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IDENTIFICATION OF TWO PHASE FLOW REGIMES BY VOID FRACTION MEASUREMENTS

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Abstract. This paper will present a method to identify flow patterns (bubble & slug flow) in vertical air-water two-phase flow by void fraction measurement (using an impedance probe) at Inst. of Mechanics Hanoi.

1. INTRODUCTION

Identification of flow patterns is one of the most fundamental problems in investigating the basic phenomena of two-phase flow. At present, there are two available methods to identify two phases flow patterns: direct observation (including visualization, high speed photography, X-ray) and indirect determination (including measurement, the analytical tools such as probability density function (pdf) or power spectral density (psd), etc...) However, this paper is only mentioned of an indirect determination method, which is generally preferable to direct observation at Inst. of Mechanics Hanoi. Void fraction measurement of two-phase flow in the pipe is one of the indirect determination methods. There are many results of various authors which showed that the void fraction could be used as a parameter to identify two-phase flow patterns, especially for gas-liquid two phase flow in the pipe. Y. Ma et al 1991 [1] and Wang et al 1991 [2] have proposed a simple and effective method (using the void fraction sensor) to identify the flow patterns. Costigan and Whalley 1997 [3] developed and used this method for slug flow regimes identification in vertical air-water flow. Recently, M. J. Watson and G. F. Hewitt 1999 [4] have carried out the investigation using the impedance probe to determine from the slug to churn flow pattern transition at various flow rate and pressure in vertical upwards gas-liquid flow. In general, most of previous investigations are based on a certain statistical analysis of fluctuating characteristics of the flow.

In this paper, a method based on the measurements of the average void fraction (using impedance probe) is proposed. This method is similar as the methods based on statistical analysis of fluctuating characteristics of the flow, however it's not sophisticated and it is combined of two methods: visual observation and measurement. It means that we create a bubble flow (or slug flow) first and to measure the output voltage signals on each case. The measurement will be repeated many times at the same condition and then we will identify which kind of the output signal corresponds with the bubbly flow or slug flow.

In general, the impedance probe is a relatively simple, precise instrument for high frequency void fraction measurements, and particularly suitable for void fraction measurements in pipe without further integration. Moreover this method has some advantages such as economical, simple installation, small perturbation to the flow field, suitable for fast transient phenomena and for data acquisition due to its analog output.

2. EXPERIMENTS

2.1. Experimental facility

Fig. 1 is a schematic of the experimental equipment. This facility includes a water supply system, a gas supply system, a separate tank, and a test section. The test tube is a transparent tube, 25 mm inner diameter and 4m long. An impedance probe was manufactured locally to fit in the test tube. The position of the probe is located 3.5 m above the bottom of the test tube. This probe based on the designing of Y. Ma et al. [1] and Costigan and Whalley [3]. The facility used in this study is basically similar to that used in Ref. [5]. In principle, we can use some probes and they can be placed at several distances along the tube, however in this experiment, only one probe unit is used. The measurement of void fraction signals by this probe was previously reported by T. Bui Dinh [5]. The test fluids were water and air at atmospheric conditions. In this study, the airflow rate range from 0.1 to 0.5 m/s, and the water flow rate from 0.01 to 0.05m/s, are used and they are correspondent to bubble & slug flow patterns in Taitel et al.'s [6] flow regime map in vertical tubes.

2.2. Measuring principle

The principle of void fraction measurements (using an impedance probe) in an air-water flow is based upon the variation or the difference in conductivity between the gaseous and liquid phase. In this flow, the air can be considered as electrically insulating, whereas water has a conductivity. When the probe is in contact with the continuous liquid the circuit is closed, whereas a bubble will break the circuit. A detailed sketch of the impedance probe is given in Fig. 2.

The probe was connected to a signal generator (1.6 MHz) and a signal processing circuit. This processing circuit is designed to linearly amplify the amplitude of the output signals and to rectify the AC signals to DC voltage output. When the flow circulates between two electrodes, the electrical signals are appeared, and these output signals are connected to the signal processing circuits, whose outputs could be either displayed on an oscilloscope or recorded using a high-speed data acquisition.

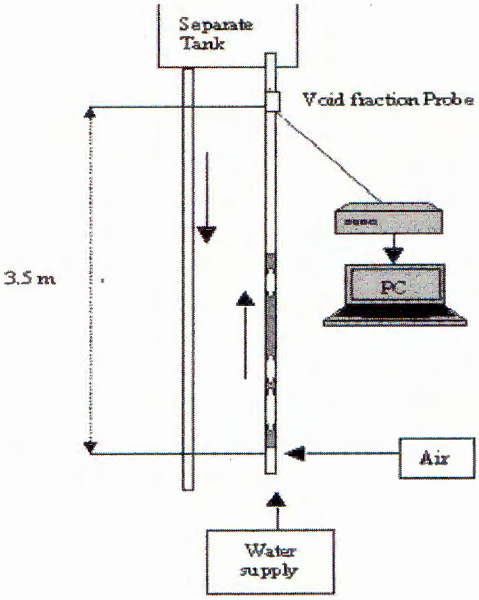

Fig. 1. Experimental facility

The results of Y. Ma et al. [1] showed that for a vertical pipe, when the cross sectional area of the electrode and the average distance of the electrodes are fixed, the voltage drop between the electrodes depends on the variation of the conductivity of the mixture inside the pipe. In this study we assume also that the variation of the probe output signals correspond to the void fraction in the test section, it means that the output voltage between the electrodes is directly proportional to the void fraction since the conductivity of the gas phase is small enough to be neglected in comparison with similar parameter of liquid phase.

2.3. Theory of void fraction measurement

According to the theoretical measurement of a capacitive transducer, the impedance for a series circuit can be calculated by

$$Z = \frac{1}{\frac{1}{R} + J2\pi fC}, \tag{2.1}$$

where R : pure resistance, f : Frequency of the signal, C: Capacitance and $J = I/A$ current flux.

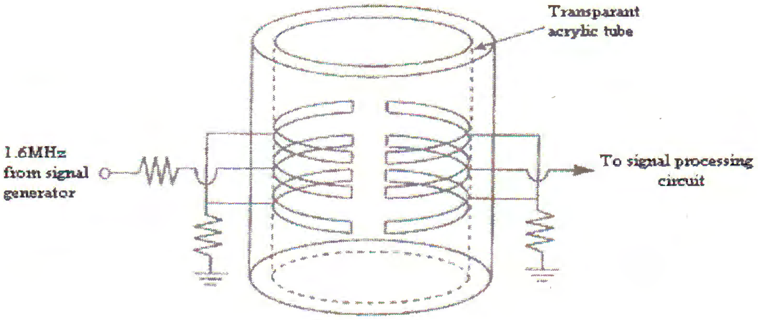

Fig. 2. The impedance probe

The conductance between the electrodes:

$$G = \frac{1}{R} \tag{2.2}$$

is proportional to the ratio of the cross sectional area of the electrode and the distance between the electrodes:

$$G = \frac{\gamma}{l}A, \tag{2.3}$$

where γ: Conductivity, l : distance between the electrodes, A : cross sectional area.

The capacitance is proportional to the ratio of the cross sectional area and the distance between the electrodes:

$$C = \frac{\varepsilon}{l}A, \tag{2.4}$$

where ε is the dielectric constant (ε=1).

Equations (2.1) through (2.4) show that the impedance (Z) is proportional to A/l . Moreover, we know that the electric field intensity E is defined to be proportional to the ratio of the drift velocity ν of the electron and the mobility μ of the electron.

$$E = \frac{\nu}{\mu}. \tag{2.5}$$

The drift velocity ν may also be presented as the ratio of the current flux J and the charge density ρ_e (where $\rho_e = \gamma/\mu$).

$$\nu = \frac{J}{\rho_e}. \tag{2.6}$$

Thus equation(2.5) becomes

$$E = \frac{J}{\gamma} = \frac{I}{\gamma A}. \tag{2.7}$$

This formula recognized as Ohm's law. It means that the conduction current is proportional to the applied voltage. By definition, the electric field intensity is the potential gradient dV/dx, then equation (2.7) becomes:

$$V = \int E dx = \int \frac{I}{\gamma A} dx, \tag{2.8}$$

where: V is the voltage across the electric field and x is the distance between the electrodes (fixed).

As similar as Y. Ma et al. [1], base on the relative output voltage of the signal processing circuit, the values of void fraction (α) can finally be calculated:

$$\alpha = \frac{V - V_g}{V_l - V_g}, \tag{2.9}$$

where V_l is measured voltage with pure water and V_g is measured voltage with pure gas. Values of V_l and V_g will be measured before of each series of experiment (In our experiments $V_g \cong 0.05\,V$ and $V_l \cong 0.3\,V$).

3. RESULTS

By measuring the variation of the average output voltage between two electrodes of impedance probe, the flow patterns in vertical pipe are identified. About 30 data sets are collected and each equivalent attribution of flow patterns is identified by visual observation. The probability distribution (histograms) of void fraction was recorded for each experiment. At each flow pattern, a measurement of the void fraction variation was taking every 0.005 s for 4 s. Before each experiment the probe must be calibrated.

Fig. 3 shows an example of histograms of a bubbly flow. The bubble diameter in this case is about 1-3 mm and the amplitudes of signals are approximately $\pm 0.10\,V$, so the mean value of void fraction in this case can be derived from (2.9) $\alpha \cong 0.2$.

Fig. 4 is an other example of the output voltage signal in slug flow. In this figure, we remark that the histograms are strong variation and very different in two parts respectively. In the high signal part, which is corresponding to the appearance of liquid slug, the amplitudes of signals are approximately $\pm 0.25\,V$, and in the low signal part which is corresponding to the appearance of the Taylor bubble in the slug flow, the amplitudes of signals are approximately $\pm 0.125\,V$. Finally the mean values of the void fraction (α) derived from (2.9) are varied from 0.3 to 0.8.

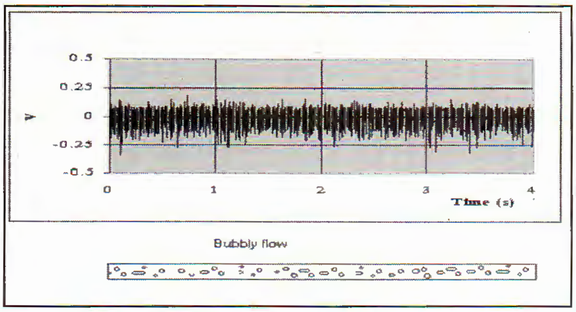

Fig. 3. Histograms of void fraction
(Bubbly flow)

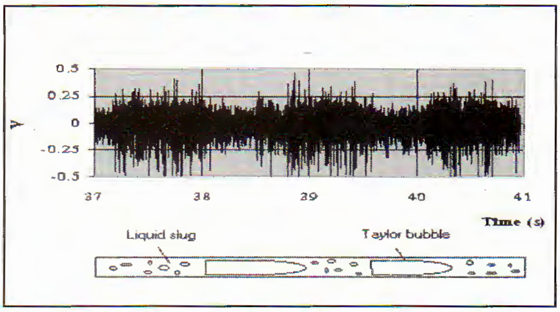

Fig. 4. Histograms of void fraction
(Slug flow)

By intuition we remark that the amplitude and signal variation in bubbly flow are smaller then in slug flow. Moreover in the cause of the amplitude of the output voltage signal is directly proportional to the void fraction, so we can conclude that the void fraction variation in bubbly flow is also smaller then in slug flow.

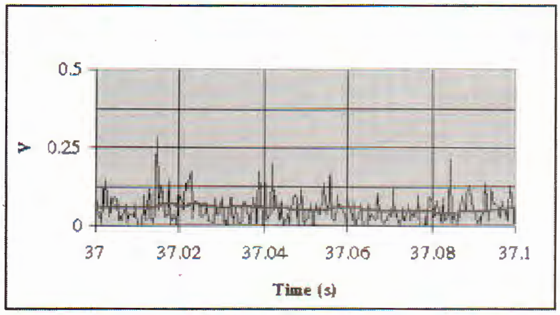

Fig. 5. Avg. void fraction (0.1 s bubble flow)

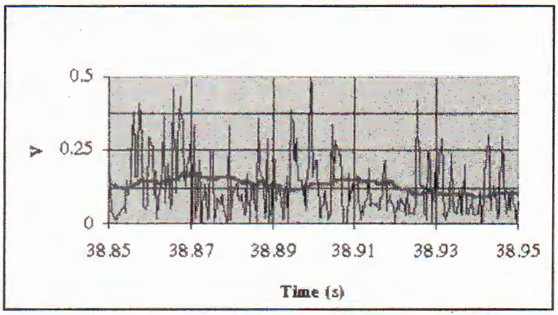

Fig. 6. Avg. void fraction (0.1 s slug flow)

Figures 5 and 6 are the histograms (positive half) of average amplitudes of signals of the bubbly and slug flow for 0.1 s. We remark also here that there is strong difference between two cases. In fig.5 the fluctuating of the average amplitude of signals of the bubbly flow are about from 0.06 V to 0.07 V while the similar values of the slug flow (Fig. 6) are from 0.125 V to 0.15 V.

Fig. 7 shows the transition of the average amplitude of signal line from bubbly flow to slug flow. The average signal line have a change from 0.06 V (in bubbly flow) to 0.125 V (in slug flow), it is correspondent to the variation of their void fraction, from 0.2 (bubbly flow) to 0.8 (slug flow).

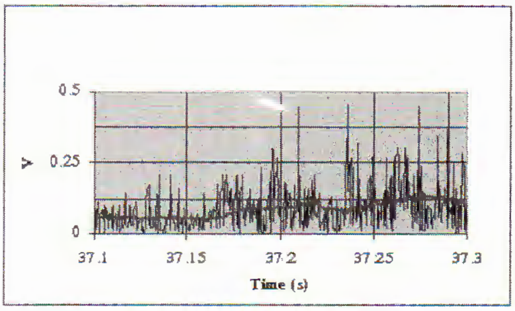

Fig. 7. Avg. void fraction
(bubble - slug flow transition)

The results obtained in this study show that the output voltage of an impedance probe can be used for prediction of the variation of the void fraction, or there is the direct relationship between signals and the void fraction value, in particular, there is the similarity of the fluctuating characteristics between average signal lines and the void fraction.

Fig. 8 and the table below show a comparison of the results of Y. Ma et al (in vertical pipes) with the measured void fraction in our experiment, for two cases bubbly and slug flow respectively. We remark that the values of the measured void fraction are approximate with the calculated results and Y. Ma et al.'s results.

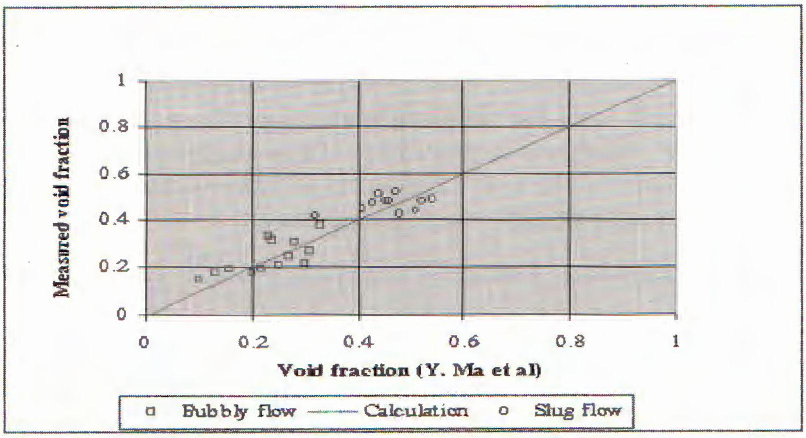

Fig. 8. Void fraction comparison

4. CONCLUSION

Table

Bubbly Flow		Slug flow	
Ma et al	Measured	Ma et al	Measured
0.10	0.15	0.32	0.42
0.13	0.18	0.41	0.45
0.16	0.19	0.52	0.48
0.20	0.18	0.48	0.43
0.22	0.19	0.44	0.51
0.25	0.21	0.47	0.52
0.30	0.22	0.46	0.48
0.28	0.31	0.51	0.44
0.31	0.27	0.54	0.49
0.24	0.32	0.43	0.47
0.27	0.25	0.45	0.48
0.23	0.33		
0.33	0.38		

- A method to identify the flow patterns, based on the measurements of the average void fraction (using impedance probe) is proposed.

- By using the output voltage signals (which are directly proportional to the void fraction value), flow pattern of bubbly or slug flow is identified.
- Taitel et al.'s flow regime map is used as a reference for identifying flow patterns obtained by visualization in our experiments.
- In comparison with published literature, these results are in good agreement with the results of Y. Ma et al. (Fig. 8).
- This method shows that it's possible to identify two phase flow patterns in vertical pipe, by the void fraction measurement and it's a solution very economical and practical for use both in laboratories & industries.

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Bài báo trình bày một phương pháp nhận dạng chế độ dòng chảy (dòng bọt và dòng chảy nút-túi khí) của dòng 2 pha khí-nước trong ống đứng bằng cách đo tỉ phần rỗng (sử dụng đầu đo trở kháng) tại Viện Cơ Học Hà Nội.

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