Measurement of Local Bubble Parameters with Optical Fibers along a Vertical Annulus

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1. Introduction

A subcooled boiling has been studied over the past decades since it is closely relevant to heat transfer and characteristics in nuclear systems. The subcooled boiling could occur under accidental conditions of a nuclear power plant. Especially, at the near-atmospheric condition, it could be important for the passive heat exchanger and the external reactor vessel cooling strategy for in-vessel melt retention.

In order to understand subcooled boiling, parameters for the bubble have been measured in the 2000s. However, measurement was limited to a one-dimensional parameter such as void fraction which is averaged in cross-sectional area. Advance on measurement techniques such as conductivity probes [1, 2] and optical fiber [3, 4] allow measuring the multi-dimensional parameter such as local void fraction and velocity of the gaseous phase.

In this study, as an effort to understand the subcooled boiling at near-atmospheric pressure, experiment for forced convection in steam-water subcooled boiling was conducted. Parameters for the bubbles were measured using single-sensor optical fiber probes in 4 different perpendicular direction and 10 different radial direction along the vertical annulus tube.

2. Methods and Results

2.1 Experimental Facility

The experimental facility for the subcooled boiling has been used to measure local parameters of the bubbles as depicted in Figure 1. It consists of the main loop, a pump, a test section, the main pump, a preheater, a heat exchanger. As working fluid, water is circulated by the main pump. Water was boiling by the heater (Okazaki Manufacturing Company, Japan) which is placed along the center of the test section. The heater can be heated up to 24kW (382kW/m^2). Water flows in the test section along the annulus tube which has 30 mm of outer diameter, 10 mm of the inner diameter and 2235 mm of length.

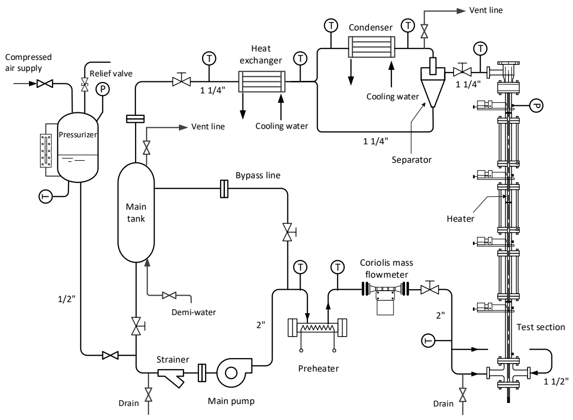

Fig. 1. Experimental Facility for two-phase flow [8].

2.2 Measurement of Bubble parameters

Bubble parameters were measured by single-sensor optical fiber probes as described in Figure 2. It can detect the change of the phases between the liquid and the gas by measuring the intensity of the reflected laser from the beam generator. By considering the occupied time for each phase, local void fraction can be obtained. For the speed of the bubble, it can be derived by dividing the length of the sensing part by the dewetting time. Bubble arrival frequency can be countered by measuring the number of the phase change and the Sauter mean diameter can be obtained by considering the local void fraction and interfacial area concentration which can be presented by the bubble arrival frequency and the bubble velocity.

Optical fibers were mounted at the positions of L/D_h = 21.5, 46.5, 71.5, 100 and they can traverse along the radial direction over the traversing device which can be adjusted in a 0.01 mm of resolution.

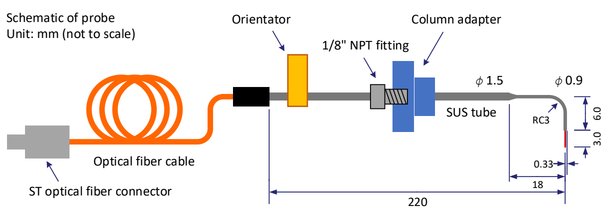

Figure 2. Schematic image of the optical fiber sensor

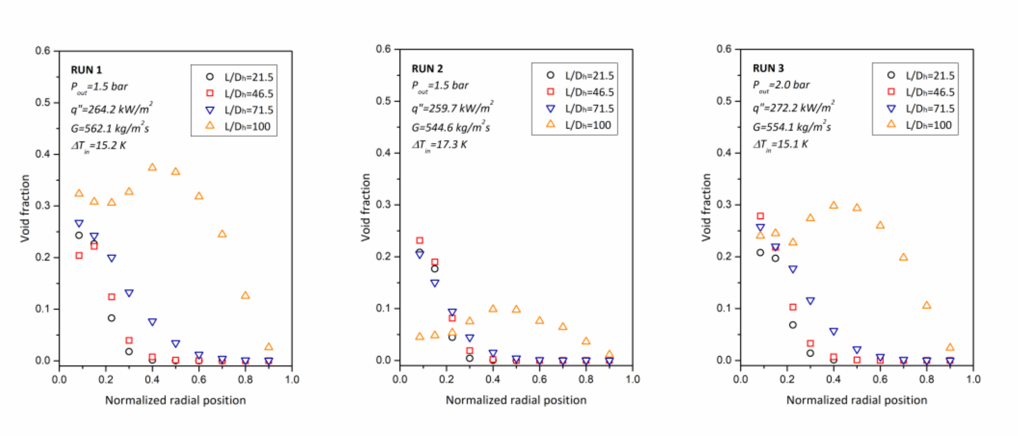

Figure 3. Void fraction at multi-dimensional location

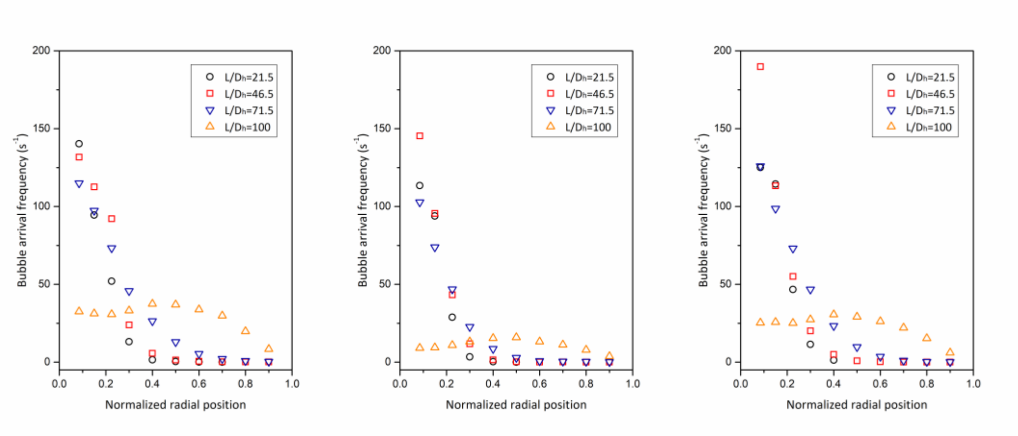

Figure 4. Bubble arrival frequency at multi-dimensional location

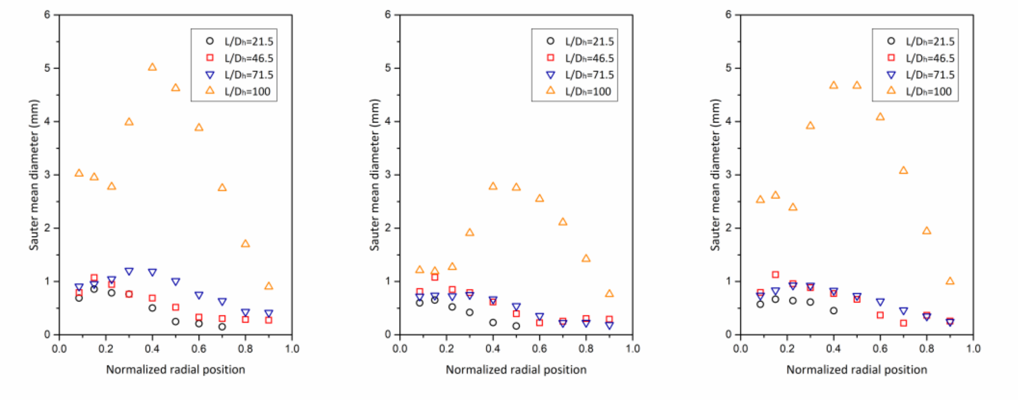

Figure 5. Sauter mean diameter at multi-dimensional location

2.3 Experimental results

Figure 3 presents the local void fraction for three test conditions. The second run represents higher subcooling (2K) compared with the first run while the third run represents higher pressure (0.5 bar) compared with the first run, respectively. In all cases, the profile of the local void fraction along the radial direction varies at between 71.5 and 100 of L/D_h. It represents coalescence of bubbles and change of the flow regime from bubbly to slug, respectfully. It can be observed that local void fraction decreases when subcooled boiling increases or pressure increases in this test. Further experiments would be helpful to figure out the effect of subcooling or operating pressure on the profile of the local void fraction. Figure 4 present bubble arrival frequency. Flattened profiles of bubble arrival frequency at 100 of L/D_h can be proof of the change of the flow regime. Figure 5 present Sauter mean diameter which can be derived by the interfacial area concentration and void fraction. It presents also the change of the flow regime at 100 of L/D_h. Except for data for 100 of L/D_h, it can be considered as valuable data for predicting the bubble diameter along the channel [5]. Further study will be performed to provide well-controlled data to advance the wall boiling model in a CFD-scale analysis code.

3. Conclusions

As an effort to understand subcooled boiling, experiments for measuring local bubble parameters by applying the single-sensor optical fiber probes. Multi-dimensional bubble parameters could be obtained by installing the probes at four height and mounting traversing devices. In these experiments, we measured bubble parameters which are a local void fraction, bubble arrival frequency and Sauter mean diameter. We observed that they can be affected by subcooling and also by pressure. Further experiments will be performed to provide data for advancing the prediction for the wall boiling model.

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