A Review of Methodologies to Determine Bubble Diameter and Bubble Velocity

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Abstract- The study of two-phase flows has formed the basis of several industrial applications. The analysis of the concentration gradient of the two phases and the transformation of a particular flow pattern to another has played a vital role in estimating the durability of the machinery used in industries. For efficient analysis of the flow characteristics, one needs to obtain experimental data depicting bubble size, velocity of the bubbles. This paper reviews a time trace method to measure the bubble diameter and velocity in a two-phase gas-liquid flow using a conductance probe. A comparative study on the design of the probe electrodes has been done and an appropriate geometrical design of the probe electrodes has been mentioned. This paper also presents the electronic circuit development of the probe. The principle of the experiment revolves around the difference in electrical conductivity of the two-phases and the corresponding voltage changes noted when each phase is in contact with the probe electrode. The output signal is finally analyzed by an oscilloscope. In addition a few experimental results in regard with the transition of flow pattern and gaseous phase concentration are analyzed. Also an appropriate design of probe electrodes has been selected at the end.

Index Terms- two-phase flow, conductance probe, bubble diameter, bubble velocity

I. Introduction

The detailed analysis of two phase flows has a wide ranging industrial applications like power generation, chemical, oil processing industries etc.. the study of the distribution of two-phases and the possible changes of one flow to other plays a vital role in the designing of industrial equipment such as pipe lines. Different forces govern the stability of the two-phase flows; the most important ones are the effect of gravity on the two-phases and the action of shear and surface tension forces at the interface of the two phase flows. Different flow patterns can be obtained changing the mass flow rates of the two-phases. When there is a substantial increase in the air flow rate into the phases, bubbly, slug, plug, churn, and annular flows can be obtained. The main character of the bubbly flow is the presence of relatively regular but non-periodic bubbles of small diameter. These small bubbles can coalesce to form a larger bubble, but the larger bubble formed is smaller than the cross section of the pipe whereas in slug flow, bubbles of diameter as much as the cross section of the pipe are formed.

A bubble can basically be divided into three parts (i) Head (ii) Central region (iii) Tail. The major area of the pipe's cross section is covered by the gas in the head region; the gas phase in the central region occupies a majority of the pipe section except a thin liquid film at the walls. The tail region describes the end of the bubble with a minimal amount of gas in it.

Cap flow: It is characterized by the immediate occurrence of the tail region after the head region.

Slug flow: It consists of elongated bubbles having as much diameter as the pipe's cross section. Here proper distinction of head, tail, and central regions is possible.

Plug flow: In this flow the central region is dominant and requires higher values of gas mass flow rate.

Churn flow: This flow requires high value of gas mass flow rate. The waving liquid film drains down the wall. Short and highly accelerated slugs are formed.

***Annular flow*:** Has thin annular film separating the walls of the tube and the gas phase of the bubble.

The flow patterns can be identified by the analysis of void fraction present. Many studies have been proposed to analyze the void fraction characteristics such as impedance measurements, pressure fluctuations, optical methods etc.. Among different methods proposed impedance technique proves to be the most reliable one due to its minimal dependence on both the external and internal factors. Also a high quality time series is necessary to observe the dynamics of the two-phase flows. Our main aim is to set up an appropriate apparatus to sketch out the complex dynamics of two-phase flows and to calculate the bubble velocity and diameter existing in two-phase flows.

II. PRINCIPLE OF OPERATION

This technique is based on the electrical impedance measurement between the two electrodes mounted in the test sample volume. Impedance of such mixtures two components (i) Resistive (ii) Capacitive and is represented as follows

$$Z = R + \left(\frac{i}{\omega c}\right)$$

Capacitance factor mainly depends on the geometric size and shape of the electrodes.

$$c = \epsilon A/d$$

To suppress the capacitive effect we apply an AC signal between the electrodes with a high frequency. So when $\omega \rightarrow \infty$ the impedance $Z = R$. AC signal is thus supplied to make the resistive point predominant and also it avoids the phenomenon of polarization and electrolysis. Thus it becomes

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easy to calculate only the resistance of the mixture. Conductance of the mixture (G) is given by

$$G = \left(\frac{1}{R}\right) \rightarrow \text{eq. 2.1}$$

Also

$$G = \left(\frac{A}{d}\right) \rightarrow \text{eq. 2.2}$$

Where A = effective area of the contact surface
d = distance between the two electrodes.

When the electrode gets immersed in the liquid phase, the circuit is closed (ON) and when in contact with gaseous phase, it is open (OFF) due to high impedance of the gaseous phase.

III. EXPERIMENTAL APPARATUS

The experimental apparatus consists of a pump connected to a reservoir. The flow is regulated up to 150 L/min by valves and bypasses. The two phase flow section is a 3m long vertical pipe of 0.26m diameter. A mixing section is employed to present the mixture in the pipe. Electromagnetic flow meter is used to measure the velocity and the mass flow rate of water. The conducting fluid taken is *brine solution* (conc. = 1.5 g/L). A constant temperature of about 22^{o}c is maintained. The air is supplied to the mixing section by a compressor. Two void fraction probes are at a distance of 5cm from each other, the lowest one at a distance of 2.40m from the mixing section. A pair of measuring electrodes has been setup. They are made up of gold-plated wires with a diameter of 0.6mm forming two half rings each facing one another and subtending an angle of 90˚ at the centre. A similar pair of guard electrodes has been placed at a distance of 1mm on either side; they are also maintained at the same potential as the measuring electrodes. Then the probes are connected to an electronic circuit and an appropriate data acquisition system.

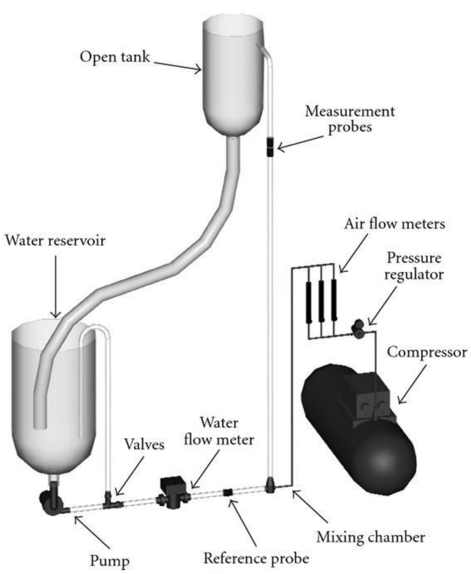

Fig.1 Experimental apparatus
(Source: Cantelli et al., 2006)

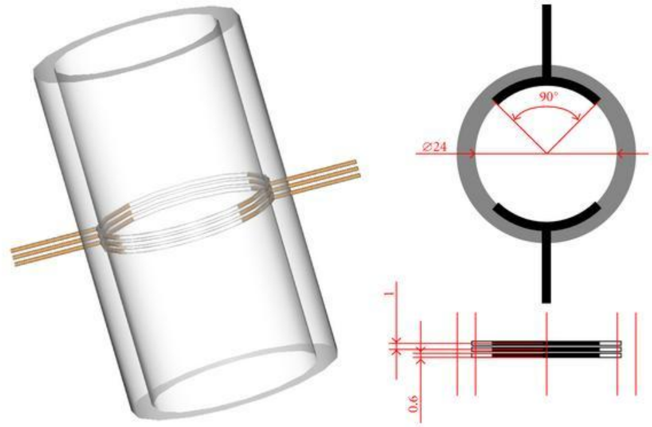

Fig.2 Probe electrode design
(Source: Cantelli et al., 2006)

Electronic circuit development:

The probe is being operated by supplying a frequency of 20 KHz. The elements for this purpose are

Generator: An XR 8038 IC was employed to generate a sinusoidal waveform. This IC has been selected because with less number of components used we can generate the desired waveform.

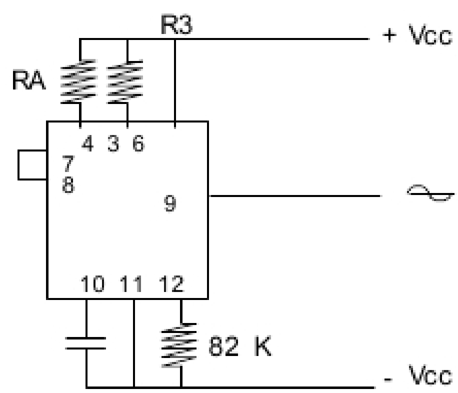

Fig.3 Structure of the generator for an AC signal
(Source: Sanchez et al., 1997)

The frequency of the waveform generated is given by

$$f = \frac{1}{\frac{5}{3} R_A C \left(1 + \frac{R_B}{2R_A + R_B}\right)}$$

Taking $R_A = R_B = R$

$$f = \frac{0.45}{RC}$$

Amplifier: The sinusoidal signal generated is amplified by using a amplifier as in fig.

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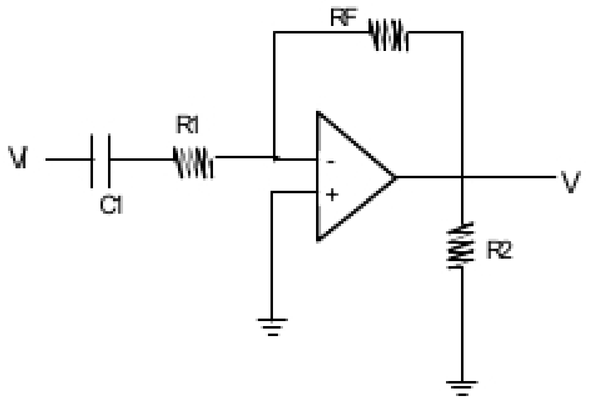


Fig.4 Amplifier for the probe signal (Source: Sanchez et al., 1997)

The characteristic of an amplifier is

$$V_{in} = KV_{out}$$

Where K= gain and is given by $\boldsymbol{R_f}$ / $\boldsymbol{R_i}$

Capacitor C_1 is employed to absorb the DC component generated by XR8038.

The principle used here is that a capacitor acts as an open circuit for a DC signal and as a short circuit for an AC signal of high frequency. Current that charges a capacitor is given by

$$i = C\frac{dV}{dt}$$

For a DC voltage source

$$\frac{dV}{dt} = \mathbf{0}$$

Thus the capacitor acts as a barrier for DC voltage sources.

Output calculations: A filter is taken (RC type) to find the output voltage. The switch does the job of transition of one phase to the other due to the electrical difference between the phases of the flow.

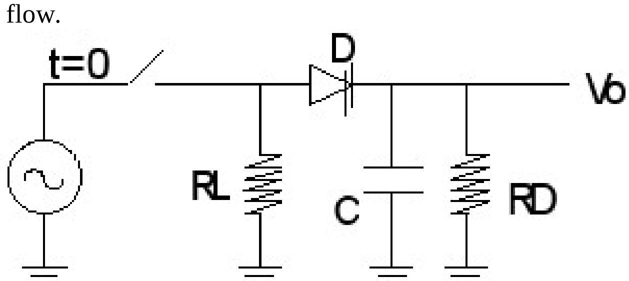


Fig.5 RC filter used for the bubble size probe (Source: Sanchez et al., 1997)

'V_L' is the voltage obtained after a drop in 'V_{in}' due to the presence of either of the two phases of the mixture.

By Kirchhoff's voltage law,

$$V_C = V_L - V_D$$

'V_D' is the diode umbral voltage

$$V_D \approx 0 \Rightarrow V_L = V_C$$

Let us assume that the switch is open, more precisely a bubble has slipped in between the electrodes

By Kirchhoff's current law, at the node immediately after the diode,

$$i_C + i_E = 0$$

$$C\frac{dV}{dt} + \frac{V}{R} = 0$$

$$V = V_C = V_L$$

$$\frac{dV}{dt} = -\frac{1}{RC}V$$

$$\frac{1}{V}\frac{dV}{dt} = -\frac{1}{RC}$$

Integrating on both sides

$$\int \frac{1}{V}\frac{dV}{dt} = \int \frac{-1}{RC}\,dt$$

$$\ln V(t) = \frac{-t}{RC} + K$$

$$V(t) = e^{\frac{-t}{RC}+K} = e^{\frac{-t}{RC}}e^{K}$$

Setting initial conditions that is at t=0,

$$V(0) = e^{K}$$

$$V(t) = V(0)\, e^{\frac{-t}{RC}}$$

V (0) is the initial voltage across the capacitor when the liquid phase was in contact with the electrodes. The capacitor thus gets charged up.

$$V(0) = \frac{q}{C}$$

q = Maximum charge the capacitor can hold
C = Capacitance

Hence plugging these values in the equation

$$V(t) = \frac{q}{C}\, e^{\frac{-t}{RC}}$$

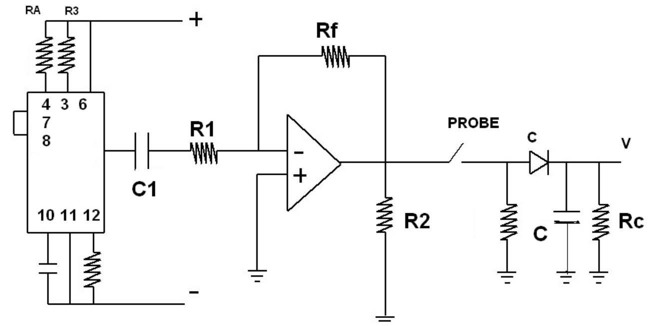
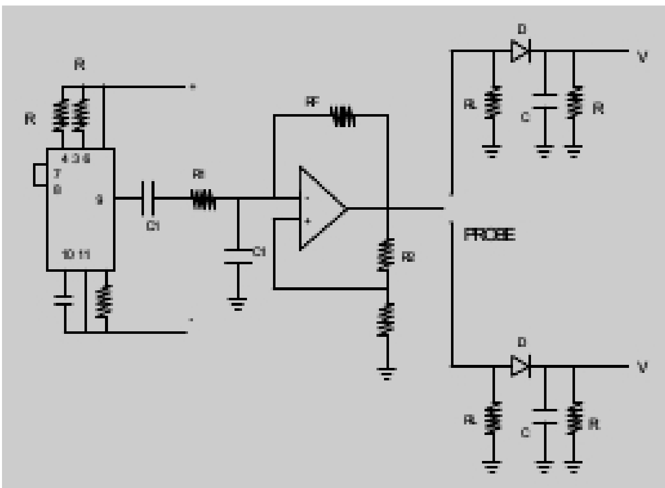


Fig.6 Electronic circuit for bubble size probe
(Source: Sanchez et al., 1997)



Fi g.7 Electronic circuit for bubble velocity probe
(Source: Sanchez et al., 1997)

Circuit for signal processing:

The following figure shows the required circuit development.

The instrumentation amplifier ensures high dynamic response and perfect decoupling of the electronic circuit from the measuring section. The gain can be varied by operating the input resistance value. A cut-off frequency of 200 Hz has been adopted in order to allow adequate removal of the input frequency and to avoid aliasing with the sampling frequency. The electronic circuit has been tested and calibrated with different proportions of the two-phases. The final output has been sent to a data acquisition system.

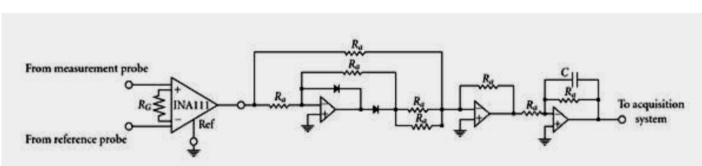


Fig.8 Electronic circuit for signal processing.
(Source: Cantelli et al.,2006)

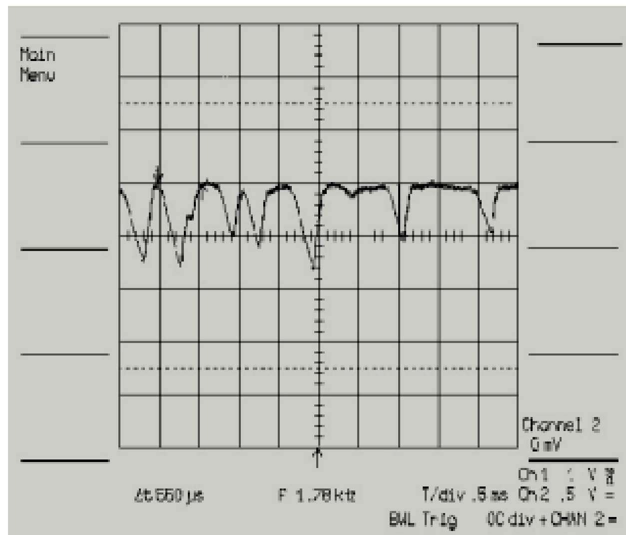
IV. Experimental Measurements

A series of experiments have been performed by alternating passage of air and water flow rates. The probe provides a voltage signal with amplitude determined by the characteristics of the conductive medium corresponding to the phases. The signal attains a maximum value for liquid phase and a minimum value for the gaseous phase. By observing the interruption time of the signal due to the presence of the bubbles. We can calculate the bubble diameter, assuming that the bubbles move with the liquid velocity.

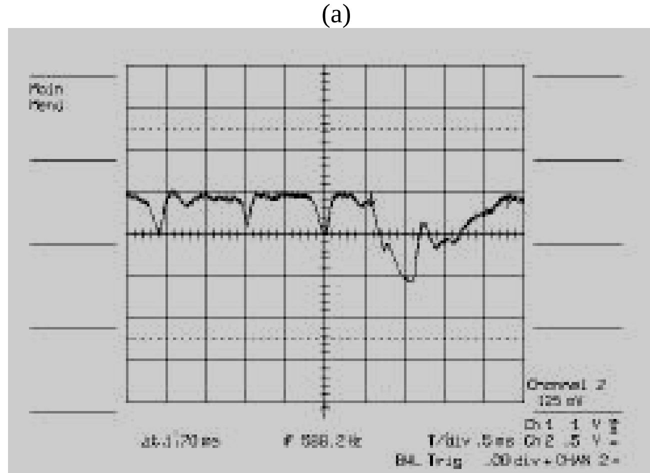
$$D_b = U_m \Delta t.$$

An important characteristic of the signal of the signal is that the signal is interrupted regularly when the bubbles are newly formed and interact with the electrode, a larger interruption time is observed when the bubble grow larger in size as in fig. The velocity has been found out through the evaluation of the delay in the cross correlation function between the time series measured by two probes placed at a known distance (5cm).

$$U_b = l/\Delta t$$



(a)



(b)

Fig.9 Typical time trace signal for (a) stable bubble flow and (b)for the transition to slug flow
(Source: Sanchez et al., 1997)

Bubble diameter plays a vital role in detecting the transition of one flow pattern to another. Fig 10 represents the bubble growth in a horizontal pipe when the superficial gas

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velocity was kept constant (U_{SG} = 10m/s) and the superficial liquid velocity was gradually increased from 4m/s to 6m/s. The figure shows a point where the bubbles grow suddenly and this point represents the transition trend of bubble flow to slug flow.

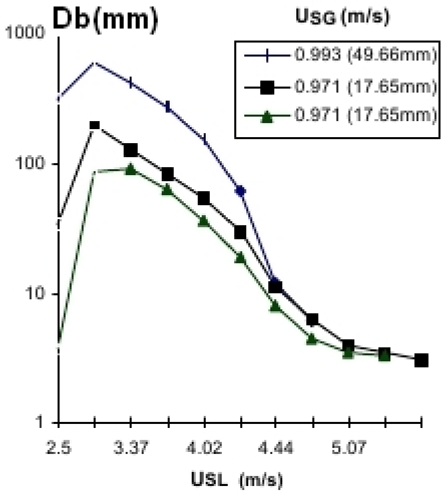
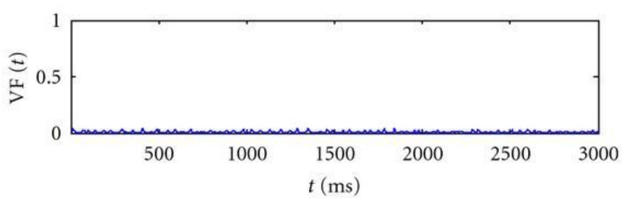
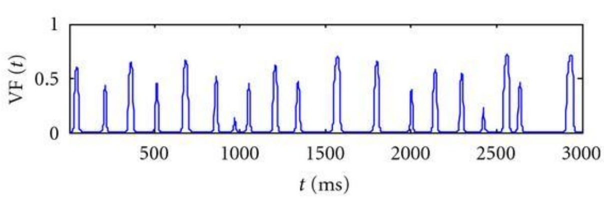


Fig.10 Transition of bubble flow to slug flow using bubble growth technique
(Source: Sanchez et al., 1997)

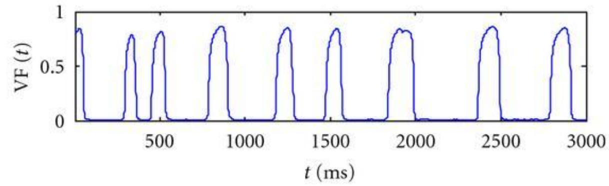
An important observation is that the quality of the time series has a substantial lack of noise. The dynamic behavior of the time series is being plotted in fig. all of the time series are characterized by the relevant amplitude and frequency differences between consecutive oscillations. This shows the non-periodic nature of the series.



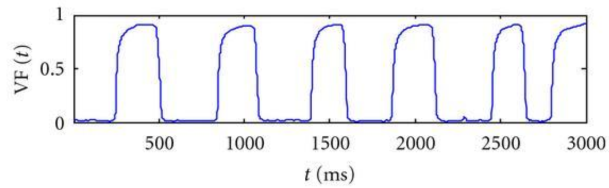
(a)



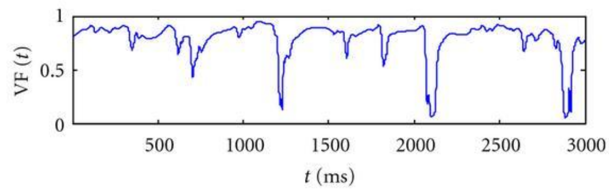
(b)



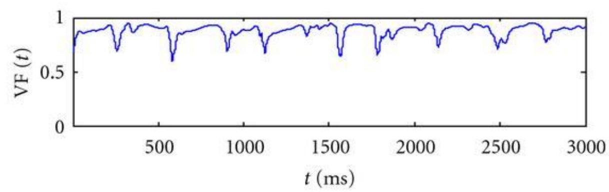
(c)



(d)



(e)



(f)

Fig.11 Void fraction time series for various flow patterns (a)Bubble flow (b)Cap flow (c)Slug flow (d)Plug flow (e)Churn flow (f)annular flow
(Source: Cantelli et al., 2006)

V. RESULTS AND DISCUSSIONS

The study deals with the design, construction and calibration of a conductance probe for the measurement of bubble velocity and bubble diameter. The apparatus was also used to analyze the void fraction time series of various flow patterns. Caution must be taken in analyzing the data to eliminate discrepancies. Suppose a bubble touches the first electrode but due to turbulence or change in flow direction it is unable to make contact with the second electrode, thus usage of adequate criteria to reject the signals not satisfying the acceptance conditions must be stressed upon. The geometrical shape of the electrodes too plays a major role in deciding the flow pattern. Rectangular or any other shaped electrodes with sharp edges should not be used as they may disturb the flow pattern and cause flow perturbation, circular electrodes are preferred because they do not alter the flow pattern. The probe is placed parallel to the flow else undesirable errors are encountered. The analysis of different flow patterns has also found coincidence in literature, representing a quality time series with least influences of noise from external sources.

VI. CONCLUSIONS

From our analysis, we could be able to conclude that the conductance method is effective and is recommended to be employed in experimental studies in order to get information about two-phase mixture behavior such as local void fraction, flow pattern transitions, local mixture flow behavior and size of particles.

The conductance transducer is the best suitable one for the measurement of bubble size (diameter), its velocity and characteristics. Conductance transducers are recommended in several industrial applications as they are easy to install and use.

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