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Study on bubble and liquid velocities in an area-varying horizontal channel

Thanh Tram Tran [a,b], Byoung Jae Kim [c,*], Hyun-Sik Park [a,b,*]

[a] Advanced Nuclear System Engineering, Korea University of Science and Technology, 217 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea
[b] Thermal-Hydraulic Safety Research Division, Korea Atomic Energy Research Institute, 111 Daedeok-daero 989, Yuseong-gu, Daejeon 34057, Republic of Korea
[c] School of Mechanical Engineering, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134, Republic of Korea

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A B S T R A C T

Two-fluid equations are widely used to simulate thermal-hydraulic phenomena in a nuclear reactor. Simulation accuracy depends on the modeling terms in the two-fluid equations. For a dispersed flow, the overall two-phase pressure drop by wall friction must be apportioned to each phase in proportion to the fraction of each phase (Kim et al., 2014). By applying this approach, the prediction of bubble phase velocity can be close to that of liquid for a fully developed flow in a horizontal pipe with a constant area. One may want to know what would happen in the area-varying channels. It is always true that the bubble density is much lower than the water density. Hence, the bubble would accelerate faster than the liquid in a nozzle in which the pressure decreases along the downstream; the bubbles would decelerate more quickly than the liquid in a diffuser in which the pressure increases along the downstream. The purpose of this study was to investigate those behaviors in an area-varying channel using the experimental data and MARS simulations. Experiments were made of turbulent bubbly flows in an area-varying horizontal channel. The velocities of two phases were measured with the help of the PIV technique. The experimental result showed that the two-phase velocities were no longer close to each other in the area-varying regions. The bubble was faster than the liquid in the nozzle region; in contrast, the bubble was slower than the liquid in the diffuser region. MARS code simulations were performed to assess the wall drag model. By replacing the original wall drag partition model in the MARS code with Kim's one, the simulation results were consistent with experimental observations.

1. Introduction

Two-fluid equations are widely used to simulate thermal-hydraulic phenomena in a nuclear reactor. The simulation accuracy depends on the modeling terms in the two-fluid equations. In particular, the wall drag term in the one-dimensional two-fluid momentum equation plays a significant role in the determination of gas and liquid velocities.

However, the physical meaning of the wall drag force for the dispersed phase was still not clear until now. For this reason, the treatment of the wall drag term for the dispersed phase differs among thermal-hydraulic codes. TRACE, CATHARE, and COBRA-TF codes do not consider the wall drag force for the dispersed phase because the dispersed phase is not in contact with the wall (Bestion, 1990; Paik et al., 1985; USNRC, 2013). With that approach, the dispersed phase is predicted to be faster than the liquid phase even in the fully developed flow with a horizontal pipe for a constant area (Kim et al., 2014; Kim et al., 2015). RELAP5 considers the wall drag force for the dispersed phase using the wetted perimeter concept. However, the magnitude of this force for the dispersed phase can be unrealistic because the application of the wetted perimeter concept to the dispersed phase is questionable.

Kim et al. (2014) theoretically showed that, for one-dimensional dispersed flow, the magnitude of the wall drag acting on each phase must be each volume fraction multiplied by the overall two-phase pressure drop induced by the interaction between the continuous phase and the wall. Base on their wall drag model, the prediction of bubble phase velocity is close to the liquid phase velocity in the fully developed flow with a horizontal channel for a constant area. This prediction is straightforward and correct. Then, what would happen in the area-varying channels? The bubble density is much lower than the water

* Corresponding authors at: School of Mechanical Engineering, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134, Republic of Korea (B.J. Kim). Thermal-Hydraulic Safety Research Division, Korea Atomic Energy Research Institute, 111 Daedeok-daero 989, Yuseong-gu, Daejeon 34057, Republic of Korea (H.-S. Park).

E-mail addresses: bjkim@cnu.ac.kr (B.J. Kim), hspark@kaeri.re.kr (H.-S. Park).

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density. Accordingly, the bubbles would accelerate faster than the liquid in a nozzle in which the pressure decreases along the downstream, and they would decelerate more quickly than the liquid in a diffuser in which the pressure increases along the downstream. The mentioned behavior was discussed by Kim et al. (2014).

There have been several experimental studies on horizontal bubbly flows (Bottin et al., 2014; Kocamustafaogullari and Huang, 1994; Kocamustafaogullari et al., 1994; Kocamustafaogullari and Wang, 1991; Kong and Kim, 2017; Talley et al., 2015). However, those experiments were performed in a horizontal pipe or channel with a constant area. In addition, the liquid phase alone or the bubble phase alone was measured using a conductance/optical probe. To the best of our knowledge, there has been no study on the measurement of both liquid and bubble velocities in an area-varying channel.

The purpose of this study is to ascertain Kim's wall drag partition model through experiment and simulation for bubbly flow in an area-varying channel. The measurement was made using the particle image velocimetry (PIV) technique. Simulations were then done by using the MARS code.

2. Experimental method

Fig. 1 shows the schematic diagram of the horizontal test loop for air-water bubbly flows in the rectangular duct. The water and air supplied from the water tank (1) and air tank (2), respectively, are mixed in the mixing chamber (3) in which two-phase mixture is formed and injected into the main test section (4). FI-01, FI-02, and FI-03 are the rotameters to control and measure the inlet flow rates of water and air.

Fig. 2 shows a schematic diagram of the main test section of the horizontal test facility. The total channel length was 2000 mm, and its width was 40 mm throughout the whole channel. The bottom figure shows in detail the test section information, consisting of a nozzle section, a flat-area part, and a diffuser part. The original channel height was 40 mm. The channel height decreased to half through the nozzle section and returned to the original height through the diffuser part. The test section was made of acrylic for flow visualization.

In this paper, we simultaneously measure the water and bubble velocities with the help of image processing techniques. Fig. 3 presents a schematic diagram of the measurement system. Experiments were conducted for dispersed bubbly flows. This PIV system includes a high-speed camera, a continuous and high power laser source and other optical structure components. Having a good quality of images requires not only a high-speed camera but also a high laser power. A continuous laser source, MGL-W-532, is operated at power up to 8.0 W. In Fig. 3, a continuous laser source was fixed on a shell, while optics was mounted on a movable structure to measure the phase velocity in the area-varying test sections.

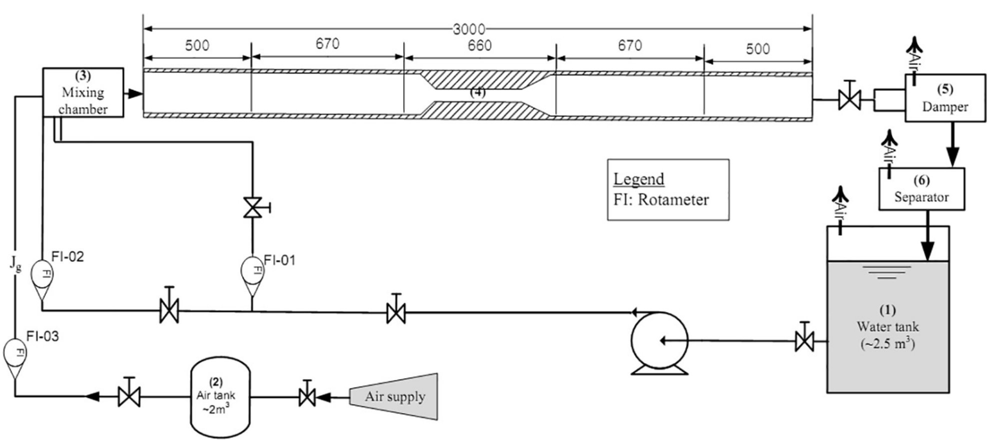

Fig. 1. Schematic of the horizontal rectangular test facility.

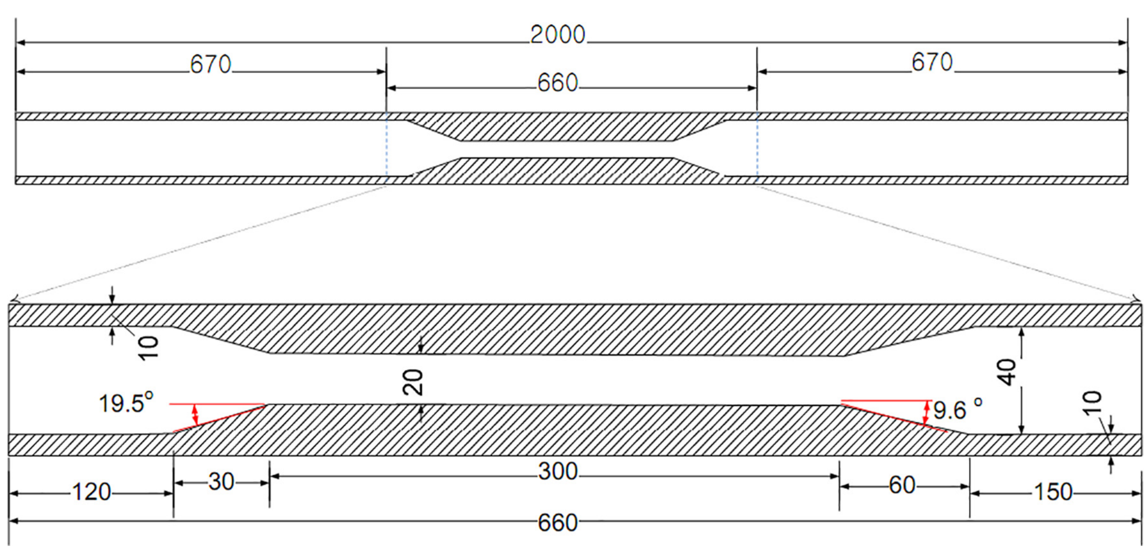

Fig. 2. Schematic diagram of the main horizontal test channel.