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Preliminary Study on the Bubble Lift-off Diameter in a Vertical Subcooled Boiling Flow

In-Cheol Chu and Chul-Hwa Song
Korea Atomic Energy Research Institute, 1045 Daedeok-Daero Yuseong Daejon Korea, chuic@kaeri.re.kr

1. Introduction

The bubble lift-off diameter, i.e., the bubble diameter when a bubble is detached from a heated surface is an important boundary condition for boiling flows. Together with an active nucleation site density and a bubble detachment frequency, the bubble lift-off diameter determines the evaporative heat flux. They play an important role for the prediction of wall heat flux partition in a subcooled boiling flow. Also, an increase of an interfacial area concentration by a wall boiling nucleation, i.e., the boiling source term in an interfacial area transport equation, is expressed by the above three terms.

Several studies were carried out to measure the bubble lift-off diameter and to develop a model to predict it in the forced convective boiling flows. Zeng et al. [1] studied the bubble lift-off diameter for flow boiling of saturated refrigerant R-113 in a horizontal channel, and proposed a lift-off diameter model. Situ et al. [2] measured the bubble lift-off diameter and proposed a model for a subcooled water boiling flow in a vertical annulus. They used a simplified force balance on a bubble for their flow condition. Bae [3] also proposed the bubble lift-off diameter model for a vertical boiling flow. He considered the force balance only after when the bubble departed from its nucleation site, and the departure diameter was calculated from Unal et al.'s model [4].

Two important forces were a bubble growth force and a buoyancy force in the case of Zeng et al., and a bubble growth force and a shear lift force in the case of Situ et al. and Bae. Zeng et al. obtained bubble growth curves and implemented them into their bubble lift-off diameter model. of Situ et al. and Bae used Zeng et al.'s bubble growth model for the development of the bubble lift-off diameter model even though boiling conditions are quite different from those of Zeng et al.

In the present study, the bubble growth rate and the lift-off diameter were measured for the subcooled water boiling flow in a vertical annulus.

2. Experimental Setup and Results

An annulus boiling channel was used to examine the bubble behavior from the nucleation to the lift-off. The test channel had a transparent polycarbonate pipe outside a central heater rod. The inner diameter of the polycarbonate pipe was 31.75 mm and the outer diameter of the heater rod was 9.5 mm. The total length of the channel was 1,270 mm. The heating length of the heater rod was 700 mm, the heater had non-heating length of about 370 mm and 200 mm at the upstream and downstream of the heating region, respectively.

The bubble behavior was captured by a digital high speed video camera at the rate of 3,000 frames per seconds. The measurement elevation was 640 mm high from the bottom of the heating region. A rectangular image box was installed outside the polycarbonate pipe. The box was filled with water at almost saturated temperature to minimize the optical image distortion due to the curvature of the pipe.

Table 1 shows the summary of the experimental conditions. G, q", $\Delta T_{sub}(z)$, P(z), $D_{lo,avg}$ denote mass flux, heat flux, local subcooling at the measurement elevation, local pressure at the measurement elevation, and mean bubble lift-off diameter. Two sets of experiments were performed. A total of 72 bubble lift-off diameters were analyzed for 7 different nucleation sites. The mean lift-off diameters were used to consider the stochastic bubble behavior.

Table 1 Experimental condition

Test No.	G kg/m^2s	q" kW/m^2	$\Delta T_{sub}(z)$ ^oC	P(z) kPa	$D_{lo,avg}$ mm
1	499	138	4.1	134	1.2
2	197	141	5.3	127	1.6

Figure 1 shows the typical bubble behavior in a vertical boiling flow when the local subcooling is not significant. First, a bubble is generated and grows at its nucleation site. Then, the bubble starts to slide upward the vertical heating wall within 1 msec from the first detection at the nucleation site. During this sliding process, the bubble grows gradually due to the heat from the wall. After sliding some distance, the bubble is detached from the wall and moves into the water bulk flow. Figure 2 shows the bubble growth rate from the nucleation to the lift-off. The initial bubble growth rate is steep and follows the bubble growth rate suggested by Zeng et al. However, the bubble growth rate during the sliding process is significantly decreased. For the constant (b) in the bubble growth model in Eq. (1), Zeng et al. suggested the value of 1.73 but it was about 0.15 for the sliding bubbles in a vertical forced convective boiling flow of the present study. The bubble lift-off diameter models of Situ et al. and Bae were modified by implementing the bubble growth rate of sliding bubble obtained in the present study.

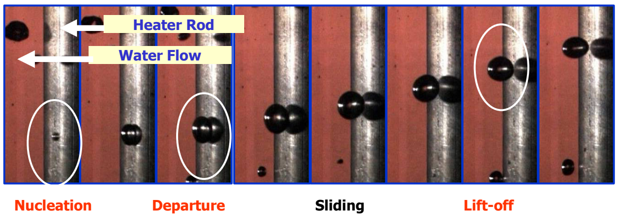

Fig. 1 Bubble behavior from the nucleation to the lift-off in a vertical forced convective boiling flow

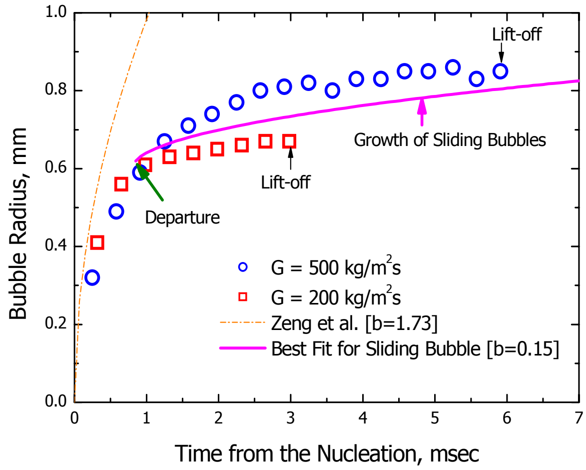

Fig. 2 Bubble growth rate from the nucleation to the lift-off.

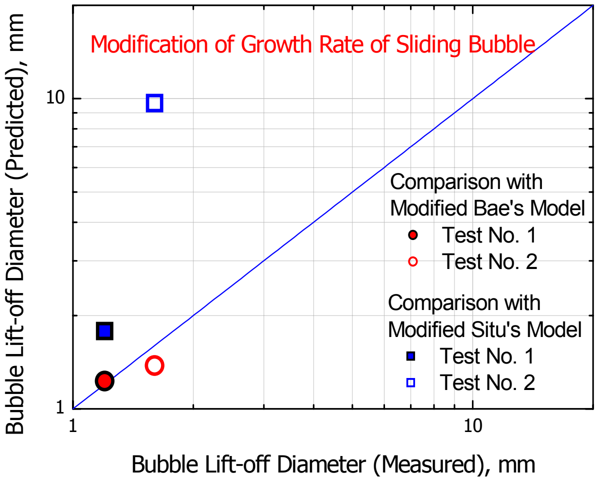

Fig. 3 Comparison of bubble lift-off diameter between measurement and prediction.

Figure 3 shows the comparison of the measured bubble lift-off diameters in the present study with those calculated from the modified models of Situ et al. and Bae. The modified Bae's model agrees well with the experimentally measured bubble lift-off diameters. The modified Situ et al.'s model overestimates bubble lift-off diameter, especially when the mass flux is low. Situ et al. adopted the suppression factor of Chen's boiling heat transfer coefficient correlation to account for the mass flux effect. Figure 3 might imply that the bubble lift-off diameter is not affected in the same way with the heat transfer coefficient. The other important force in their bubble lift-diameter model is the shear lift force. However, many things are still unknown for the shear lift force on the bubble sliding the wall where the nucleation occurs. Thus, an adequate shear lift force model should be developed to improve the prediction capability for the bubble lift-off diameter in the forced convective boiling flows.

4. Conclusions

A preliminary study was performed for the bubble lift-off diameter in the vertical forced convective boiling flow. The bubble behaviors analyzed by the high speed video camera showed that the growth rate of the sliding bubble before the lift-off is significantly different from the previously suggested model in the horizontal boiling flow. Existing bubble lift-off diameter models for the vertical boiling flows were modified by implementing the growth rate of the sliding bubbles. A good agreement was obtained for the modified Bae's model. But it is necessary to obtain more data for the bubble growth rate and the bubble lift-off diameter to improve the prediction capability for the bubble lift-off diameter in the forced convective boiling flows. Also, an adequate shear lift force model should be developed for the the bubble sliding the wall where the nucleation occurs.

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