Visualization of Metallic Mini-Tube using Neutron Imaging Technique

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1. Introduction

Due to the high penetration property of neutrons through metals and good interaction probability with liquid fluid, neutron imaging technique has been a good choice for the study of fluid dynamics in the mechanical engineering. With the recent development of high performance converters, photo detectors and high flux neutron sources, there have been many trials for the visualization of two-phase flows using neutron radiography. However, most tests are performed with the ordinary tube size more than two centimeter in diameter except the works done by H. Asano et al.[1] and Kim et al[2]. The results of Kim et al[3] demonstrated that it is possible to visualize the flows in the metallic tube more than 1/4" with the neutron beams at the BNCT HANARO although it was difficult to see the inside of tubes less than 1/4" tube due to the insufficient L/D ratio and light intensity In this study, the same feasibility test apparatus was setup for the visualization of mini metallic-tubes using the neutron image technique at BT-6, NIST(National Institute of Standards and Technology), USA. And we'll propose a guideline for the mini-tube visualization using the neutron image techniques from the experimental results at both beam lines.

2. Experimental Set-up

Figure 1 shows the schematics of test section for the mini-tubes. Upper tank and bottom tank are connected by two revolving tubes and 6 test tubes. Three different diameter (1/16", 1/8" and 1/4") copper and aluminum tubes are used for test tubes. Each test tube is winded by heating wire at the bottom for heating. Heat flux of heating wire is adjusted adequately by power supply. Tank is filled with refrigerant HFC-134a. Refrigerant is heated by the heating wire and evaporated to flow up through the test tube. Refrigerant inside upper tank flows down to bottom tank through the revolving tubes. The experiment was conducted by adjusting the heater input ranging from 4.5 to 100W.

Figure 2 shows the experimental apparatus installed at the BT-6, NIST. The experimental apparatus is mainly composed of the neutron beam from the reactor core, the test section shown in Fig. 1 and the flat panel detector which converts the neutron signal to digital data. At this test, we used the flat panel detector, which has good advantages over mirror-based CCD detector in terms of its good light collection efficiency achieved by direct optical coupling between the scintillator and the amorphous-silicon photo detector. The maximum achievable temporal and spatial resolution of the flat panel is 30 fps and 0.254mm, respectively.

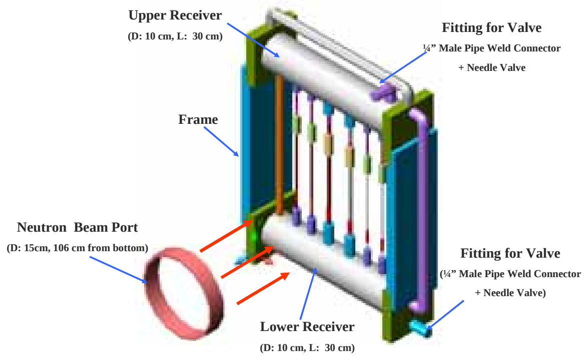

Figure 1. Schematic Diagram of Test Section:

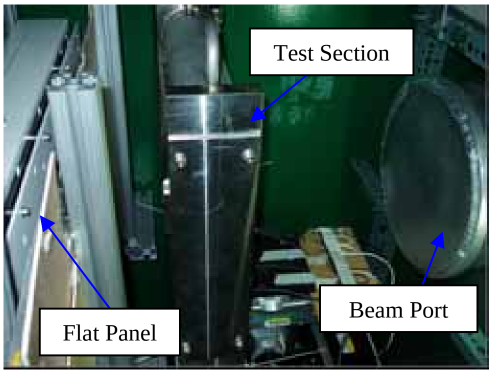

Figure 2. Photograph of Experimental Apparatus at BT-6

3. Results and Discussion

Figure 3 shows the resulting images at 1/4" Al and Cu tube with 100W of heater input and Figure 4 for 1/8" tubes with 27W of heater input. Since the neutron attenuation of aluminum is small, the tube is almost invisible in the figure. Every photographic image is quite dark and unclear at this moment because the light intensity of converter is too low on this experiment and post-processing has not been applied to them yet.

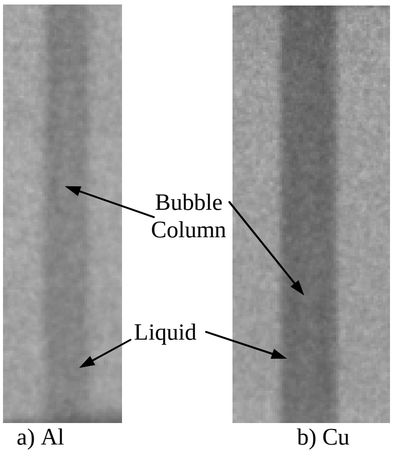

Figure 3. Acquired test images at 100 W, 1/4" Al and Cu tube

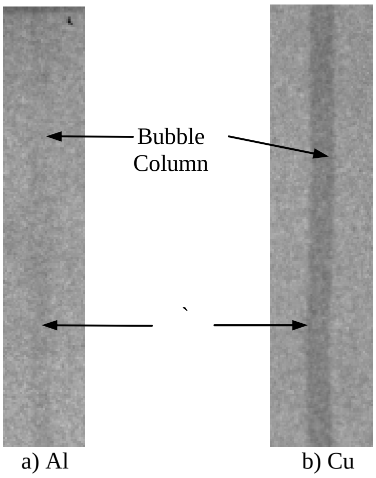

Figure 4. Acquired test images at 27 W, 1/8" Al and Cu tube

Except for the case of the 1/8" Al tube with 27W of heat condition, flow regimes of other cases are annular. But the flow pattern of 1/8" Al tube with 27W is thought churn flow because liquid exits only lower part of the tube and bubble column exits upper part. Compared with the image contrast of Cu tube, that of Al tube is poorer. But when making the moving file, we can visualize the movement of bubble and liquid inside of tube. As decreasing the input power from 100 to 4W, the size of bubble is decreased and finally become invisible.

Compared with the results at the BNCT beam port of the HANARO, South Korea, it is possible to visualize the 1/8" tube at BT-6 of the NIST. The neutron beam characteristics of both beam lines are summarized in Table 1. While the neutron flux of the BNCT is higher than that of BT-6, it has lower L/D ratio of about 50, which means image unsharpness of around 0.2 mm as shown in Table 2. If the distance between test section and scintillator is about 1 mm, we can ignore the unsharpness effect. However, since there always exits physical limitation between test section and scintillator, it is difficult to reduce less than 10 mm. Therefore, the BNCT is only suitable for the visualization of tubes larger than 2 mm in diameter unless improving neutron beam condition if the error from unsharpness is assumed to be 10%. If we use smaller beam collimater at the BNCT, we may obtain higher L/D ratio with loss of neutron flux. Therefore, it requires the optimization of experiment method for the mini-tubes. At both the BNCT and the BT-6, it is impossible to visualize the tubes smaller than 1/16" in diameter because of poor spatial resolution.

Table 1. Neutron Beam Characteristics of BNCT and BT-6

Location	BNCT	BT-6
Flux (n/cm2s)	$2.58*10^8$	$1.67*10^7$
L/D	47.3	300

Table 2 Unsharpness according to the Distance between Test Section and Scintillator

Distance [mm]	Results [mm]	
	BNCT (L/D=47.3)	BT-6 (L/D=300)
1	0.021	0.003
10	0.211	0.033
50	1.057	0.166

4. Conclusion

The neutron imaging technique was used to visualize the inside metallic mini-tube at BT-6 of the NIST. Using results of BT-6 and previous those of BNCT[3], the guideline for visualization of mini-tube is proposed. The L/D ratio is important factor for the mini-tube visualization. If the neutron beam characteristics of BNCT are improved, it is possible to visualize the tube less than 2 mm. However, in order to minimize the loss of neutrons, it is required to optimize the experimental method for mini-tube.

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REFERENCES

[1] H. Asano, N. Takenaka, T. Fujii, Y. Shibata, T. Ebisu, M. Matsubayashi, Visualization and measurement of refrigerant flow in compression-type refrigerator by neutron radiography, Nucl. Instr. and Meth., Vol.**424**, 98-103, 1999

[2] TaeJoo Kim, Kaoru Yasuhara, YongMi Jung, Moo Hwan Kim "Feasibility Test for Visualization of Two-Phase Flow Inside Metallic Mini-Tube by Neutron Radiography" 한국원자력학회 2004 추계학술발표회 논문집, 229-230, November 3-5, 2004