wettability, it was smeared with a soap solution or was treated by the method shown in [8]).

The pore dimensions were varied over the following ranges: diameter d from 0.1 to 1.25 mm, depth h from 0.25 to 2.5 mm. The thermal flux was varied in various tests from 800 W/m^2 to 60,000 W/m^2. The separation diameters were calculated as the averages of vertical and horizontal dimensions.

The first test series was performed for the purpose of qualitatively estimating the effect of contact time between heater surface and liquid on the bubble forming action of pores in that surface. Accordingly, the heater plate ($170 \times 80 \times 16$ mm) was immersed in the liquid and the latter was periodically brought to boiling for a few hours, with the intervals between boiling cycles gradually lengthened from 3 to 120 h.

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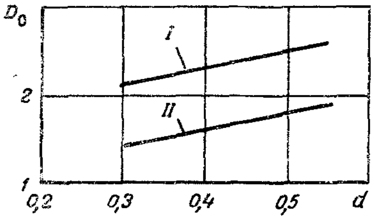

Fig. 1. Bubble separation diameter D_0 as a function of the pore diameter d: for water (I), for alcohol (II).

In the case of good wetting, during the first boiling cycle the vapor bubbles appeared both on top of pores and on the smooth surface areas of the plate. After a short time already, bubbles ceased to form on the smooth spots, however, and after lengthy boiling continued to build up only on top of the cylindrical depressions. During subsequent boiling cycles, later on, bubbles appeared from the very start on top of pores only. As the intervals between boiling cycles were increased to several days, moreover, first the shallowest and narrowest pores ceased to be active and then also the deeper and wider ones.

In the case of poor wetting of the heater surface by the liquid, on the other hand, bubbles appeared throughout all boiling cycles both on top of pores and on the smooth surface areas of the hot plate. Moreover, the "active" bubble forming spots on the smooth surface were turning yellowish. An examination of these spots under a microscope revealed single or multiple cavities 0.05 mm in diameter. The activity of unwetted pores did not diminish with time.

In the second test series the liquid was boiled under reduced pressure (about 0.1 atm.abs). The following peculiarties were noted then. The separation dimensions were much larger than those under normal pressure. At individual active pores the diameters of separating bubbles varied periodically: after a successive separation of a few bubbles of normal size, there suddenly appeared and collapsed one and another and a third, etc. much larger bubble. The sequence of large bubbles was then followed again by small ones. Periodic fluctuations of the separation volume continued at these centers throughout the entire boiling process. It was not possible to explain the causes of such a behavior characterized by fluctuations of the bubble diameter D_0.

As under normal pressure, in this case too the shallower and narrower pores gradually ceased to be active during boiling on wetted surfaces. Under lower pressure, however, this trend started much sooner (an hour and a half after the start of boiling pores h = 0.25 mm deep became saturated).

In the third test series the authors studied the dependence of the bubble separation diameter D_0 on the depth and the width of a cylindrical pore. We have found that on a wetted surface D_0 is an approximately linear function of the pore width (Fig. 1) for pores of equal depth (h = const). For pores of equal width (d = const), D_0 first increases with increasing h, but 15-20 min after the start of boiling D_0 continues to increase so slightly that it may be considered practically to become independent of h.

In the case of poor wetting of the surface, D_0 (of pores 0.55-0.10 mm in diameter) does not depend on the pore dimensions and is determined by the critical wetting angle.

Considering the kinetics of bubble separation from a depression in the heater surface, an analysis of the cinematograms has confirmed the theoretical hypotheses propsed in [3]: that on a wettable surface the base of a bubble continues to adhere all the time down the pore orifice so that separation occurs along the necking.

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