Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 30-31, 2008

Visual Observations of Bubbly Flow in a Subchannel by using Optical Measurement Methods

Seok Kyu Chang, Yeon Jun Choo, B.D. Kim and Chul-Hwa Song
Korea Atomic Energy Research Institute, 105, Dukjin-Dong, Yusong-Ku, Daejon, 305-353, Republic of Korea
skchang@kaeri.re.kr, chooyj@kaeri.re.kr, bdkim@kaeri.re.kr and chsong@kaeri.re.kr

1. Introduction

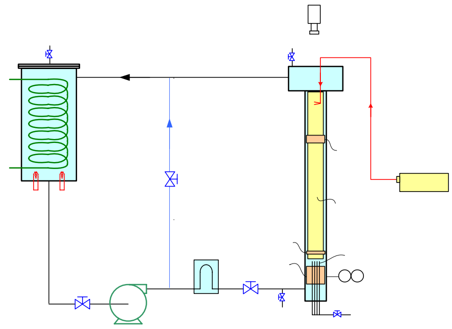
PIV (Particle Image Velocimetry) measurement technique is widely used in the experimental study on the fluid flow in many industrial fields. In the study of the subchannel mixing in a nuclear reactor, there have been many works by using optical measurement techniques [1, 2] and almost of these were limited to the single phase flow. But many occasions of safety issues in a nuclear power plant are in a condition of two phase flow. In an application of two phase flow in subchannels, intrusive probes i.e., a conductivity sensor or an optical sensor were generally used [3]. But these probes cause breaks or distortions of bubbles when contact. PIV technique is one of the non-intrusive measurement methods which can avoid the problem of intrusive probes. This study presents an applicability of the PIV technique on an experimental study of a bubbly flow in the subchannel geometry. The bubble peaking in a subchannel according to the bubble sizes was demonstrated. The HSC (high speed camera) was also used to confirm the PIV measurement results.

2. Experimental Works

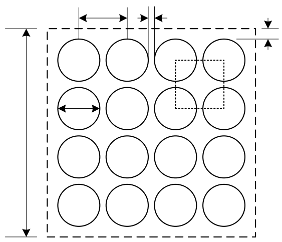
In this section the test facility and the measurement methods are described. The test facility which is called MATiS-V (Measurements and Analysis of Turbulence in Subchannels – Vertical) includes a cold loop and the test rig which was newly constructed to simulate the air/water two-phase flow in a rod bundle. The test rig was designed to adopt various measurement techniques such as PIV, HSC and sensor probes and so on.

2.1 Test Facility

The experiments have been conducted at the cold test loop (MATiS-V) in KAERI which performs the hydraulic test at normal pressure and temperature conditions. The loop 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 a schematic of the test facility and the dimensions of a rod bundle cross section. A 3x3 nozzle-type air/water injection unit was installed at the inlet of the rod bundle. Each air/water injectors were located at the center of the subchannel. As shown in Fig. 2, the air/water injection unit was designed to inject finely dispersed bubbly flow into the bottom of the test section with bubbles of approximately uniform diameter of 0.5~3 mm by adjusting the air /water flow rate.



(a)



(b)

Fig. 1 Schematic of the test facility (a) and the dimensions of the bundle cross section (b)

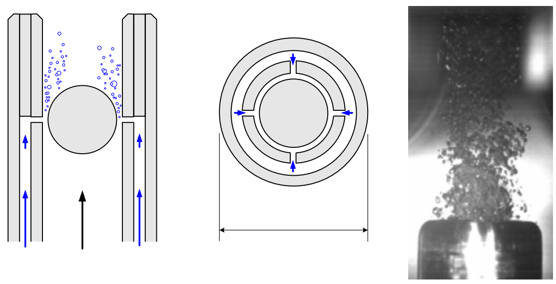


Fig. 2 Nozzle-type air/water injector

Experiments were performed at the conditions of *Re* = 44,000 (equivalent to W_{avg} = 1.477 m/s), 30 ºC and 1.5 bar in the test section. Air was injected into only one center subchannel and its flow rate was limited to small quantity of j_g = 0.005~0.03 as shown in table 1. The generated bubbles from the air injector were confined almost within the center subchannel region at this small range of air flow rate. At higher air flow rate the CCD camera could not catch the bubble images clearly because of the view interruptions by duplicated bubbles. The bubble sizes can be controlled by adjusting the water flow rate in an injector. The bubble diameter becomes smaller as increasing the water flow rate in an injector.

Table 1. Injected air flow rate

Bubble Size	Flow Rate [cc/min] , (j_g [m/s])				Remark
~ Φ3 mm	200 (0.005)	400 (0.01)	800 (0.02)	1200 (0.03)	Wall Peaking
~ Φ8 mm	200 (0.005)	400 (0.01)	800 (0.02)	1200 (0.03)	Core Peaking

2.2 Measurements

For the measurements of the liquid velocity profile and the bubble distribution in a subchannel, the PIV measurement technique was employed. The PIV system comprises a CCD camera, an optic array for the sheet beam and a laser source. For the illumination of the inner center subchannel, specially designed sheet beam delivery system was used [4]. With the PIV system, HSC was also employed to visualize the bubbly flow in a subchannel.

3. Experimental Results

Before conducting the two phase flow measurement, the single phase flow measurement was carried out for the verification of the PIV system setup in a rod bundle array. The preliminary test was performed for the case of the swirling lateral flow by the space grid in a rod bundle. Fig. 3 illustrates the successful result of the PIV measurement of a single phase flow in a subchannel.

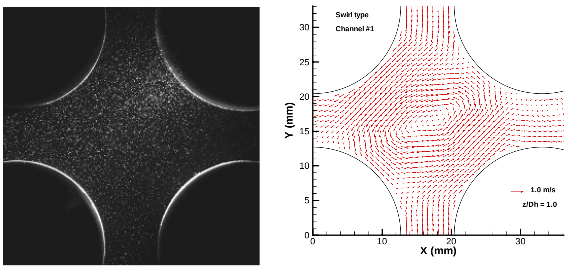
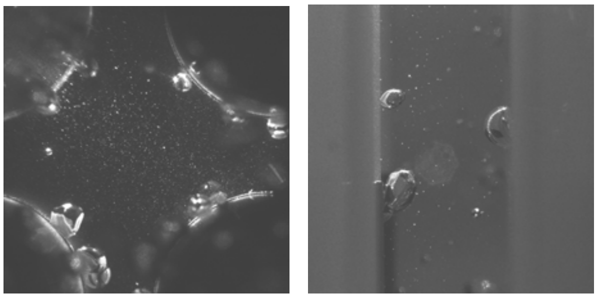
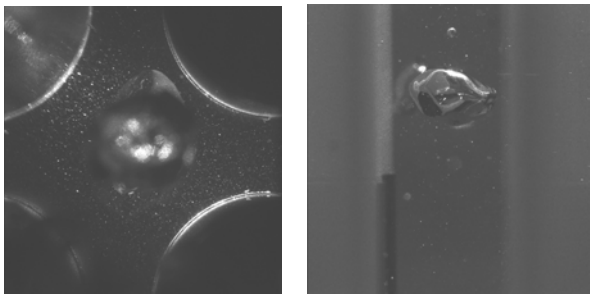


Fig. 3 Captured particle image (a) and the velocity vectors in a subchannel (b)

The PIV measurements of the bubbly flow in a subchannel were performed in cases of table 1. The typical images of the bubbly flow in a subchannel are shown in Fig. 4. In these images the characteristics of the bubble peaking [5] according to the bubble sizes is briefly demonstrated. The bubbles with diameter of 3 mm were peaked at the rod surfaces (wall peaking in Fig. 4 (a)) and the bubbles with diameter of 8 mm were peaked in a subchannel center (core peaking in Fig. 4 (b)). It had difficulties to get the clear images because of severe reflection and dispersion of the light by bubbles. It was also difficult to get the velocity vectors of liquid with sorted images because of the arbitrary distributed bubbles. The visualization of the bubbly flow in a subchannel at the same condition was conducted with the high speed camera. The peaking behavior of the bubbles in a subchannel was clearly demonstrated also.



(a) Wall peaking (bubble diameter ~ 3 mm)



(b) Core peaking (bubble diameter ~ 8 mm)

Fig. 4 Captured particle image of bubbly flow in a subchannel

The visualization of the bubbly flow in a subchannel at the same condition was conducted with the high speed camera. The peaking behavior of the bubbles in a subchannel was clearly demonstrated also.

4. Conclusions

The applicability of the PIV measurement technique which is well established in a single phase flow was employed in a rod bundle. There were difficulties to get the clear images of the particles and bubbles because of the light dispersion. Nevertheless, the PIV technique would be useful in some limited two phase flow applications. This study briefly shows the bubble peaking behavior in a subchannel.

REFERENCES

[1] H. L. McClusky, M. V. Holloway, D. E. Beasley and M. E. Conner, Development of Swirling Flow in a Rod Bundle Subchannel, J. of Fluids Engineering, Vol.124, p.747, 2002.
[2] S. K. Chang, S. K Moon, W. P. Baek, and Y. D. Choi, Phenomenological Investigations on the Turbulent Flow Structures in a Rod Bundle Array with Mixing Devices, Nuclear Engineering Design, Vol.238, p.600, 2008.
[3] B. J. Yoon, G. C. Park, J. E. Julia and T. Hibiki, Flow Structure of Subcooled Boiling Water Flow in a Subchannel of 3x3 Rod Bundles, J. of Nulear Science and Technology Vol.45, No.5, p.1, 2008.
[4] S. K. Chang, Y. J. Choo and S. K. Moon, PIV Measurement of Lateral Flow on Fuel Subchannel, *KNS Spring Meeting, Jeju, Korea, May 10-11*, 2007.
[5] 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, 2002.