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Experimental investigation of the bubble behavior under rolling oscillations

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1. Introduction

Nuclear power systems generate electricity by utilizing high temperature fluid flow, and ensuring safety and reliability is important. The main thermal-hydraulic concerns of nuclear power systems are the generation of CHF, which can cause damage to nuclear fuel due to boiling, and the resulting DNB. Since two-phase flow dominates under these conditions, it is important to accurately predict the void fraction, which has a great role on the heat transfer and pressure drop of the fluid.

Recently, marine SMR suitable for small-scale distributed power grids have been developed [1]. The marine reactor system causes complex two-phase flow due to the six-degree-of-freedom motion of ships on the sea surface. Therefore, the thermal-hydraulic effect of oscillation must be additionally considered. Recent thermal-hydraulic research has focused on multidimensional analysis and experimental studies to increase the precision of nuclear safety analysis. However, more research is needed on two-phase flow experiments under various oscillation conditions. In this study, we investigated the behavior of bubbles under various oscillating conditions. Additionally, numerical simulations were performed to analyze additional bubble induced effects.

2. Experimental setup

The experimental set for the upward bubbly flow consisted of an oscillation system, a test section, an air-water mixing chamber, an air compressor, a mass flow controller, two water pump, and two electromagnetic flow meter, optical-fiber Doppler probe (OFDP), etc.

Schematic diagram of the experimental set is shown as Fig. 1. The oscillating system that implements sine wave motion was constructed in order to investigate the bubble behavior at sea level. The center of gravity is designed to be located below the center of rotation, therefore the oscillation axis is located at the top of system. The water flow is separated into two main and four sub flows. Air flow rate is uniformly controlled by mass flow controller, and the air flow is separated into four sub flows. Air is injected into a narrow gap (1.25 mm), and mixed it with water in the mixing chamber to form bubbles. Bubble size can be controlled of desired size by changing the water flow rate in the sub flow passage, and this mixing method was devised by Serizawa et al. [2].

The test section was made of transparent acrylic pipe with an inner diameter and length of 50.8 mm and 1 m, respectively. The test section was placed in the center of rolling platform. Measurements with the OFDP were carried out at the axial position of z/D = 16.1, sufficiently far from the hydrodynamic entrance length of z/D = 10.9. The variables z and D are axial distances from the inlet and inner diameter of the pipe, respectively.

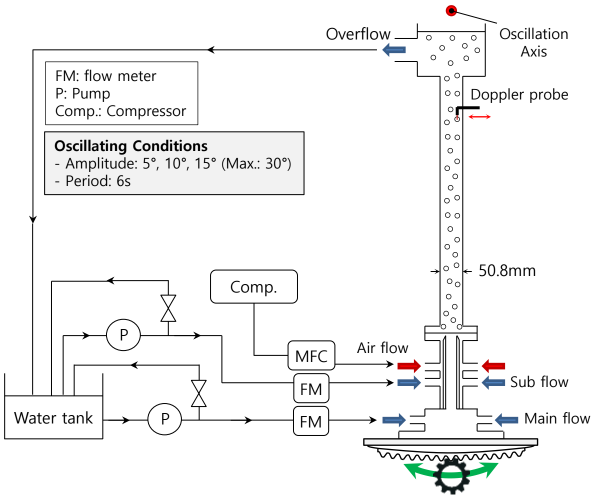

Fig. 1. Schematic of experimental apparatus.

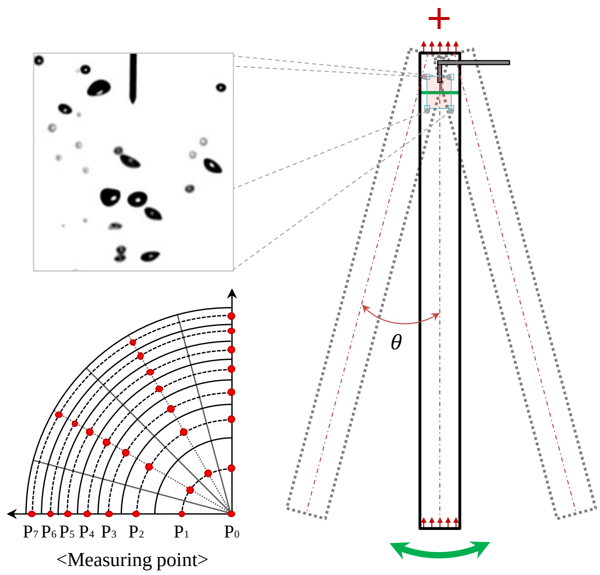

Fig. 2. Experimental conditions: oscillating motion and measuring positions.

We use the OFDP in order to measure the bubble parameters. The OFDP combines a conical optical probe that is phase detector with velocity measurement based on Doppler shift. The laser pulse with a wavelength of 1550 nm sent from the optoelectronic module is emitted into the medium when the tip is surrounded by water and bounces back toward the optoelectronic module when the tip is exposed to air. As long as the tip is surrounded by water, the output signal remains at a low level; when the tip is surrounded by air, the signal rises to a higher level. The refractive indices of water and air have values of 1.33 and 1.00, respectively, under standard temperature and atmospheric pressure [3, 4], and the amount of laser reflected when a bubble passes through the tip is converted into a voltage signal by the photodetector.

The bubble parameters were measured at several angular positions (0°, 30°, 60°, and 90°) in the flow path, considering the complex rotational flow caused by oscillations. According to Fig. 2, a total of 8 measurement points (P_0 to P_7) at each position were selected as locations having the same area. The measurements were performed at eight radial positions denoted by r/R = 0, 0.267, 0.463, 0.598, 0.707, 0.802, 0.886, and 0.964. The experiments were conducted with an angular amplitude (θ) of 5, 10, and 15°, and a period of 6 seconds.

3. Results and discussion

The experiment was conducted for two cases, a stationary condition and rolling oscillations. For the rolling oscillation, we set a rolling amplitude ranging from 5 to 15 degrees and a period of 6 seconds. As shown in Table 1, the area-averaged superficial air velocities, $\langle j_g \rangle$, were set in 0.00308 and 0.00493 m/s, and the area-averaged superficial water velocity, $\langle j_l \rangle$, was set in 0.093 m/s.

Table 1. Experimental conditions for bubbly flow.

	$\langle j_g \rangle\ (m/s)$	$\langle j_l \rangle\ (m/s)$
Case 1	0.00308	0.093
Case 2	0.00493	0.090

Fig. 3 shows the time-averaged void fraction distribution for various rolling oscillations in Case 1. In the figure, the rolling motion is indicated by a blue arrow. In a stationary state, the void fraction showed an off-center peaked profile, and similar results were shown in all measurement points under the condition of rolling amplitude of 5 degrees. The peak of the void fraction became stronger as the oscillation amplitude increased, but no or weak peaks were observed at regions C and D.

Fig. 4 shows the time-averaged void fraction distribution for various rolling oscillations in Case 2 where the void fraction was increased compared to Case 1. As the bubble flow rate increased, the effect of

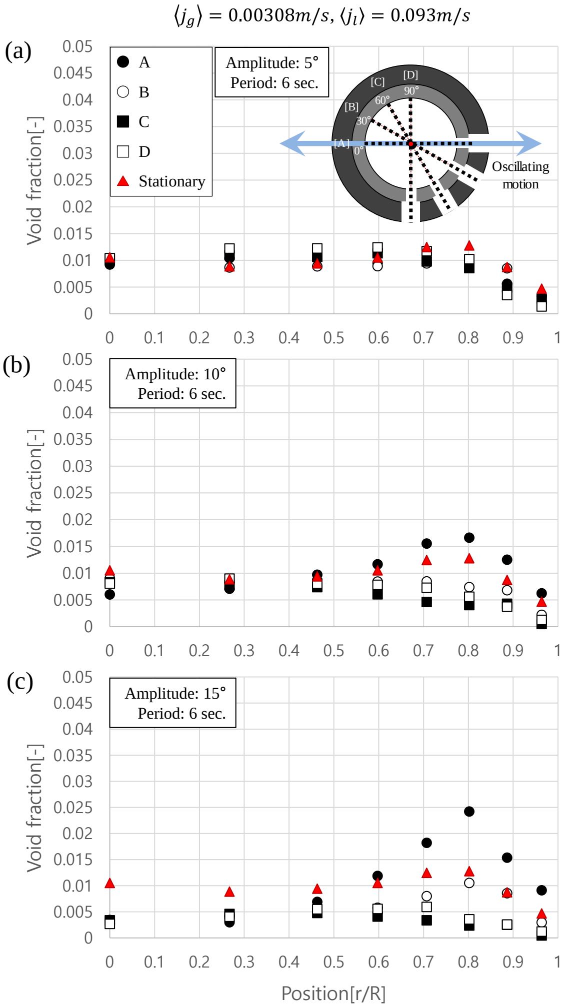

Fig. 3. Radial profiles of the time-averaged void fraction at local points under various rolling oscillations (Case 1).

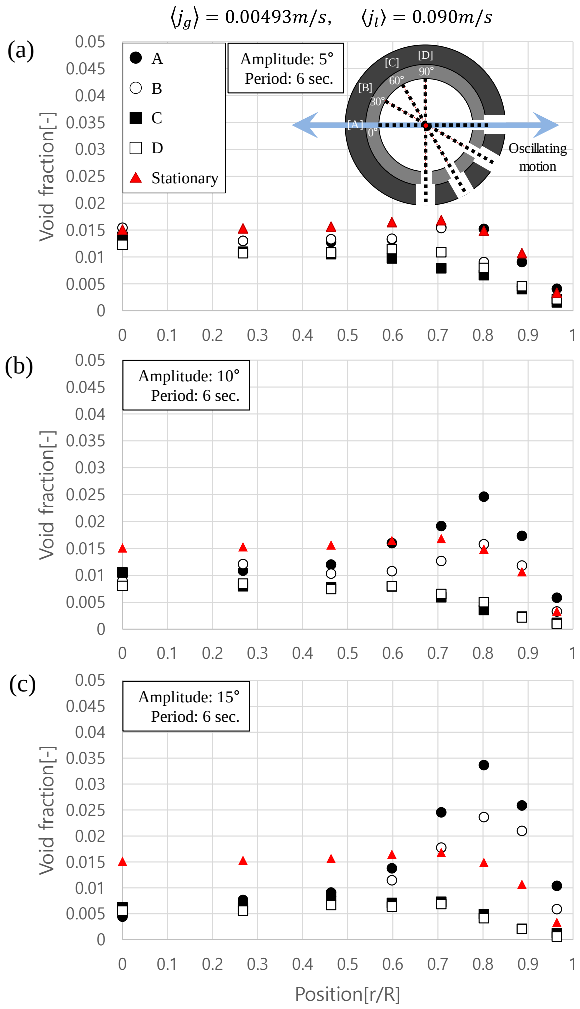

Fig. 4. Radial profiles of the time-averaged void fraction at local points under various rolling oscillations (Case 2).

oscillation-induced void fraction reduction became more pronounced than before. The void fraction showed an off-center peaked profile under the condition of rolling amplitude of 5 degrees. However, wall-peaked profile was shown as the oscillation amplitude increased. In addition, A and B with oscillation amplitude of 0 and 30 degrees showed similar tendencies. For positions C and D with oscillation amplitudes of 30 and 60 degrees, the void fraction tendencies were similar to those in Case 1. This indicates that the rolling had no significant effect on the void fraction at positions C and D.

4. Conclusions

This study measured the void fraction at each position by installing a single optical fiber Doppler probe in a vertical pipe. Under the experimental conditions, a bubbly flow pattern was observed, and the distribution and peaking phenomena of the void fraction were well represented. Additionally, bubbles tended to be more concentrated near the rolling motion line, and it was confirmed that there was almost no effect of oscillation on the positions far from the oscillation line.

5. Acknowledgements

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