Basic Study for Active Nucleation Site Density Evaluation in Subcooled Flow Boiling

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1. Introduction

Numerous studies have been performed on a active nucleation site density (ANSD) due to its governing influence on a heat transfer. However, most of the studies were focused on pool boiling conditions.

Kocamustafaogullari and Ishii [1] developed an ANSD correlation from a parametric study of the existing pool boiling data. Also, they extended the correlation to a convective flow boiling condition by adopting the nucleation suppression factor of Chen's heat transfer correlation. However, the appropriateness of applying the Chen's suppression factor to an ANSD correlation was not fully validated because there was not enough experimental data on ANSD in the forced convective flow boiling.

Basu et al. [2] performed forced convective boiling experiments and proposed a correlation of ANSD which is the only correlation based on experimental data for a forced convective boiling. They concluded that the ANSD is only dependent on the static contact angle and the wall superheat, and is independent of the flow rate and the subcooling, which contradict the general acceptance of the nucleation suppression in the forced convective boiling. It seems that no reliable ANSD correlation or model is available for a forced convective boiling.

In the present study, the effect of the flow velocity on the suppression of the nucleation site was examined, and the effectiveness of a Brewster reflection technique for the identification of the nucleation site was also examined.

2. Suppression of Nucleation Site

Annulus boiling channel was used to examine the suppression effect of the flow velocity on the nucleation sites. The test channel has a transparent polycarbonate pipe outside a heater rod. The inner diameter of the polycarbonate pipe is 31.75 mm and the outer diameter of the heater rod is 9.5 mm. The total length of the channel is 1,270 mm. The heating length of the heater rod is 700 mm, the heater has non-heating length of about 370 mm and 200 mm at the upstream and downstream of the heating region, respectively.

Two sets of convective boiling experiments were performed, and the experimental condition is shown in table 1. The number of the nucleation sites was manually counted from the 300 consecutive pictures taken from high speed video recording system. The actual length of the view field was 38 mm.

Table 1 Experimental condition

No.	G kg/m^2s	q" kW/m^2	ΔT_{sub} ^oC	ΔT_{sat} ^oC	z_H m	N_A
1-a	499	139	6.1	23.0	0.64	4
1-b	197	141	5.5	21.7	0.64	27
2-a	498	138	6.9	19.4	0.09	23
2-b	195	140	8.1	19.7	0.09	61

G, q", z_H, $\Delta T_{sub}(z)$, ΔT_{sat}, N_A denote mass flux, heat flux, central elevation of the view field from the bottom of the heating region, local subcooling at the measurement elevation, wall superheat at the top of the heating region, and cumulative number of the active nucleation site.

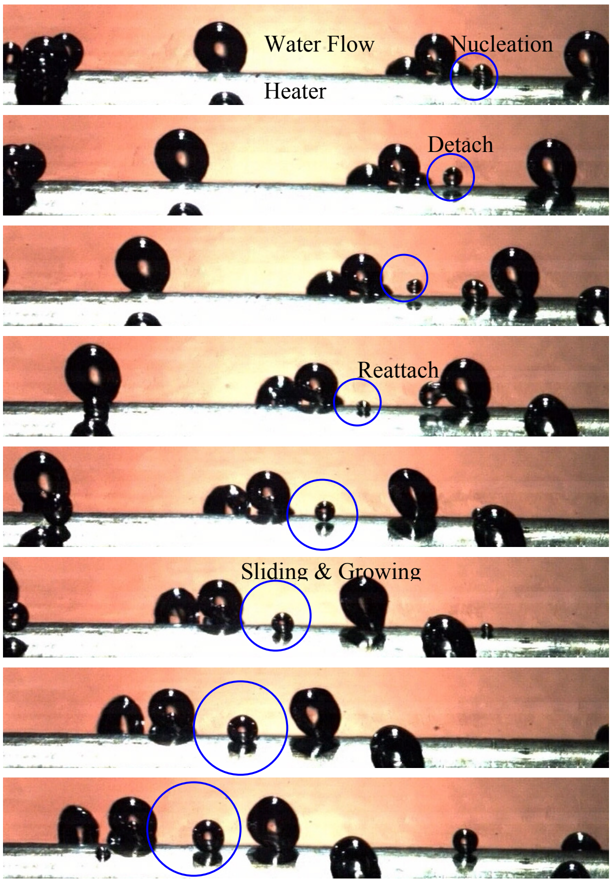

Fig. 1 Some consecutive pictures of test 1-a showing the nucleation suppression, and the reattachment and sliding process. Pictures are rotated 90^o counter-clockwise.

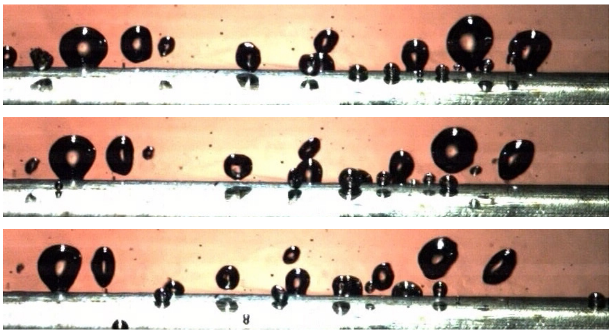

Fig. 2 Some consecutive pictures of test 1-b showing the active nucleation process. Pictures are rotated 90^{o} counter-clockwise.

As can be seen in Table 1, the number of active nucleation site was significantly decreased as the mass flux increase from 200 to 500 kg/m^{2}s. Especially, the suppression of the nucleation site was more severe at the top region of the heater (test 1-a vs. test 1-b).

The bubble nucleation behaviors for test 1-a and test 1-b are shown in Fig. 1 and Fig. 2, respectively. It can be clearly seen that the number of nucleated and growing bubble is much smaller in the case of test 1-a. As the mass flux increased, some of the detached bubble did not migrate into the subcooled bulk water but remained close to the wall and reattached to the wall. After the reattachment, the bubble slid a long distance and disappeared from the view field.

The suppression of the nucleation site is mainly due to the decrease of the effective wall superheat with the increase of the mass flux. Beside, the increased number of the sliding bubble at a higher mass flux had an influence on the suppression because the sliding bubble enhanced the transient conduction heat transfer resulting in less energy being extracted from the heater for the nucleation.

3. Feasibility of Brewster Reflection Technique

Simple pool boiling test apparatus was set up to check the feasibility of the Brewster reflection technique [3] for the identification of the active nucleation site density. The working fluid was R-113, the boiling surface was Pyrex glass which had a diameter of 2 inch and a thickness of 1 mm. A small hot air blower was placed under the Pyrex glass and used as a heat source for boiling the R-113. The temperature of the jetted air reached 600 ^{o}C and violent boiling of R-113 was observed. Ion laser was used as a light source for the Brewster reflection. Beam expander, 1:10,000 linear polarizer, narrow bandpass filter, mirror are installed between the laser and the heating surface.

The incident angle of the laser beam to the Pyrex glass was adjusted to satisfy the Brewster angle when the upper surface of the glass was exposed to air. Then, the reflected image was dark because no reflection occurred at the interface between the glass and air. When the R-113 was poured into the pool, the reflection of the incident laser beam occurred, and a bright reflection image was obtained for the whole area of the laser beam. When the violent boiling of R-113 occurred, the dry bubble base at each nucleation site produced dark circles in the reflected image of the laser beam. The nucleation sites could be clearly identified as shown in Fig. 3.

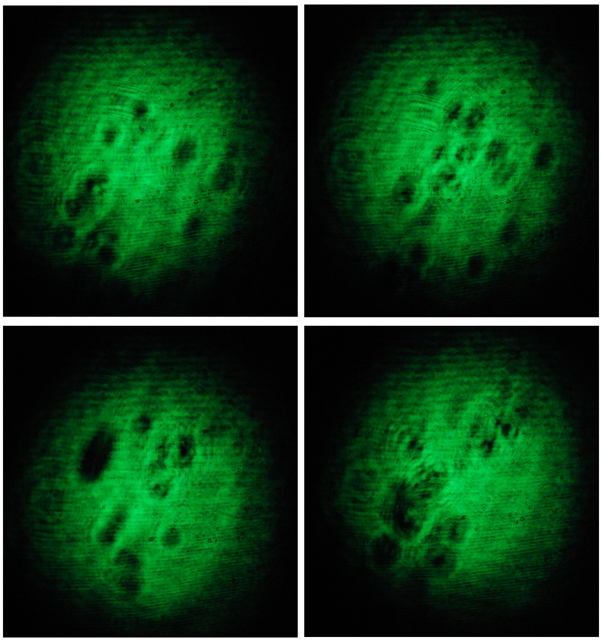

Fig. 3 Identification of the nucleation sites using Brewster reflection technique.

4. Conclusions

Suppression of the nucleation sites in a forced convective boiling and the effectiveness of the Brewster reflection technique for the identification of a nucleation site were confirmed. Experiments and modeling of the ANSD for a subcooled boiling flow will be carried out based on this work.

REFERENCES

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