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Observation of Boiling Structures on a Horizontal Heating Surface Using a Total Reflection Technique

In-Cheol Chu[a*], Chul-Hwa Song[a], and Hee Cheon NO[b]
[a]*Korea Atomic Energy Research Institute, 1045 Daedeok-Daero Yuseong Daejon Korea*
[b]*Korea Advanced Institute of Science and Technology, 335 Gwahak-ro Yuseong Daejon Korea*
**Corresponding author: chuic@kaeri.re.kr*

1. Introduction

Several models were suggested to explain the boiling structures on a horizontal heating surface at high heat flux nucleate boiling conditions [1-5]. However conclusive experimental evidence is still lacking because vigorous boiling blocks the direct observation of the boiling structure near the heating surface. The present study is aiming at the visualization of the boiling structures for various pool boiling and flow boiling conditions by applying multiple visualization techniques simultaneously. As a first step, the boiling structure on a horizontal heating surface in a pool was visualized by using a total reflection technique for water and Freon 113.

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 laser lighting system and a high speed digital video camera system (Fig. 1). The cubic shaped boiling pool was made by a transparent polycarbonate plate and its dimension was 140(W) × 200(D) × 170(H) mm. A reflux condenser was installed at the top plate of the boiling pool. Two auxiliary cartridge heaters were inserted through the side walls to control the pool temperature. The bottom plate was made of aluminum plate, and a rectangular sapphire glass, 80 × 120 mm^2 and 1 mm thick, was sit at the central part of the bottom plate.

A 350 nm thick transparent ITO (Indium Tin Oxide) layer was sputtered at the bottom surface of the sapphire glass. The ITO layer was used as a heating source because it was electro-conductive, and the heating area was 8 × 80 mm^2. A nucleate boiling occurred at the top surface of the sapphire glass when a desired D.C. voltage was applied to each opposite ends of the ITO layer. The top surface of the sapphire glass was polished by diamond powders in order to make the surface be closer to the practical metal surfaces. As a result, the surface roughness became about 0.2 μm and the static contact angle was around 80^o for distilled water.

A prism was attached to the ITO layer to accommodate the total reflection angle at the top surface of the sapphire glass. Ion laser with the wavelength of 458-514 nm was used as a light source. The laser beam was expanded about 20 times before it entered into the prism and the sapphire glass.

A total reflection occurs at the top surface of the sapphire glass when the surface is dry, while it does not occur when the surface is wetted by liquid. That is, the total reflection occurs at the areas where the bubbles are attached to the heating surface. The total reflection images were recorded by Memrecam GX-3 high speed digital video camera of NAC Inc. MICRO NIKKOR 105 mm 1:2.8 lens was used. The recording speed and image size of the camera were set to 20,000 frames per second and 320×192 pixels. The distance between neighboring pixels in the recorded image was about 60 μm.

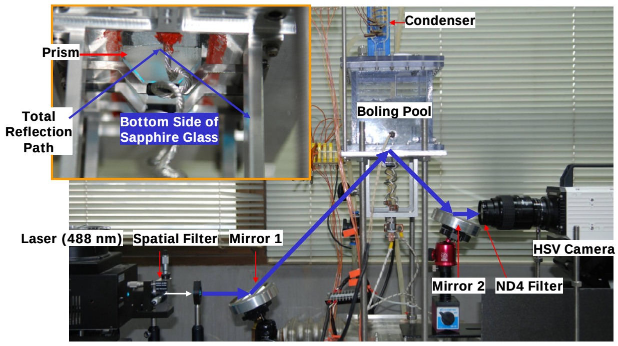

Fig. 1 Photo of the test apparatus

Total reflection images were obtained for saturated water and Freon 113 pool boiling conditions. Six tests were performed for water boiling by changing the heat flux from ONB condition to 600 kW/m^2, and 15 tests for Freon 113 by changing the heat flux from ONB to CHF.

In the case of water boiling, the total reflection from the microlayer and the dry spot underneath the bubbles could be clearly discerned especially for the discrete bubble regime. From the total reflection image of the growing bubble, it could be found that the dry spot was undetectably small at the beginning period of the bubble growth. That is, the growth of the microlayer preceded the growth of the dry spot. Then the growth of the dry spot occurred due to the evaporation of the microlayer. The bubble base became totally dry when the most of the microlayer was depleted. Large dry patches were observed as the heat flux increased. Usually, a dry patch was initiated by the dry spot of a rapidly growing bubble. This dry spot easily merged with the several neighboring dry spots, forming larger dry area. Figure 2 is the consecutive total reflection images of water boiling condition. Dark area corresponds to the wetted area by water pool, and bright areas correspond to the bubble bases. It can be clearly seen that a dry patch is formed by the lateral coalescence of neighboring dry spots, and a large dry area is formed by the coalescence of neighboring dry patches.

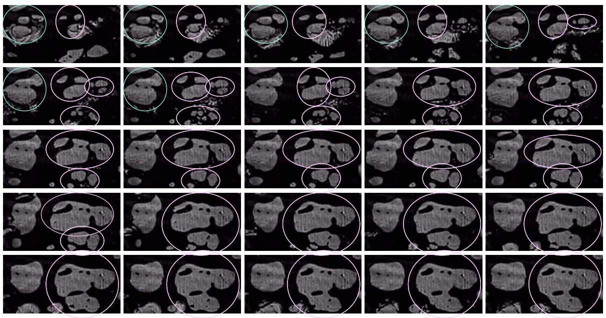

Fig. 2 Consecutive total reflection images of saturated water pool boiling at the heat flux of 400 kW/m^2 [time step is 0.5 ms from left to right; image size is 9.5(H)×6.1(V) mm].

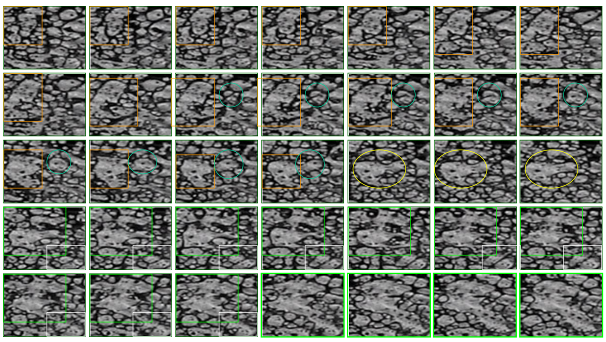

Fig. 3 Consecutive total reflection images of saturated Freon 113 pool boiling at the heat flux of 80 % CHF [time step is 1.0 ms from left to right; image size is 4.4(H)×6.1(V) mm].

Figure 3 is the consecutive total reflection images of saturated Freon 113 boiling condition at the heat flux of 80 % CHF. Total reflection image of Freon 113 is much more complicated than water because the size of individual bubble and dry spot is several times smaller than water, and the dry patch is very easily quenched due to its high wettability. In contrast to water boiling, the coalescence of neighboring dry spots formed much smaller dry patch rather than leading directly to the formation of large dry patch. These small dry patches were easily quenched as mentioned. And, intermediate size dry patches were formed by the merge of several small dry patches. At times, large dry patch was established by the coalescence of these intermediate size dry patches, as shown in Fig. 3. However, the large dry patch did not last long but shrunk to intermediate dry patch due to high wettability of Freon when the heat flux is lower than CHF. CHF condition was reached when the generation rate of dry spot and small and intermediate dry patches overcome the quenching rate of large dry patch.

3. Conclusions

The boiling structure on the heating surface in a horizontal pool boiling was investigated focusing on the dynamic behaviors of dry spots and establishment of large dry patches. In water boiling case, a dry patch was formed by the lateral coalescence of neighboring dry spots, and a large dry area was formed by the coalescence of neighboring dry patches. In Freon 113 boiling case, the coalescence of neighboring dry spots formed a small dry patch, intermediate size dry patches were formed by the merge of several small dry patches, and the large dry patch was established by the coalescence of the intermediate size dry patches.

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