Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

A Preliminary Study on the Reconstruction Algorithm of the Bubble Size to Inspect Two-phase Flows Using Single Cone-beam X-ray

Che Wook YIM [a], Song Hyun KIM [a], and Chang Ho SHIN [a,*]
[a]*Department of Nuclear Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, 133-791, Korea*
[*]*Corresponding author: gemini@hanyang.ac.kr*

1. Introduction

In two-phase flow, the motions of dispersed bubbles influence fluid properties such as heat transfer. In order to analyze how the bubble motion affects the fluid property, various techniques have been developed. An optical method has been used for the analysis of the single-phase flow such as Liquid Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV). However, it has some significant application problems which cannot be used for the opaque fluid and two phase flows [1]. Phase-Doppler Method, another optical method, can be applied to the two-phase flow analysis. It is noted that the method also has difficulty to analyze the opaque flows [2]. In a previous study, x-ray PIV method [3] was proposed as the technique to measure the flow velocity and to get the flow vector field. However, there is no appropriate approach to analyze the bubble size for the two phase flows. In this study, a technique to estimate the bubble size by using x-ray is proposed as a preliminary study to develop an algorithm of the two phase flow analysis.

2. Methods and Results

2.1 Proposal of Bubble Size Reconstruction Method

The experimental overview of the bubble size inspection system based on the x-ray source is given as shown in Fig. 1. The x-ray source and multichannel detector are located in front of and behind of the boiling pool, respectively. The maximum energy of the x-ray is 450 keV, and average energy is about 70 keV. As a preliminary study, the detector is assumed to be 9 x 9 multi-channels that each grid has 3 mm x 3 mm size. Also, it is assumed that the incident radiation is vertical on detector grids because the detection region is very small.

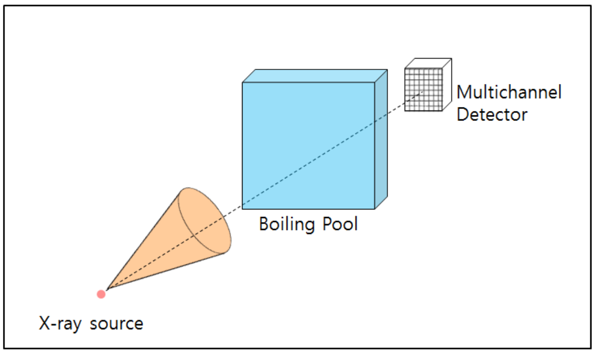


Fig. 1. Schematic Diagram of X-ray Based Flow Inspection System

Using the multichannel detector, 2-dimensional counting rate can be obtained for each channel. If the bubble is located at a specific position, the attenuations are relatively lower than the other regions that the bubbles are not located. Using the property, the length passing through the bubble can be estimated as shown in Fig. 2.

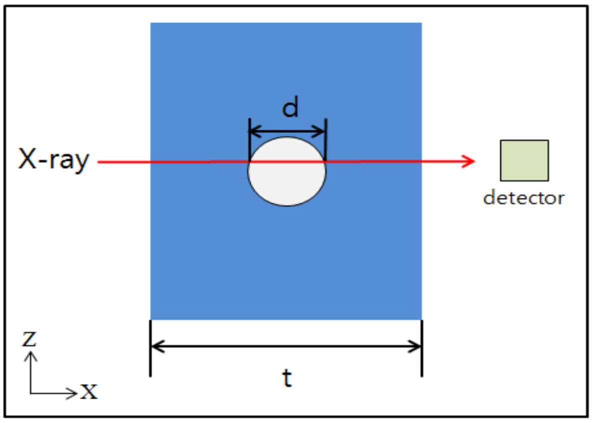


Fig. 2. Principle of the Bubble Size Detection

Let the length of the boiling pool be t and the length of passing the bubble be d. If the x-ray beams are passing the bubble, the attenuated intensity I_v can expressed as

$$I_v = e^{-\frac{\mu}{\rho_L}\rho_v d} \cdot e^{-\frac{\mu}{\rho_L}\rho_L (t-d)} \quad (1)$$

where μ is the average attenuation coefficient of the fluid, ρ_L and ρ_v are the densities of liquid and gas phase of the fluid, respectively. If the beam does not pass the bubble, Eq. (1) can be rewritten to Eq. (2).

$$I_L = e^{-\frac{\mu}{\rho_L}\rho_L t} \quad (2)$$

Then, relative intensity, which are the intensity passing the bubble per non-passing case, can be derived as Eq. (3).

$$\frac{I_v}{I_L} = \frac{e^{-\frac{\mu}{\rho_L}\rho_v d} \cdot e^{-\frac{\mu}{\rho_L}\rho_L (t-d)}}{e^{-\frac{\mu}{\rho_L}\rho_L t}} = e^{-\frac{\mu}{\rho_L}(\rho_L - \rho_v) d} \quad (3)$$

Finally, the bubble length can be estimated by Eq. (4) derived from Eq. (3).

$$d = \frac{\rho_L}{\mu(\rho_L - \rho_v)} \ln(\frac{I_v}{I_L}) \quad (4)$$

The average attenuation coefficient μ can be obtained from NIST XCOM [4], density of liquid and gas phase can be obtained by steam table if the temperature and pressure is known.

In case of which two or more bubbles are overlapped, measured bubble length is not matched with real one. In these cases, the bubbles can be separated from the reconstruction algorithm using the symmetric assumption of the bubbles. This will be performed in the future work.

2.2 Estimation and Analysis of Single Bubble Case

For the verification, a benchmark problem was assumed as shown in Fig. 1. The depth of the boiling pool is 5 cm. Temperature of the fluid is 100 ℃ and pressure is 1 atm. At this temperature and pressure, the density of liquid and gas phase is 1 and 0.000598 g/cm^3, respectively. It is assumed that the single bubble is located at the center of the boiling pool and the shape is sphere of 0.5 cm radius. MCNPX 2.7 code [5] was used to simulate the benchmark problem for the bubble reconstruction. Using the detected responses, the bubble length *d* in each detection region was calculated using Eq. (4) as shown in Table I.

Based on the bubble length distribution, the bubble was reconstructed by using *d*/2 distribution information and regression method [6]. The results are given in Fig. 3. The results show that the 3-D bubble size can properly be reconstructed using the proposed method.

Table I: Distribution of Bubble Length *d* for Each Grid Detector in Single Bubble Case

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0.087	0	0	0	0
4	0	0	0.0074	0.5767	0.7937	0.5368	0	0	0
5	0	0	0.0863	0.7622	0.9833	0.8205	0.0966	0	0
6	0	0	0.0059	0.5811	0.7546	0.5909	0.0115	0	0
7	0	0	0	0.0057	0.0659	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

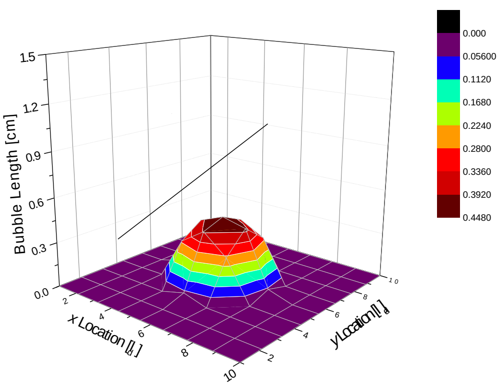
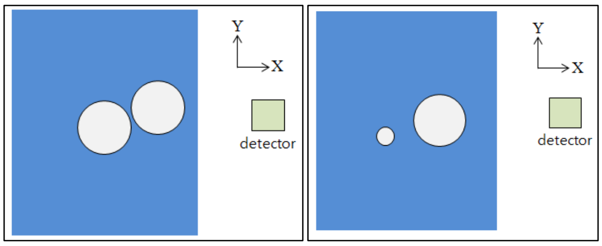


Fig. 3. 3-D Reconstruction Image of Single Bubble Case

2.3 Preliminary Study for Multi-Bubble Cases

For the multi-bubble cases, a preliminary study on whether the multi-bubble can be separated by the proposed reconstruction algorithm is pursued. For reconstructing the multiple bubbles, two cases are selected. One is that two bubbles have same 1 cm of diameter, and the other is case of big and small bubble of which radius are 0.5 cm and 0.2 cm, respectively. Fig. 4 shows the configuration of two cases. As a same way with Section 2.2, the distribution *d* was calculated from the detection results estimated by MCNPX code.

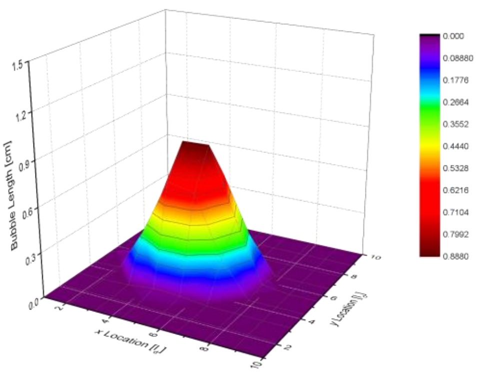


(a) Case 1 (b) Case 2

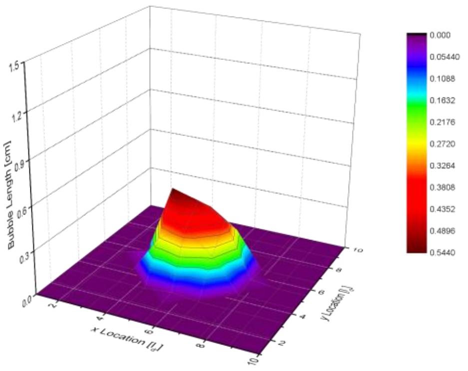
Fig. 4. Location of the Bubble in Two Multi-bubble Cases

The result of the Case 1 is shown in Fig. 5 (a). The graph has two peaks, and two circles are appeared in *xy*-plane. The diameter of the circles is estimated about 1 cm each. The spheres are centered at region of detector y = -0.3 cm and y = 0 cm, respectively. Based on these data, combined with projection length, about 0.5cm radius of bubble at the center can be reconstructed.

The result for Case 2 is given in Fig. 5 (b). The peak where the symmetry is broken is appeared. This means the multi-bubbles are present in that position. Through the information of xy-plane, the sphere of 1 cm diameter at the center is reconstructed. Then, subtracting the sphere size from the combined detection length, the diameter of the other sphere is 0.3 cm and centered at y = -0.3 cm. Real diameter of small one is 0.4 cm. It is analyzed that the error is caused by the spatial resolution of the grid detector.



(a) Case 1



(b) Case 2

Fig. 5. *d* Length Distributions of the Multi-bubble Cases Reconstructed by Using Regression Method

3. Conclusions

In this study, a reconstruction algorithm of bubble size in two-phase flows using single x-ray was proposed. The analysis shows that 3-dimensional bubble size can be estimated by the multichannel detectors with the detection information. Also, a preliminary study on multi-bubble cases was performed. The analysis of the results show that that multiple bubbles can be separated by using the property that is the symmetry of bubbles. This proposed algorithm can detect the bubbles in flow of opaque fluids or nontransparent pipes which cannot be analyzed by optical methods. It is expected that the proposed method can utilized to inspect the bubbles in two-phase bubbly flow.

4. Acknowledgement

This work was supported in part by Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by KOREA government Ministry of Knowledge Economy (20121620100070) and Innovative Technology Center for Radiation Safety (iTRS)

REFERENCES

[1] A. Seeger, U. Kertzscher, K. Affeld, L. Goubergrts, and E. Wellnhofer, X-ray Based Particle Tracking Velocimetry for Bubble Columns with High Void fraction, Bubbly Flows, Springer, p.129-138, 2004.

[2] M. Sommerfeld and H. –H. Qiu, Particle Concentration Measurements by Phase-Doppler Anemometry in Complex Dispersed Two-Phase Flows, Experiments in Fluids, Vol.18, p.187-198, 1995.

[3] A. Seeger, K. Affeld, L. Goubergrits,U. Kertzscher, and E. Wellnhofer, X-ray Based Assessment of the Three-Dimensional Velocity of the Liquid Phase in a Bubble Column, Experiments in Fluids, p.193-201, Springer-Verlag, 2001.

[4] M. J. Berger, J. H. Hubbell, S. M. Seltzer and et al., XCOM: Photon Cross Section Database (Version 3.1), National Institute of Standards and Technology, Gaithersburg, MD, USA, 2005.

[5] D. B. Pelowitz, editor, MCNPXTM User's Manual ver. 2.7.0, LA-CP-11-00438, Los Alamos National Laboratory, 2011.

[6] P. J. Besl and N. D. McKay, A Method for Registration of 3-D Shapes, IEEE Transactions on Pattern Analysis and Machine Intelligence Vol.14 No.2, 1992.