Image Processing for Bubble Departure Frequency in a Subcooled Boiling Flow

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1. Introduction

For the subcooled boiling problem, a bubble departure due to nucleate boiling acts as an important mechanism in a mechanistic analysis for the two-phase flow in the form of a boundary condition. Few works have been performed for an experiment and modeling of a bubble departure frequency under a convective flow boiling. The purpose of this paper is to develop an image process method by a visualization of the bubble nucleation and to study the bubble departure frequency in a vertical upward forced-convective subcooled boiling flow. The generated data are compared with previous models and a new model is proposed.

2. Methods and Results

An experimental facility was setup for the subcooled boiling phenomena in the annulus geometry with a central single heater rod. The flow channel is an annulus with an inner diameter of 19.1 mm and an outer diameter of 38.1 mm. Pyrex® pipes are used for pressures up to 350 kPa in order to enable flow visualization. The test section has a 2845 mm heated section followed by a 1632 mm unheated section.

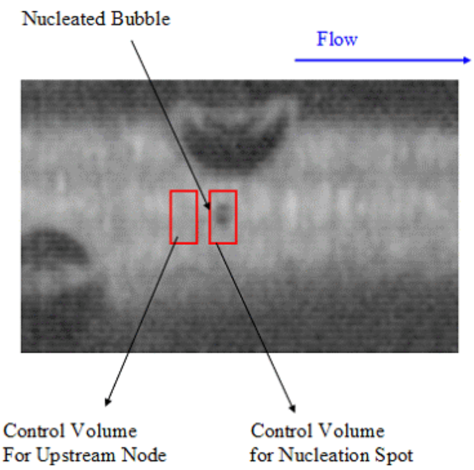

Fig. 1. Sample of the image and control volume to measure the bubble departure

The flow visualization system is setup on a vertical annulus test section with a heater rod. The region for investigation is set near the onset of a boiling point. A KC microscope video lens was utilized with a speed of 5000 frames per second. Each image consists of 128 X 80 pixels. The real pixel size is 64 μm under the current configuration of the visualization system and test section. The corresponding image size is 8mm X 4mm.

Two control volumes for each frame of the images were set for the boiling site and upstream part of it, respectively, which is illustrated in Fig. 1. The averaged intensities at each pre-defined control volumes were obtained along with the measuring time. Since, when a nucleated bubble is formed, the bubble is expressed as a dark color as shown in Fig. 1, the intensity of the control volume becomes low from a high level at the boiling site. It is convenient to define the time of a departure by converting the continuous type peak signals into a rectangular form as shown in the figure. Fig. 2 shows intensity graphs during a bubble nucleation at the boiling site and its upstream location with a solid and a dotted line, respectively. The rectangular type line is the identified signal for the nucleated bubbles. The bubble departure frequency is obtained by the time interval of each nucleated bubble signal. The final form of the bubble departure frequency is defined as the following formula.

$$f_d = \frac{\sum_i}{\sum_i \tau_i} \qquad (1)$$

where

i: index of the bubble signals

τ_i: i-th interval of nucleated bubbles

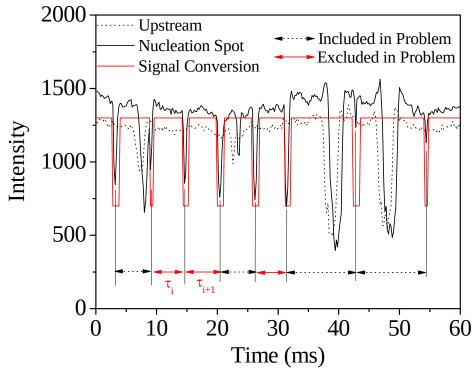

Fig. 2. Bubble departure frequency from intensity plot

The visualization was performed at three different boiling sites under various thermal hydraulic boundary conditions for each site. One second of data with a 5000 frame/sec speed, in words, 5000 images, were utilized for the analysis for each case. The experimental test range is summarized in Table 1 with a comparison of those shown in the literature. The present experimental data have a wider range in respect to the mass flux as well as the pressure conditions. The data shows a definite trend in that the bubble departure frequency is increasing as the pressure and heat flux are increased, in the meanwhile, it is decreasing as mass flux and subcooling are increasing.

Few works have been performed for an experiment and modeling of a bubble departure frequency under a convective flow boiling. Although many studies were found for the pool boiling conditions, the mechanism for the bubble departure is significantly different from the flow boiling conditions. Situ's et al.(2008) showed that the models developed on the pool boiling in the literatures have a poor agreement with data of the convective flow boiling conditions.

Table I: Test Conditions

	Values
No. of Points	76
Pressure,kPa	167~346
G, kg/m^{2}s	214~1869
Re Number	1.75e4~1.78e6
Subcooling, K	7.5~23.4
Heat Flux, kW/m^2	79.3~238

In this study, Basu et al. (2005), Situ et al. (2008), and Podowski et al.'s (1997) models which were developed in the convective flow boiling conditions, were validated with the present data. Basu et al. (2005)'s model was developed with two *Ja* numbers based on the wall temperature and liquid temperature respectively. The present study showed that the Ja_w is not a unique parameter in order to characterize the bubble departure frequency. The Basu et al (2005)'s model underestimates the present data. For the higher pressure conditions, the degree of underestimation is increased. Situ et al. (2008) model also has a large discrepancy with the current data. However, the comparison shows a considerably reduced scattering degree. Therefore, the model approach can correlate the current data with modified experimental constants. The podowski et al.'s (1997) model predicts the present data for the low pressure conditions within a permutable band. However, it shows results that underestimate the data at the higher pressure conditions.

Although all the models do not predict the current data well, the dimensionless parameter that Situ et al. (2008) pointed out is a good one for the present conditions with respect of the data scattering degree. This study proposed a new model based on the Situ et al.(2008)'s study as follows:

$$\frac{f_d D_d^2}{\alpha_l} = 1.6 N_{qNB}^{1.3} \tag{2}$$

where

$$N_{\mathrm{qNB}} \equiv \frac{q''_{\mathrm{qNB}} D_{\mathrm{d}}}{\alpha_{\mathrm{f}} \rho_{\mathrm{g}} i_{\mathrm{fg}}}$$

The results of the comparison with the proposed model are shown in Fig. 3. The model predicts the current data within a 76% deviation.

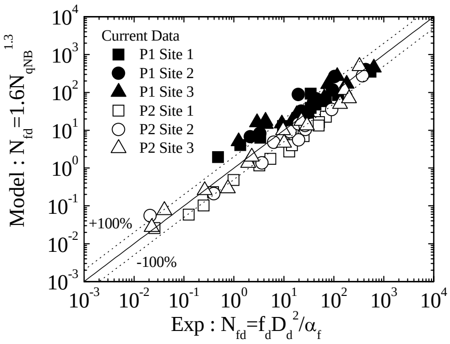

Fig. 3. Comparison of Experimental Data and Prediction

3. Conclusions

A visualization test was performed under subcooled boiling conditions in annulus geometry with a central heater rod to investigate the bubble departure frequency. The present study developed an efficient methodology to achieve the bubble departure frequency data by using a variation of the intensity at a pre-defined control volume including the boiling site. The parametric investigation shows a definite trend that the bubble departure frequency is increasing with the heat flux and pressure; in the meanwhile, it is decreasing with the mass flux and subcooling degree. The data were compared with the literature models for the convective flow boiling conditions and a new model was presented.

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