Experimental investigation of air-water two-phase flow through inclined circular channel with wire-mesh sensor: preliminary test

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1. Introduction

Channels with various orientations are utilized in numerous fields operating fluid systems. The nuclear engineering field is no exception, but, the relation between behavior of two-phase flow and inclination angle of channel is still challenging to understand and predict due to complex nature of the two-phase flow. To contribute to this issue, experimental investigation is being performed in Seoul National University to produce experimental database on the migration phenomena between the two parallel inclined channels such as reactor core subchannels in a floating nuclear reactor. In this paper, a preliminary experimental result on the air-water two-phase flow in a single inclined channel is presented focusing on the wire mesh installation and sensor tests.

2. Experimental method

2.1 Experimental rig

The experimental rig consists of two parts which is a drive module and inclination adjustable test-section mount.

The drive module serves as a water flow source having pump with inverter, flow meter, separator, reservoir and valves to control the flow rate. To be connected to an external device, two port for 12 mm flexible tubing was installed.

On the other hand, the inclination adjustable test-section mount, which can adjust from 0° (vertical) to 90° (horizontal) was employed for two-phase flow experiments with various orientations.

For the air supply system, the compressor, pressure regulator, and rotameter with a flow control valve was utilized supplying air to the test-section.

2.2 Test-section and experimental conditions

The test-section having flow channel of 13 mm diameter was built in acrylic for simultaneous visualization of the two-phase flow with the wire-mesh sensor and the high-speed camera as shown in Fig.1. The section has two light sources attached to the back and side, also a mirror was utilized to acquire side view with the front view recording with the high-speed camera.

There are three variables determining experimental conditions, water flow velocity, air flow velocity, and the inclination angle of the test-section. In this paper, the result with water flow superficial velocity of $j_L = 0.5$ m/s with varying air flow superficial velocity from $j_G = 0.04$ m/s to $j_G = 0.4$ m/s will be provided. The inclination angle was adjusted from 0° / 30° / 45° / 60° for each water and air velocity condition.

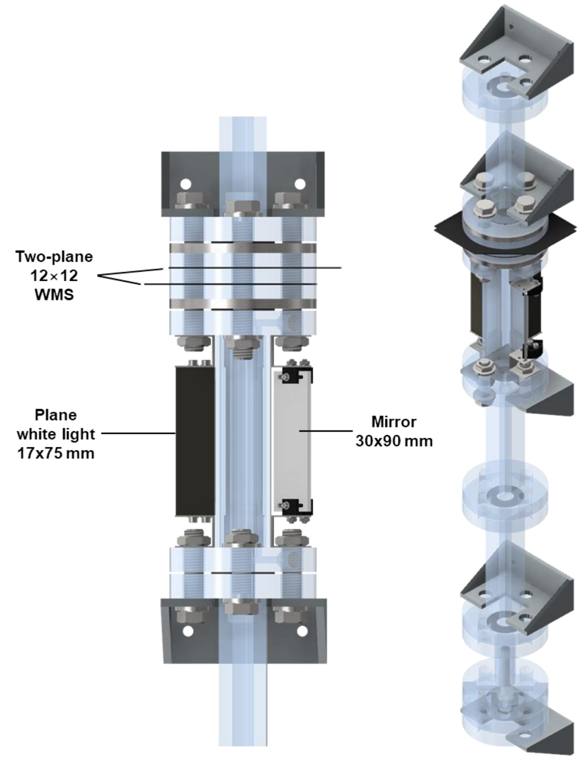

Fig. 1. 3D modelling of the measurement section.

2.3 Wire-mesh sensor

The wire-mesh sensor developed by Prasser et al. [1] is an intrusive sensor installed along the cross-section of the flow channel measuring local void fraction throughout the cross-section with high temporal resolution. In this study, wire-mesh sensor manufactured in HZDR (Helmholtz-Zentrum Dresden-Rossendorf) was utilized.

A pair of sensors were used, forming two measuring-plane located in axial direction with spacing of 10 mm allowing the estimation of gas phase velocity by assessing time delay between the sensor measurements.

Each sensor has a mesh configuration of 12×12 (pitch 1 mm) measuring conductance of volume near each crossing points. The sensor can measure up to 10,000 frames per second, however in this case, it was fixed to 1,024 frames per second considering low velocity of the liquid and gas phase.

2.4 Data processing

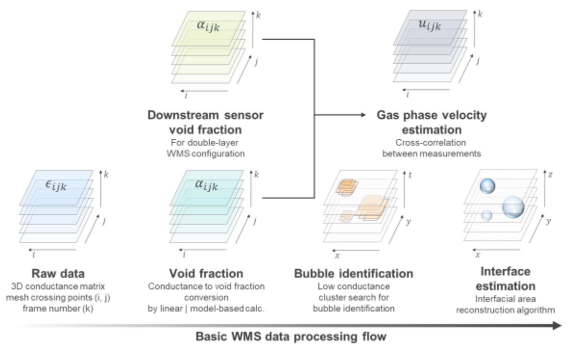

Fig. 2. Schematics of wire-mesh sensor data processing flow

The basic data processing flow is shown in Fig. 2. At first, the acquired raw data with the wire-mesh sensor which corresponds to the instantaneous conductance at each measuring volume was converted to the void fraction. The conversion was performed based on simple linear model which assumes void fraction and conductance to have linear relationship. For the conversion, reference values were utilized which was obtained by measuring in liquid only condition. After conversion, the bubble was identified and labelled with the algorithm developed by Prasser et al. [2], which allows statistical analysis of bubble parameters and distributions. As described the measurement of each sensor was cross-correlated to evaluate the delay between similar signals allowing estimation of the gas phase velocity. In this case, the cross-section average void fraction for each sensor was cross-correlated to obtain the cross-section average gas phase velocity. Lastly, 3D reconstruction of bubble was processed by the marching cube algorithm developed by Lewiner et al. [3] utilizing implementation included in scikit-image library [4].

3. Experimental result

3.1 Low air flow condition (j_L = 0.5 m/s, j_G = 0.04 m/s)

Under vertical condition, uniformly distributed small bubbles were observed which can be seen in Fig 2. When the inclination angle increased, the change of gravitational force direction caused bubbles to migrate towards upper part of the channel. This increased interaction between bubbles resulting formation of larger bubble compared to the vertical condition. Also, deformation of bubbles' cross-sectional geometry from circular to ellipsoidal was found with the increase of inclination angle compared to the bubbles having near spherical geometry in the vertical condition.

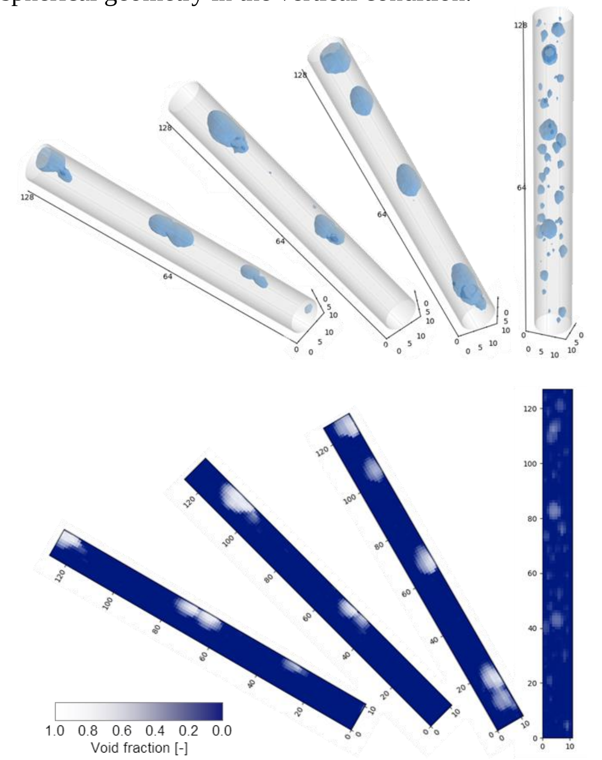

Fig. 3. 3D reconstruction result and virtual side view for different inclination angles (vertical / 30° / 45° / 60° displayed from right to left) for low air flow condition (j_L = 0.04 m/s).

3.2 High air flow condition result (j_L = 0.5 m/s, j_G = 0.19 m/s)

Fig. 4 shows the 3D reconstruction results for high air flow condition. When air flow rate increased from 0.3 lpm (0.04 m/s) to 1.5 lpm (0.19 m/s), under vertical condition, small dispersed spherical bubbles had disappeared, and large cap bubbles was started to be observed. With an increase of the inclination angle, bubbles started to form a Taylor bubble which can be identified with a distinctive bullet shaped geometry. This result can be viewed as a two-phase flow regime transition from bubbly to the slug flow. Also, bubbles were again shifted to the upper part of the channel however, no significant deformation of circular cross-section of bubble was observed compared to the low air flow condition.

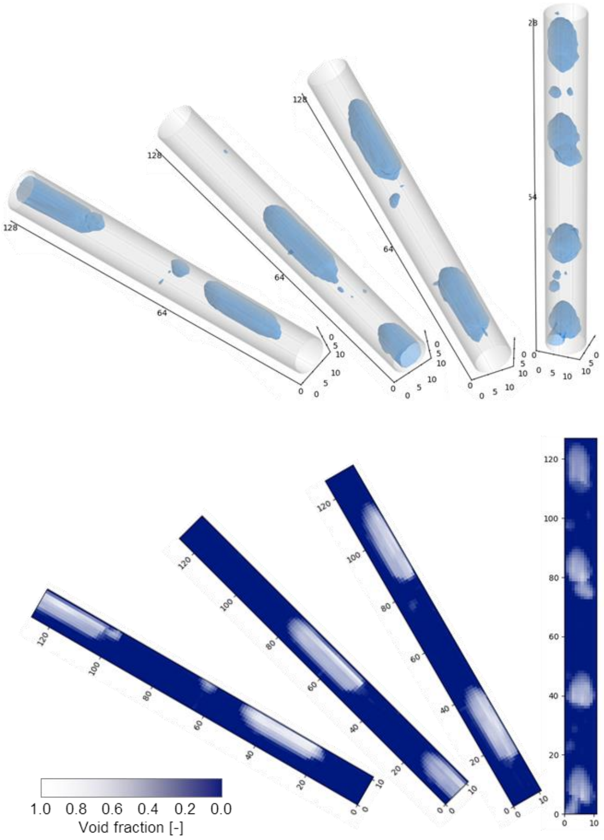

Fig. 4. 3D reconstruction result and virtual side view for different inclination angles (vertical / 30° / 45° / 60° displayed from right to left) for high air flow condition (j_G = 0.19 m/s)

3. Conclusions

In this study, the experimental rig for inclined channel air-water two-phase flow experiment was constructed and measured gas phase velocity utilizing wire-mesh sensor. The wire-mesh sensor measurement was processed to visualize two-phase flow allowing direct observation of flow behavior and quantitative assessment of inclination effect on two-phase flow behavior.

The inclination of channel causes bubbles to migrate towards upper part of the channel relative to gravity direction. This caused an increase of bubble coalescence and deformation in low air flow conditions. In case of high air flow conditions, the result which can be assessed as two-phase flow regime transition from bubbly flow to slug flow was also found.

In this paper, only few experimental results with preliminary qualitative assessment was done. Further investigations, consisting of expansion of experimental database and quantitative analysis with advanced data processing will be conducted.

4. Acknowledgements

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