Preliminary observation of air bubble behavior in the vertical square pipe under pool scrubbing conditions

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1. Introduction

Pool scrubbing is a method to retain the aerosols in the water pool and filter the carrier gas. It is used to filter the radiative aerosols in the nuclear power plant under the severe accident conditions. Previous research has been focused on the scrubbing effect and the decontamination factor [1, 2]. However, bubble hydro-dynamics is also a crucial element to understand pool scrubbing.

In this study, an experimental apparatus was set up to simulate the pool scrubbing condition. Bubble behavior was observed by using a high-speed camera. Two-sensor optical fiber probe (OFP) was utilized to measure the local void fraction and bubble velocity at the inlet region.

2. Experimental method

2.1. Experimental setup

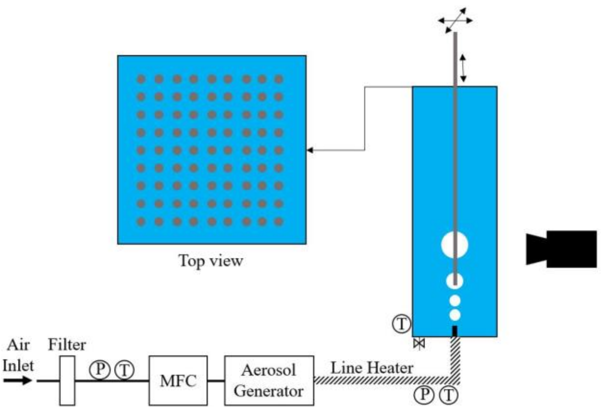

Figure 1. Schematics of the test facility

Figure 1 shows the schematics of the test apparatus. Experimental facility consists of two parts, a water pool, and an air injection part. The cross-sectional area of the water pool was 25 x 25 mm^2. This size is equivalent to the hydraulic diameter of the secondary side in the steam generator (SG) tube bundle. There were two types of water pools, one with a 1.5 m height and the other with 0.4 m height. The water pool was made of transparent acryl for the visualization.

The air injection part had two mass flow controller (MFC) to control the flow rate of the injecting air. The size of the air injection nozzle was 1 mm. The air was injected with respect to the Weber number (We) condition, which is a ratio between inertial force and surface tension force. The equation (1) shows the definition of the Weber number where $\sigma, v, D,$ and σ represent the density of the liquid, gas velocity, nozzle diameter and surface tension respectively.

$$\text{We} = \frac{\rho v^2 D}{\sigma} \qquad (1)$$

A high-speed camera was used to observe the bubble behavior in this experiment. The frame speed of the camera was 1000 frame per second (fps), and it provided resolution of 1280 x 1024 pixels. The bubble observation took place at three different position, injection region where is 3 cm above the nozzle, bubbly to slug transition region (30cm above the nozzle), and the water surface region (1 m above the nozzle).

2.2. The two-sensor optical fiber probe

The optical fiber probe was used to measure the local void fraction and the bubble velocity. It distinguishes the phases at the interface by detecting the change of the refractive index between two phases [3]. The local void fraction α was calculated by using the equation (2) where t_b and T represent bubble residence time and total measuring time respectively.

$$\alpha = \frac{\sum t_b}{T} \qquad (2)$$

The local void fraction was measured at the bubble injection region right above the nozzle.

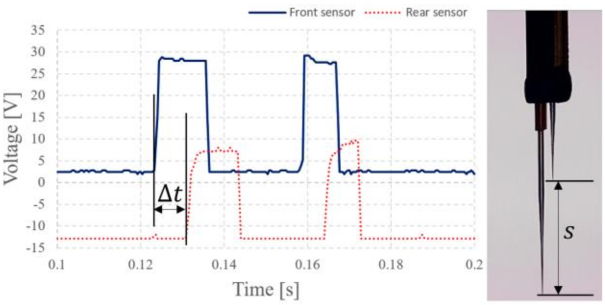

Figure 2. Characteristics of two-sensor OFP

Figure 2 shows the two-sensor OFP and voltage signal obtained from the probe. The local measured velocity was computed by using equation (3). The s represents the distance between the front sensor and rear sensor and Δt is the time interval between the passing bubbles.

$$v_m = \frac{s}{\Delta t} \qquad (3)$$

Only the front interface was considered to measure the bubble velocity because the bubble movement could be hindered after contacting the probe.

3. Results

3.1. Bubble visualization

Bubble behavior was observed by using the high-speed camera respect to the Weber number conditions. The Weber number of 10^5 case is the typical criteria that injection regime turns into the jet regime [2]. Figure 3 shows that the injection regime changes from bubbly to jet as the Weber number increases.

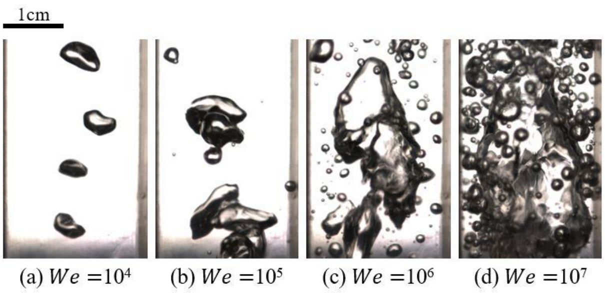

Figure 3. Bubble visualization at the injection region

The visualization was conducted at the 30cm above the injection nozzle. As the figure 4 presented, the bubbles started to merge rising through the pipe except for low Weber number case (a). In the image (c), small bubble coalesced and formed a cap bubble. Image (d) showed a Taylor bubble and the flow regime became slug flow.

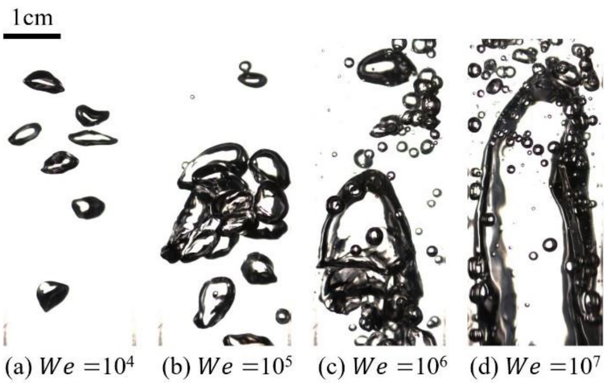

Figure 4. Bubble visualization at the transition region

Figure 5 shows the visualization image at the 1m above the injection nozzle, which is near the water surface. As the image (b) shows, small bubbles stick together, but they are not perfectly merged. Image (c) and (d) shows the Taylor bubble and the flow regime is the slug flow.

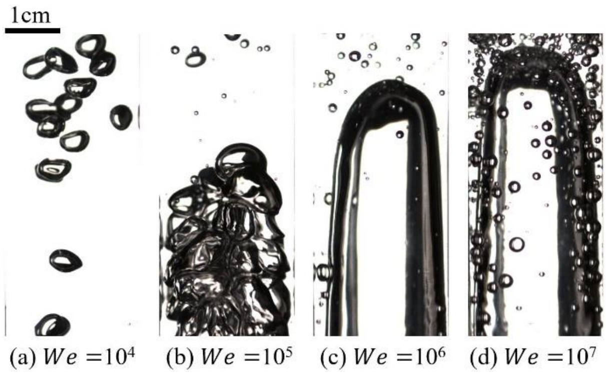

Figure 5. Bubble visualization at the water surface

3.2. OFP measurements

The local void fraction and local bubble velocity were measured at the injection region by using the two-sensor OFP. Figure 6 shows the void fraction respect to the Weber number increases. Only the front sensor was used to measure the void fraction. The total elapsed time of the measurement was 10 sec. The local void fraction increases as the Weber number condition increases. The void fraction of the Weber number 10^4 and 10^5 cases were comparable. It is because of the missing bubbles and the fluctuation. Total measurement time needs to be enlarged to obtain much reliable void fraction data.

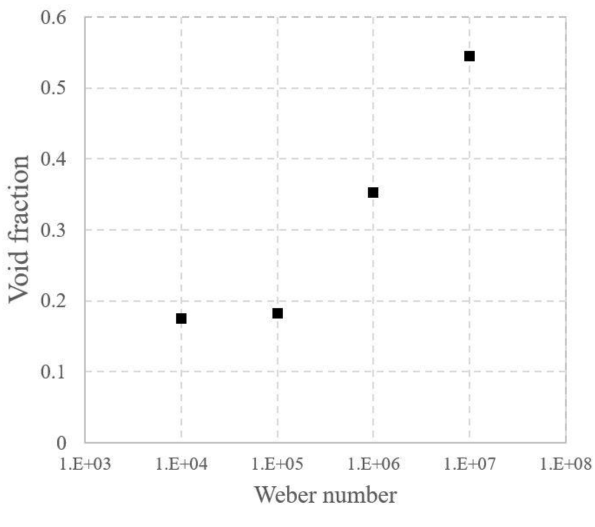

Figure 6. The local void fraction at the injection region

Figure 7 shows the local measured bubble velocity at the injection region. The measured velocity increases as the Weber number condition increases. However, in the high Weber number cases, especially the Weber number 10^7 case, it was tough to distinguish the interface signal between the front and rear probe. It is because the void fraction is too high to differentiate the bubble position. For that reason, the measured velocity data for Weber number 10^7 case has a limited number of the sample, so reliability is relatively low.

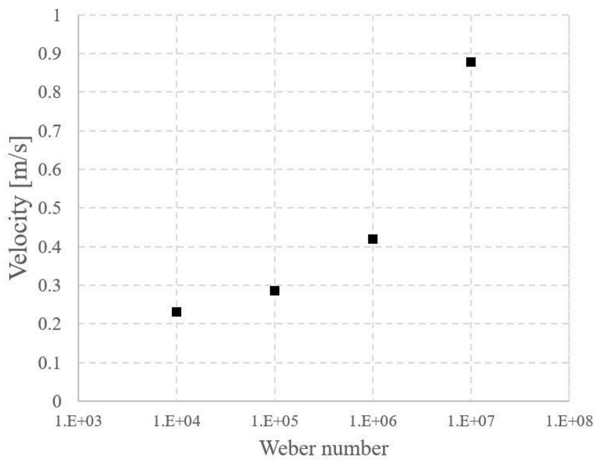

Figure 7. Local measured bubble velocity at the injection region

4. Conclusions

In this study, preliminary observation of bubble characteristics was conducted for the pool scrubbing conditions. The water pool with the single nozzle air injection system was set up to simulate the secondary side of the SG tube bundle. The air flow rate was controlled matching with the Weber number condition.

The high-speed camera was used for the bubble visualization. Bubble behavior and the flow regime change was observed at the three different position. Two-sensor OFP was adopted to obtain the local void fraction and the local measured bubble velocity at the injection region. From the OFP parameter calculation, it was found that longer measurement time and a larger number of bubble data is needed to have high reliability in the high Weber number case.

ACKNOWLEDGMENTS

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