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Experimental Study on Flow Dynamics of Air-Water Bubbly Flow in a Bundle Array

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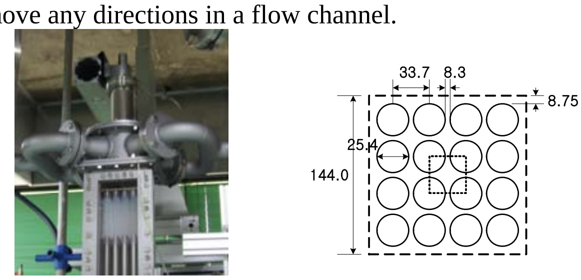
1. Introduction

Understanding of the two-phase flow structure in a subchannel is extremely important in a view point of the safety analysis in nuclear power plants. The basic characteristic of bubble behavior in a two-phase flow is clarified by two parameters such as void fraction and interfacial area concentration. The other important parameter of liquid behavior is a velocity profile. Up to now, extensive analytical and experimental studies have been performed on basic flow channels such as round tube and annulus. But studies on subchannels were very limited because of the geometrical complexity. Recently, experimental studies on a rod bundle have been published. Yun et. al.[1] have been presented the interfacial flow structure of subcooled water boiling flow in a subchannel of a 3x3 rod bundle. Paranjape et. al.[2] have been obtained a flow regime maps for an adiabatic air-water two-phase flow through a flow channel with 8x8 rod bundle. In spite of various experimental efforts to understand the flow structure in a subchannel, there were still coarse and insufficient experimental data. From this background, this study presents precise measurements of liquid and bubble dynamics in a bundle array by using a Pitot tube and a two-sensor optical probe.

2. Experimental Works

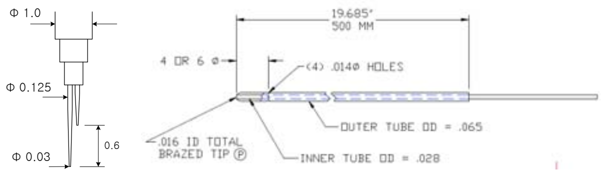
2.1 Test Rig

The experimental loop (MATiS-V) consists of a water storage tank (0.9 m^3) with a heater and a cooler, a circulation pump (2 m^3/min max.) and a test rig which includes a 1.427 m long 4x4 rod bundle. Fig. 1 shows an upper part of the test rig and the probe traverse system in (a) and the dimensions of a rod bundle test section in (b). The rod diameter and the rod pitch are 25.4mm and 33.7mm, respectively. These dimensions are 2.6 times larger than the real PWR rod bundle size. Measurement resolutions are highly improved with this enlarged rod bundle. A 3x3 nozzle-type air/water injection unit was installed at the inlet of the rod bundle (bottom side). Each air/water injectors are located at the center of the subchannel. Fig. 2 (a) shows a two sensor optical probe of 1.0mm diameter. The tips of optical fibers are apart 0.6mm to get a bubble velocity as well as a void fraction when a bubble goes upward along the subchannel. Fig. 2 (b) shows a Pitot tube of 1.65 mm diameter. The optical probe and the Pitot tube were alternatively connected to the traverse system which can move accurately in x, y and z directions according to the pre-determined coordinate. These sensor probes were inserted 100mm depth from the top end of a rod bundle and were packed with a flexible tube so as to move any directions in a flow channel.



(a) (b)

Fig. 1 Photo of the test rig (a) and the dimensions of a bundle test section (b)



(a) (b)

Fig. 2 A two-sensor optical probe (a) and a Pitot tube(b)

2.2 Measurements

For a full measurement of a subchannel, the coordinate of measurement locations was generated as shown in Fig. 3. Total 1,321 locations were selected to measure the void fraction and the bubble velocities in a center subchannel.

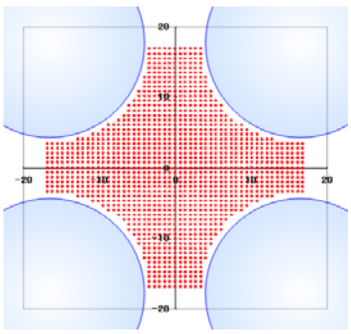


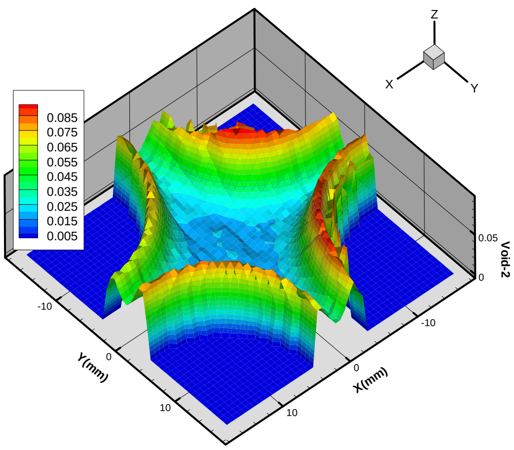
Fig. 3 Coordinate of the measurement locations

The void fraction was measure with 40K sampling rate and 60 repeats. The liquid velocity was measured with 1K sampling and 5 repeats. The PXI equipment of NI was used as a data acquisition system.

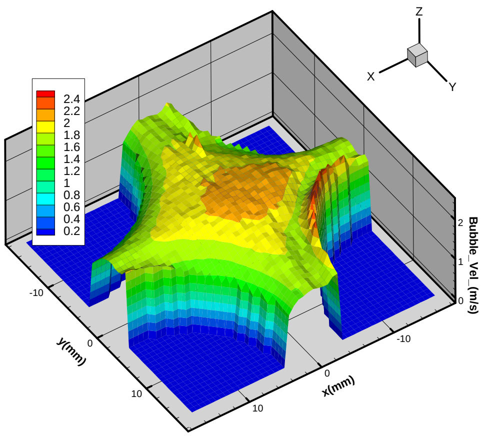
Experiments were performed at the conditions of *Re* = 49,000 (equivalent to W_{avg} = 1.60 m/s), 25 ºC and 1.5 bar in the test section. Air was injected into five subchannels (center and its neighbor four subchannels) and its flow rate was controlled at j_g = 0.13 ~ 0.53. Some typical 3-D figures of experimental results are presented and briefly discussed in the following section.

3. Experimental Results

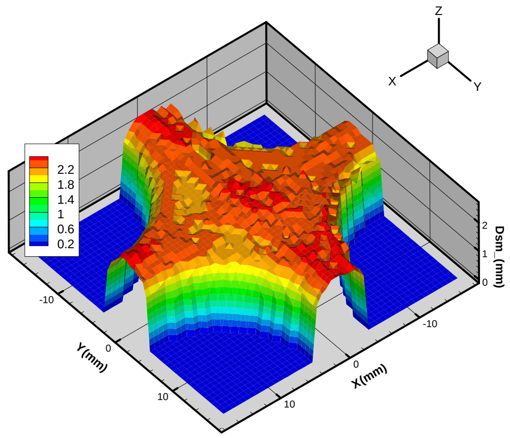
Local void fractions, bubble velocities and Sauter mean diameters were obtained from the precise measurements using an optical two-sensor probe in a subchannel. Generated bubbles were the sizes of approximately 2.3 mm diameter and these bubbles make peaking at rod walls. Fig. 4 (a) shows this well-known phenomena.[3] Local void fraction at rod wall is about 10% while about 2% in a subchannel center. Fig. 4 (b) shows the bubble velocity distribution obtained from separate two sensors. Fig. 4 (c) and (d) shows the distribution of Sauter mean diameter and the liquid velocity. From this result, bubble sizes are uniformly distributed and it was inferred that there was no vital coalescence between bubbles.



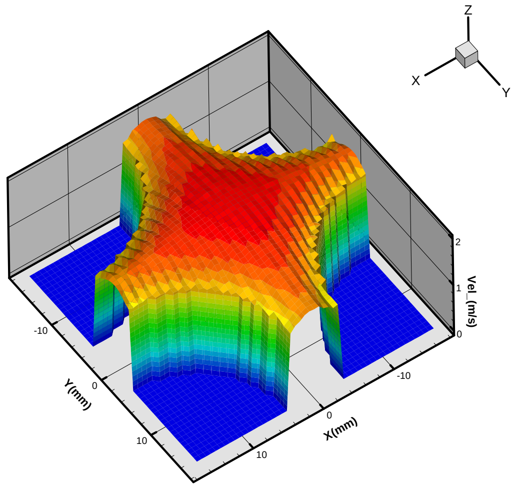
(a)



(b)



(c)



(d)

Fig. 6 Distribution of bubble diameter in a subchannel

4. Conclusions

Precise measurement of void fraction and bubble and liquid velocities in a subchannel was successfully conducted by using an optical two-sensor probe. Bubbly flow contained small bubbles (~2.3 mm dia.) showed bubble peaks at rod walls.

REFERENCES

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[3] A. Tomiyama, H. Tamai, I. Zun and S. Hosokawa, Transverse Migration of Single Bubbles in Simple Shear Flows, Chemical Engineering Science, Vol.57, p.1849-1858, 2002