ULTRASONIC TECHNIQUE FOR VOID FRACTION MEASUREMENT IN A BUBBLY COLUMN

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Abstract. The measurement of the void fraction in a bubbly flow is important for modeling two-phase gas-liquid flow for the safety of nuclear reactors and thermal-hydraulics analysis. In this work, a non-invasive ultrasonic technique was developed for the measurement of the void fraction by correlating it with the amplitude of the ultrasonic pulse reflected from the opposite wall of the tube. The technique was applied in a test section made of 52.9 mm internal diameter glass column which makes possible the visualization of the bubble flow. A special ultrasonic methodology was developed for the processing of the ultrasonic signals generated by a transducer of 10 MHz frequency and 1/2" diameter.

***Keywords**: two-phase flow, ultrasonic technique, pulse-echo, void fraction*

1. INTRODUCTION

Nucleate boiling of the nuclear reactor coolant is important for the improvement of the efficiency of heat exchangers. However, in some nuclear designs, because of the consideration of plant safety, the nucleate boiling regime is undesirable and quick information about its occurrence is necessary. There is instrumentation to detect bubbles in the liquid phase, as well as to measure the void fraction in heat exchangers but, to nuclear plants, it is always desirable to develop a new non-invasive technique, like ultrasonic technique.

Many techniques have been developed to measure parameters of two-phase flow. These techniques can be classified as invasive and non-invasive. As an example of invasive technique, recently Dvora *et al.* (1980) and Hogset et al. (1997) used conductivity probe to recognize parameters in two-phase flow. However, the possibility of leakage using invasive techniques is inherent when the pressure operation is high. Ultrasonic techniques are non-invasive and can be applied to two-phase flow in high-pressure and high-temperature metallic pipes nuclear systems. According to Chang and Morala (1990) there are three possible ultrasonic techniques for two-phase flow measurements, namely the pulse-echo, the transmission and the Doppler techniques. Stravs and Vonstockar (1985) used ultrasonic pulse transmission technique to measure interfacial area in a bubbly column and Wada et al. (2006) used ultrasonic pulse-echo technique to recognition patterns of two-phase vertical flow, but the two previous works did not comment about detection and measurement of small void fractions.

The main objective of this work is to present a study on application of an ultrasonic pulse-echo method to detect small bubbles and measure small void fractions in a bubble column. This paper is organized as follows: in Section 2, the experimental setup and the images of air bubbles are presented; the experimental results are presented in Section 3. The main conclusions of the work are presented in Section 4.

2. EXPERIMENTAL SETUP

The experimental development was carried out in Nuclear Engineering Institute (IEN/CNEN), Brazil. The experimental facility is formed by air bubbles generation system, a vertical water column and an ultrasonic system, as shown in Fig. 1. The vertical column is a glass tube of 52.9 mm inner diameter, 2.1 mm wall thickness and 1.4 m long.

A valve controls the amount of air bubbles injected into the vertical water column. A manometer measure the air pressure, which is set-up to 19.6, 39.2, 49.0 and 68.6 KPa. Therefore, the pressures are related to air void fraction injected into the column.

It was used a digital camera (Motionscope PCI 8000S model) to take images of air bubbles. The diameter of the bubbles and their quantity were measured using the software of the camera. Based on these, it was possible to calculate the void fraction. The fig. 2 shows typical images taken by the camera.

The ultrasonic system comprises a Panametrics model 500PR pulser-receiver, a Tektronix model TD53012B digital oscilloscope (100 MHz, 1.25 GS/s), a Panametrics model A541S piezoelectric transducer (6.35 mm diameter, 10 MHz), and a National Instruments PCI acquisition system. The system is capable to acquire 20 waveforms/second from the ultrasonic signals.

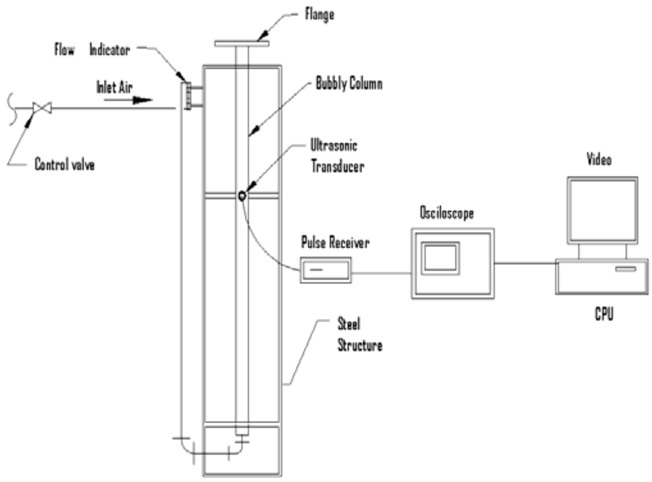


Figure 1. Schematic of the experimental facility.

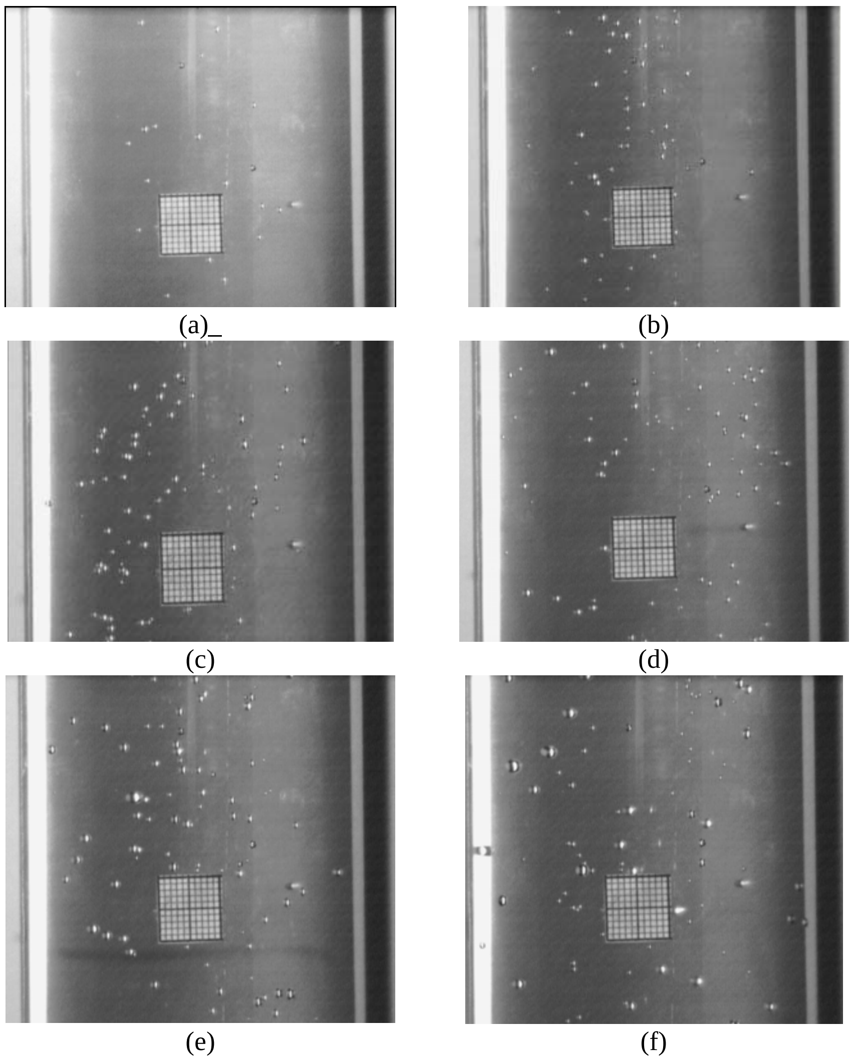


Figure 2. Images taken of the air bubbles at pressures:
(a) 19.6 Kpa (b) 39.2 Kpa (c) 49.0 KPa (d) 68.6 Kpa (e) 88.2 KPa (f) 107.8 KPa.

3. EXPERIMENTAL RESULTS

3.1. Observed phenomenon

It was observed that the ultrasonic wave behavior in the glass tube is quite similar to the that in the steel tube in terms of multiple reflections occurrying in both materials. The fig. 3 shows the ultrasonic multiple reflections in the glass tube wall. According to Lamy *et al.* (2007a) and Lamy *et al.* (2007b) the multiple reflections are inherent to ultrasonic techniques when the tube material is steel.

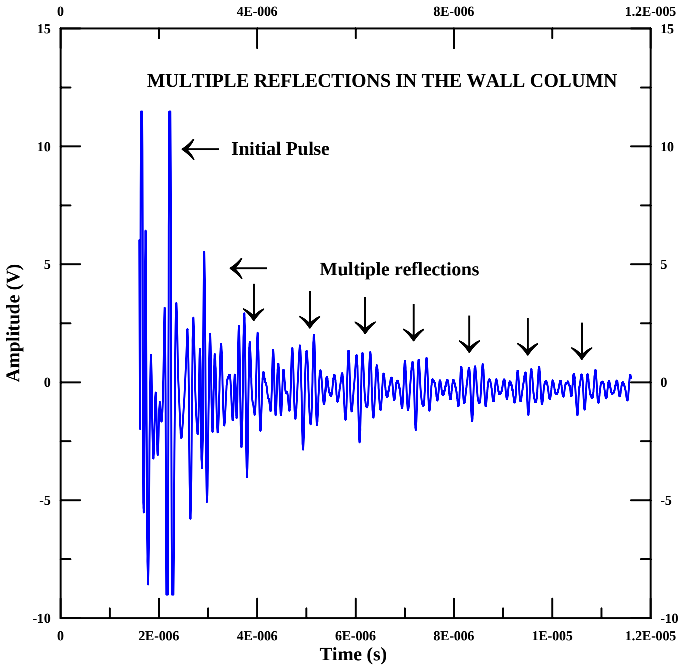


Figure 3. Multiple Reflections in the wall glass column.

3.2. Results

In the Tab. 1 the bubbles number and diameter are presented together with the void fraction measurements.

Table 1. Experimental results of the bubbles number/diameter and the void fraction.

Air pressure (Kpa)	Bubble average diameter (mm)	Number of bubbles per frame	Void fraction (%)	Area under the ultrasonic curve (area unity = Volt x second)
19.6	0.65	24	0.005	2.62E-05
39.2	0.5	42	0.013	2.46E-05
49.0	0.85	92	0.041	2.39E-05
68.6	0.86	80	0.036	2.37E-05
88.2	1.15	82	0.090	2.19E-05
107.8	1.39	75	0.145	2.10E-05

Figure 4.a shows a typical echogram where it can be seen the emitted initial pulse and the back wall echo. This echogram represents the average signals acquired during twenty seconds.

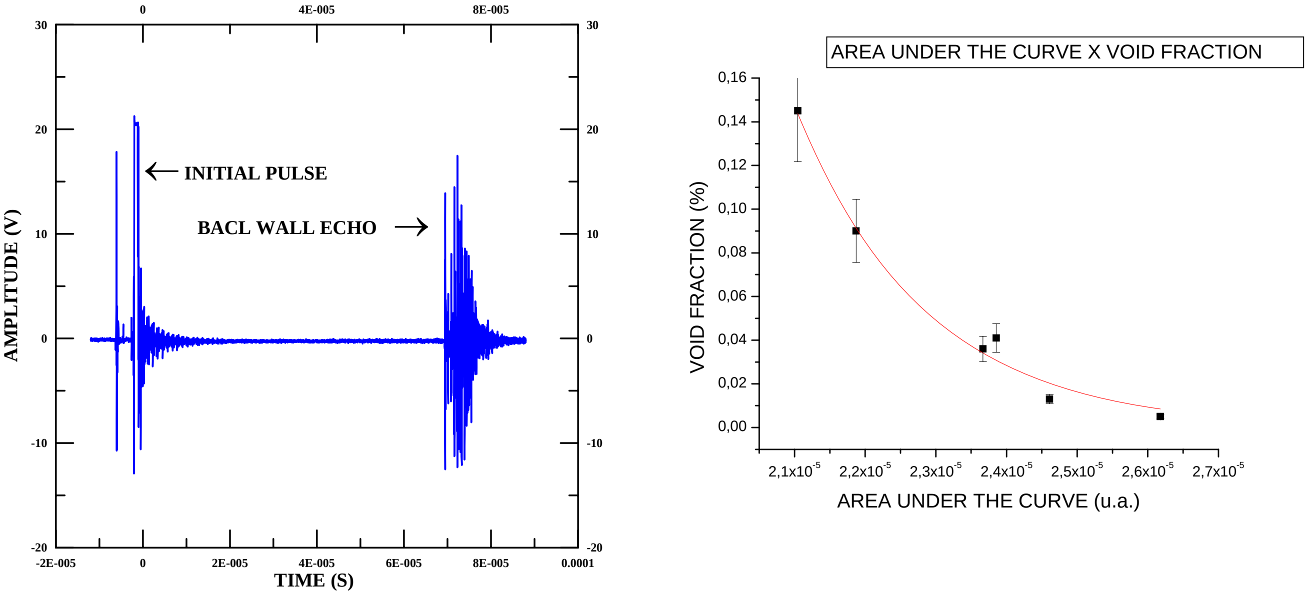
It was observed that the area under the back wall echo curve has a relation to void fraction. Increasing void fraction the area under the curve of the back wall decreases. The Fig. 4.b shows this relation.

It was acquired 15 ultrasonic signals related to the back wall echo curve. Each of these signals is formed by 1,000 points (Amplitude (V) x time (s)). The back wall echo curve studied is formed by the average of these points. To each point was calculated the average and standard deviation. Three curves were plotted: one of them was the average and the others are related to the standard deviation. The areas under these curves were calculated and it was observed a variation of ±16%. The void fraction is a function of the area under the back wall curve and so has the same uncertainty

The curve of Fig. 4.b was fitted to an exponential decay of first order that may be expressed by the following equation

$$VF = 1{,}5.10^{5}\, e^{-6{,}5.10^{-5}\,(u.a.)}$$

where VF is the void fraction and u.a. (Volt x second). is the area under the curve of the back wall echo.



(a) (b)

Figure 4. (a) Typical echogram and (b) Void fraction as a function of the area under the back wall echo curve.

4. CONCLUSIONS

This paper reports an experimental investigation of the reflected ultrasonic signal from the back wall echo of a bubbly column made of glass with small void fraction as 0,005%. It was observed that the area under the back wall echo signal has a relation to void fraction, and that the glass tube wall presents multiple reflections of the ultrasonic waves, as well as in steel tube.

Although the multiple reflections difficult the ultrasonic evaluation, the ultrasonic technique showed sufficient sensitivity to detect the nucleate boiling onset and can be a suitable technique to be applied in nuclear reactors.

5. REFERENCES

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6. RESPONSIBILITY NOTICE