Triggering Mechanism of CHF in a Horizontal Pool Boiling of Saturated Water

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1. Introduction

The present study presents the details of boiling structures at high heat flux condition and reveals the triggering mechanism of the critical heat flux in a horizontal pool boiling, based on the in-depth observations obtained by applying the visualization techniques of a total reflection, a side view, and a diagonal view in a synchronized manner.

2. Experimental Setup and Results

The experimental apparatus consists of a boiling pool with a transparent heating surface, a power supply system, a data acquisition system, a lighting system and two high speed digital video cameras. The boiling surface is made of a 1 mm thick rectangular sapphire glass, where a 350 nm thick transparent ITO (Indium Tin Oxide) layer was sputtered at its bottom center. The effective heating area of the ITO layer was 8×80 mm^2.

The principle visualization technique is the total reflection at the boiling surface, which reflects the dry area and wetted area of the boiling surface with high fidelity. The side view and the diagonal view were alternatively applied together with the total reflection in a synchronized manner. Details of the test apparatus and the visualization techniques can be found in the reference [1].

Figure 1 shows the consecutive images of the synchronized diagonal view and total reflection obtained for the coalescence of three bubbles at the heat flux of 52.3% CHF. At time 0.0 msec, the first bubble is growing in the left side. At 1.0 msec, the second and the third bubbles, marked with the arrows, grows at the right periphery of the first bubble, and start to coalesce with the first bubble. At 3.0 msec, one bigger bubble is formed from the coalescence of these three bubbles, but three dry spots underneath the coalesced bubble are still separated. The dry spots expand due to the heat transfer from the boiling surface, making the separate dry spots get closer. All three dry spots become merged into one bigger dry patch during the time from 7.0 ~ 9.0 msec. Then, the coalesced bubble starts to depart from the boiling surface, making the dry patch shrink in its size. The dry patch is totally wetted with the departure of the bubble.

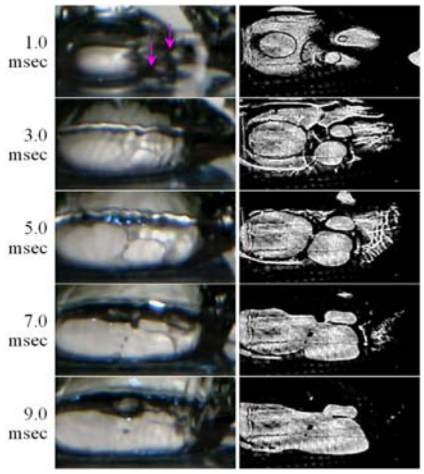

Fig. 1 Consecutive images of the synchronized diagonal view (left) and total reflection (right), showing the coalescence of three bubbles and the formation of dry patch by the merge of three dry spots.

Figure 2 shows the consecutive images of the synchronized diagonal view and total reflection, showing (1) the formation of the largest massive bubble resulting in the merge of dry patches into the largest dry patch, and (2) the wetting process of the large dry patch with the depart of the large massive bubble at the heat flux of 96.9% CHF.

At 1.0 msec, a dry patch (dry patch No. 1; DP1) was already formed under the massive bubble in the left (massive bubble No. 1; MB1) of the images, and several bubbles start to coalesce with each other in the right part of the images. The bubbles in the right coalesce with each other during the period of 5.0 ~ 7.0 msec, which results in the formation of another massive bubble in the right (massive bubble No. 2; MB2). At 7.0 ~ 10.0 msec, a few bubbles are newly generated between the massive bubbles No. 1 and No. 2 and they coalesce with each other, producing another large bubble (coalesced bubble No. 1; CB1). At about 10.0 msec, the massive bubbles No. 1 and No. 2 are bridged by the coalesced bubble No. 1, which triggers the formation of the large massive bubble all across the visualization area. At about 14 msec, the largest massive bubble is settled all across the visualization area, and three separate dry patches exist underneath the largest massive bubble. The separate dry patches mildly but steadily grow in their size by the evaporation of the trapped liquid among the dry patches until approximately 25.0 msec. As the evaporation of the trapped liquid proceeds, the dry patches No. 2 and No. 3 are merged with each other at 19.0 msec. The dry patch No. 1 is merged with the dry patch No. 2 at 27.0 msec, establishing the single dry patch largest in its area.

The departing motion of the large massive bubble starts from about 25.0 msec. Many new bubbles are generated around the periphery of the large massive bubble immediately after the dry patch is partly wetted, as seen in the images at 27.0 and 51.4 msec. They coalesce with the departing massive bubble at the bottom periphery of the departing bubble. The large massive bubble already departed from the boiling surface at 57.4 msec. Nevertheless, the boiling surface is not completely wetted but partly covered by a small dry patch (*hereafter*, a residual dry patch) because a part of bubble remains on the boiling surface (*hereafter*, a remaining bubble) at the departure of the massive bubble.

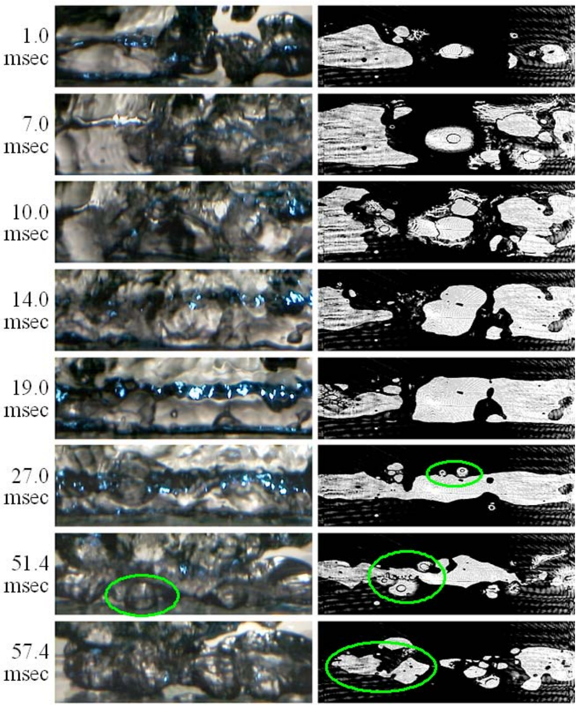

Fig. 2 Consecutive images of the synchronized diagonal view (left) and total reflection (right) at 96.9% CHF, showing the formation of the largest massive bubble resulting in the merge of dry patches into the largest dry patch.

Above the heat flux of approximately 97%, the size of the residual dry patch the activity of bubble nucleation around the residual dry patch are often sufficiently large and strong for the re-expansion of the residual dry patch to the large dry patch. As a result, a large massive bubble is produced again at its previous location of the departure. The probability of success of this re-expansion increases with the increase in the heat flux. Also the size and the location of the minimum residual dry patch become larger and more consistent with the increase in the heat flux. As a result, a part of the residual dry patches are never completely wetted throughout a series of departures of large massive bubbles, which corresponds to the appearance of the hot spot. As a results, the surface temperature in the neighboring region of the hot spot also increases in some degree, which accompanies the enhanced bubble nucleation activity in this neighboring region. If the heat production rate of the heating element is kept to be constant, the hot spot spreads widely over the boiling surface after its initiation due to the sequent temperature increase in the succeeding neighboring region, thus causing a burn-out of the boiling surface in a few seconds.

3. Conclusions

The mechanisms for the appearance of large dry area and the CHF can be summarized as follows based on the present in-depth observations:

1. A large dry patch under the large massive bubble results from the lateral coalescence of multiple bubbles while the bubbles are growing, being attached to the boiling surface. Therefore, the base of the large massive bubble is almost dry from its inception, which contradicts the common postulation that a thin liquid layer with distributed vapor stems exists under the massive bubble.
2. A residual dry patch is formed on the boiling surface at the departure of the large massive bubble at high heat flux boiling condition, which prevents the complete wetting of the large dry patch. The residual dry patch is the product of enhanced bubble nucleation activity in the wetting region of departing massive bubble.
3. The further increase of bubble nucleation activity around the residual dry patch causes the continuous re-expansion of the residual dry patch to the large dry patch throughout sequent departures of large massive bubbles. As a result, a part of the residual dry patch is never completely wetted and the dry patch evolves to the hot spot, by which the occurrence of critical heat flux is defined.

REFERENCES

[1] In-Cheol Chu, Application of Visualization Techniques to the Boiling Structures of Subcooled Boiling Flow and Critical Heat Flux, Ph. D. Dissertation, KAIST, 2011.