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Experimental study of void fraction behaviour in vertical bubbly gas-liquid flow using conductivity and measurements

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EXPERIMENTAL STUDY OF VOID FRACTION BEHAVIOUR IN VERTICAL BUBBLY GAS-LIQUID FLOW USING CONDUCTIVITY AND MEASUREMENTS

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ABSTRACT

The void fraction is an important variable in describing gas-liquid two-phase flows, since it is required to predict the heat and mass transfer coefficients and the pressure drop and is an indicator of the flow regime. The contrast in conductivity between water and air is one way to measure the void fraction in gas-liquid flow. This project has examined use of the ring conductivity electrodes to measuring the void fraction in an up-flow bubble column. The conductivity method has potential to be a low cost, safe and accurate method of measuring local void fractions in pipes and other process engineering mass transfer devices. In this project, the void fraction was measured in an air-water system by using conductivity in a 2" pipe equipped with two ring electrodes. Further gas hold-up experiments were conducted in the annular channel formed between 2" and a 4" pipe, using a system of four pairs of electrodes. The data obtained from the experiments agreed fairly well with the Maxwell and Burggeman theories which relate the dimensionless conductance to the void fraction. The measured void fractions were correlated using the drift-flux model, as proposed by Zuber and Findlay. Significant differences were observed between the void fraction measurements obtained for the annular channel and for an empty pipe, when operated at the same gas superficial velocity.

Key Words: *Annulus, Gas hold-up, Gas-liquid flow, Ring electrode*

INTRODUCTION

There are many applications in the chemical and process industries for two-phase flow. Chemical engineers usually encounter this type of flow in transportation pipelines, evaporators, condensers and gas-liquid reactors. The difference in the conductivities of a solid, gas and liquid gives the opportunity to use this phenomenon for measuring the void fraction in two-phase flow. The measurement of void fractions

in two-phase flow by the conductivity method has been applied already in water treatment processing, the food industry, the oil industry and mineral processing.

Void fraction can be measured by several methods such from the pressure drop or using quick close valve. Ultrasonic and radiation methods, such as absorption of X-rays, have been used in many studies, e.g. Smith (1971) measured the void fraction by using an X-ray tube of 100 kV and Pike *et al*. (1995) who operated an X-ray tube at 45 kV by using a tungsten target, Kendoush and Sarkis (2001) used X-ray absorption of 30-100 kV. These published methods have a limitation with a void fraction up to 0.4.

The electromagnetic signal method is one of the easiest and cheapest methods. The methods depend on the measurement of the electrical conductance of the gas-liquid region close to a system of electrodes. The difference in impedance between the gases and liquids, which is measured by the electrodes, is related to the void fraction in the cross-sectional area of vertical two-phase flow pipe.

The impedance method has been carried out in many studies in different flow regimes with various methods: some used to use two electrodes and others used a grater number of electrodes. Conductivity probe was first proposed by Neal and Bankoff (1963). The theoretical behaviour of plate electrodes wetted by liquid is described by Coney (1973). Hewitt (1978) has presented a comprehensive review of using plate electrodes to measure the void fraction. Asali *et al* (1985) were the first researchers to use the ring electrodes, but the theoretical background such type of electrodes have developed by Tsochatzidis at al. (1992) and Andreussi *et al*. (1988). Fossa (1998) has compared plate and ring electrodes equipped in a pipe in annular flow regime. The performance of the plate electrodes was investigated under annular phase distribution for void fraction up to 0.2.

EXPERIMENTAL CONDUCTIVITY MEASUREMENTS

When ring electrodes are employed to determine the void fraction in uniformly dispersed two-phase flow conditions, the normalized conductance G_E^* is expected to be proportional to the apparent conductivity of the two-phase mixture G_E. Many expressions have been proposed for evaluating G_E as a function of the liquid conductivity G_L and the mean volumetric liquid fraction, H_L which equals to (1-α), where α is the void fraction. It can be expected that the dielectric constant or the conductivity of the liquid will follow the equations given by Maxwell (1881)

$$G_E = \frac{2H_L}{3 - H_L} G_L \tag{1}$$

And hence normalized conductance, G_E^*, is

$$G_E^* = \frac{G_E}{G_L} = \frac{2H_L}{3 - H_L} = \frac{2(1-\alpha)}{3-(1-\alpha)} \tag{2}$$

Bruggeman (1935) proposed an alternative expression for the normalized conductance

$$G_E^* = H_L^{3/2} = (1-\alpha)^{3/2} \tag{3}$$

In practice, for small values of α, eqs. (2) and (3) yield similar numerical values for the normalised conductance.

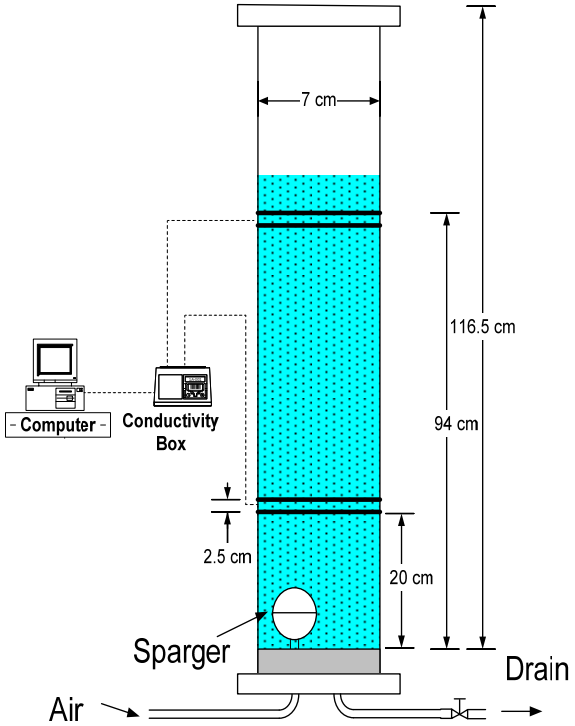


Figure 1 Flow diagram represents the Column with two electrodes, (Al-Anzi, 2007).

In the studies described here, two set of rigs have been used, 2.75" pipe with two pair of ring electrodes and 4" column with four pair of ring electrodes. The diagram in fig. 1 shows the 2.75" pipe rig. It consists of transparency plastic 2.75" pipe with approximately one meter height. The two pair of ring electrodes glued to the inner wall of the pipe. One of the ring electrodes, placed 20 cm from the bottom of the pipe and the other placed at 92 cm from the bottom. The distance between the pair of ring electrodes was carefully fixed at 2.5 cm. The two pair of ring electrodes connect to the conductivity box to convert the current signal produced from the ring electrodes to electronic signal passed to a computer with Picolog software to record the data. The rig also has a sparger to ensure the air introduced to the rig distributed uniformly along the pipe.

The 4" column (see fig. 2) consists of four sections of 4” diameter glass QVF tube, joined with flanges. A 2” diameter inner column was located concentrically, forming an annular gap into which gas introduced (the inner 2” column was sealed at the base, to prevent gas entering). The gas was supplied through a porous plastic sparger and was metered using a calibrated rotameter. The sparger had a permeability of 4.7 x10^{-14} m^2 and produced uniformly sized bubbles across the complete base area of the annular gap. The pressure in the rotameter was measured using a transducer and the rotameter

calibration was then corrected to give the flow rate of gas at the supply pressure and temperature. Hence the superficial velocity of the gas in the column could be calculated.

Each pair of ring electrodes glued to the internal wall surface of the column using silicon sealant; the wiring for each pair of electrodes left the column through short nylon section, which were sandwiched between the QVF glass sections and sealed against the pipe flanges. Four pairs of electrodes were used to measure the void fraction at four axial positions along the column. One pairs of electrodes was placed in the bottom of the column near to the source of the bubbles. Another electrode was placed in the top of the column near to the liquid surface when the bubbles become larger due to coalescence. The remaining two pairs of electrodes were located in the centre of the column, as shown in Fig1.

The pairs of electrodes are connected to a multi-channel conductivity box; each channel produces a DC voltage output which is proportional to the measured conductance in the volume between the ring electrodes. These voltages were logged by a PC, for later analysis and averaging.

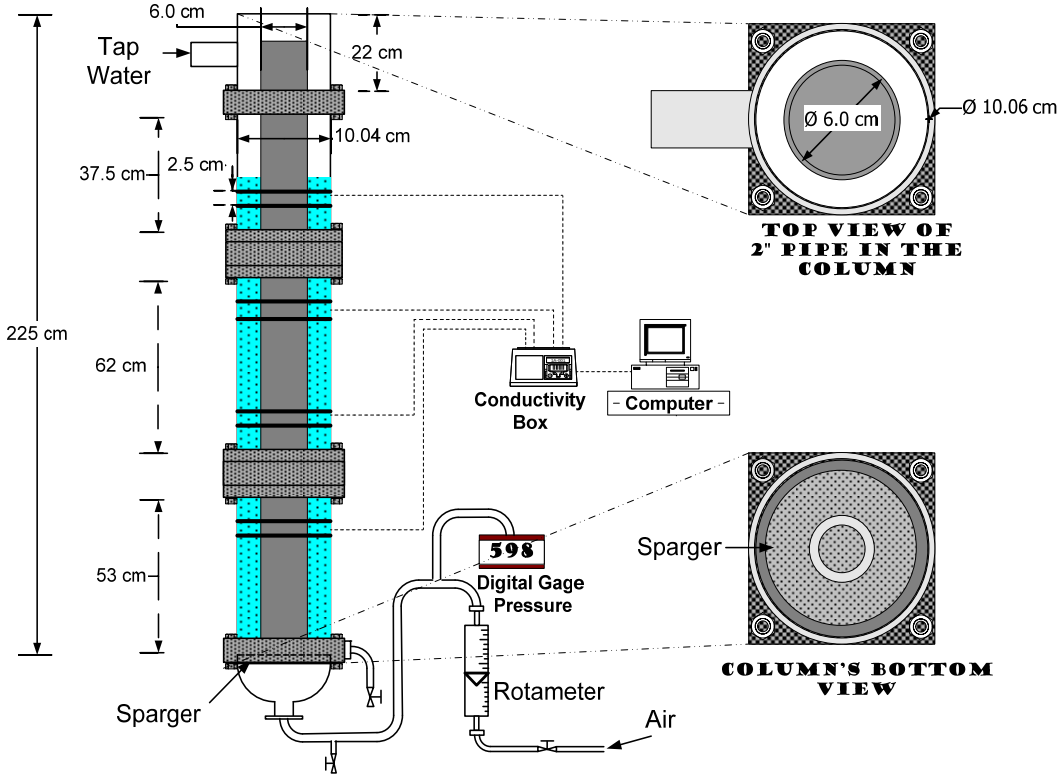


Figure 2 Schematic drawing of the experiments rig; 4" column with 2" tube, Column's top and Bottom views, the electrodes connections and air supply equipments.

DRIFT FLUX MODELLING OF THE VOID FRACTION

One of the models used to calculate void fraction is the drift flux model which has been principally developed by Zuber and Findlay (1965); it has been refined since that time by Zuber and co-workers. It provides the starting point for most of the void correlations. In the drift-flux model the void fraction α is a function of bubble terminal rise velocity, v_t , the gas and liquid superficial velocities and a phase distribution

parameter C_0. In the experiments conducted here, there is no flow of liquid, and hence the gas superficial velocity, $u_{sg,}$ is the main independent variable.

The void fraction, α for vertical up-flow can be expressed using Zuber and Findlay's model

$$\alpha = \frac{u_{sg}}{C_0 u_{sg} + v_t} \tag{4}$$

where C_0 is the distribution parameter defined by

$$C_0 = \frac{<\alpha Q>}{<\alpha><Q>} \tag{5}$$

and Q is the volumetric flux of the phase flow. The <…> symbols represent averages taken over a horizontal section. Although there is no net liquid flow in the batch bubble column studied here, there will be a liquid velocity profile, which is expected to be upwards in the centre of the annular channel and downwards at the walls. Moreover, there is likely to be void fraction profile across any horizontal section of the column. Eq.(5) shows that changing the flow geometry (for example, changing from an empty column to an annular channel, or changing the ratio of inside diameter to outside diameter for the annular gap), could affect the distribution parameter C_0 and hence would change the relationship between the void fraction and the gas superficial velocity, as represented by eq.(4). An objective of the current study is to examine the effects of the geometry of the annular channel on this relationship between the gas void fraction and the gas superficial velocity.

RESULTS AND DISCUSSION

At zero void fraction (pure water) the measured conductance was a maximum and the corresponding voltage signal was V_0. With increasing gas void fraction, the voltage, V, decreased. The relationship between $\Delta V=V_0 - V$ and the void fraction has been plotted for a pair of the ring electrodes. This method was chosen to plot the graph to avoid any errors that may caused by surrounding factors that affect the readings such as water temperature, physical and chemical changes that may occur to water properties during the experiments from the current that applied on the water from the electrode and the errors that may occur from taking the readings. The points should form an approximately straight line which passes through the original; some of the points deviate from the line due to the noise that occurs around electrodes at high void fraction. The ring electrode is very sensitive at high void fraction, as many other studies have proved.

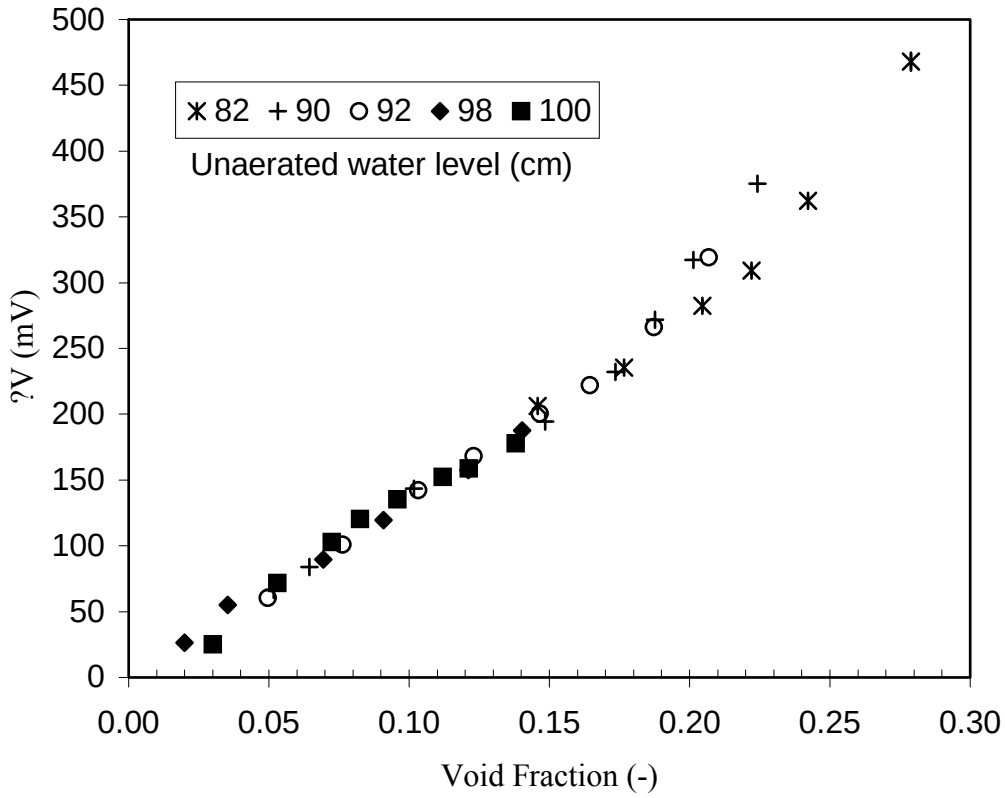


Figure 3 The approximately linear relationship between ΔV and void fraction for different initial (unaerated) water level (cm).

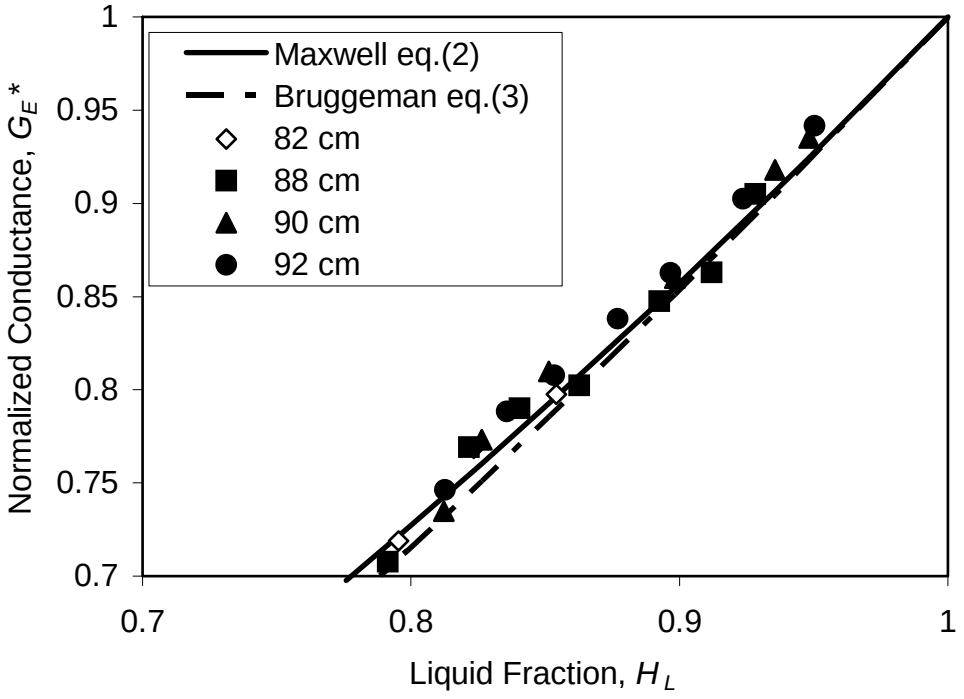


Figure 4 Measured and Predicted Dimensionless Conductance as a Function of the Liquid Fraction and the Liquid Height using Ring Electrodes.

Maxwell and Bruggeman theories suggest that, the highest value of the normalized conductance should be when the void fraction equal to zero (pure water); $G_E^*=V/V_0$ should then fall with increasing void fraction, or decreasing liquid volume fraction, H_L. The results in fig. 3 show good agreement with both Maxwell and Bruggeman theories. Over the range of $0.8<H_L<1$ (i.e. for $\alpha<0.2$), there is only a very small difference between the predictions of eqs. (2) and (3) and both are in close agreement with the measured $G_E^*=V/V_0$. The latter is equivalent to the usual definition of $G_E^*=G_E / G_L$, since in both cases the voltage is proportional to the conductance.

The conductivity experiments carried out in the four ring electrode show exactly the same results that obtained from the rig with two electrodes above. The results also show that the void fraction profile doesn't change along the pipe which means there is no need to have four electrodes along the pipe as proved by the results obtained from gas hold-up experiments, fig.5.

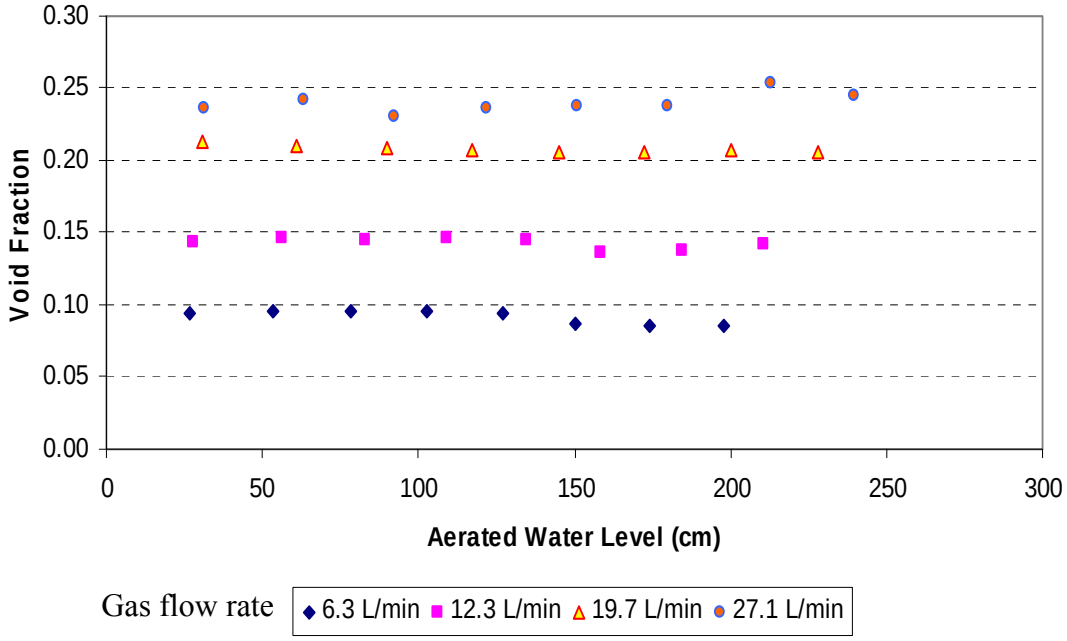


Figure 5 Relationship between void fraction and aerated water level at constant gas flow rate in the empty 4" diameter column.

Fig. 4 shows the results obtained using different gas flow rates in the empty 4" diameter pipe over a range of unaerated liquid levels. The purpose of these experiments was to see if liquid level would affect the void fraction, α, indicating end effects on the two-phase flow. Note however, that changing the liquid level changes the hydrostatic pressure at the base of the column. In turn this affects pressure in the rotameter; hence it is important to correct the calibration for this effect to maintain a constant gas flowrate, whilst varying the liquid level. The results from figure 4 do not show a large effect of unaerated liquid height, indicating that for column aspect ratios greater than about 5 the end effects become negligible.

Figure 5 shows that the void fraction for the two conditions (empty 4" column and 4" column with 2" tube) at the same gas superficial velocity. The measured void fraction close to the predicted void fraction and the points fit in the solid line. The prediction

void fraction obtained from Zuber and Findlay equation (eq.1) at distribution parameter C_0 of 1.2 and rise velocity v_t = 1.1 m/s.

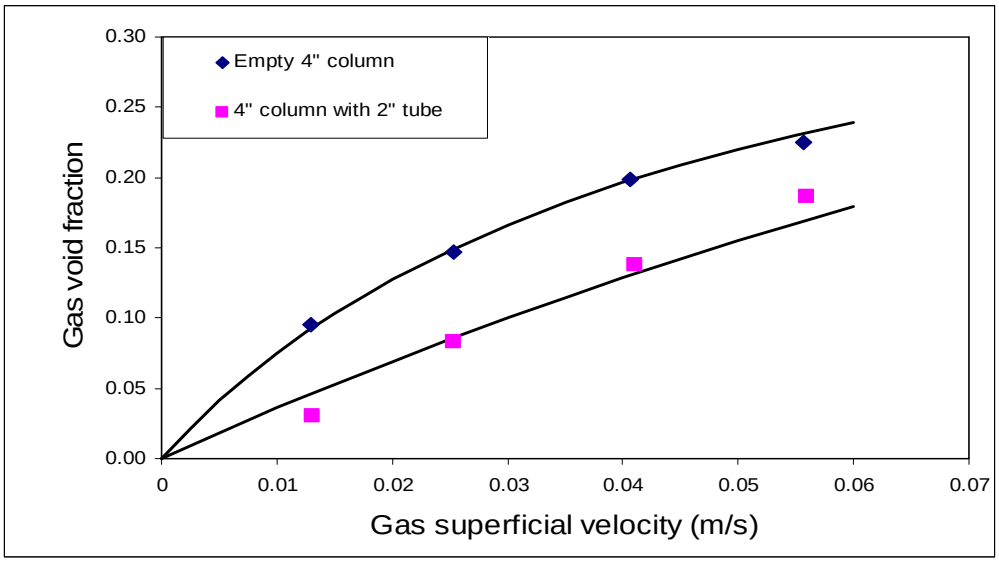


Figure 6 Drift flux model in the experiments obtained from the two conditions.

Clearly there is a different relationship between α and u_{sg}, yet figure 6 shows that the drift-flux model is able to predict both sets of results equally well. The void fraction is plotted as a function of the superficial velocity in empty 4" column and 4" with 2" tube. The experiments done at constant superficial velocity in both conditions, so each point represents different airflow rates in the two column configurations. The solid line predicted from drift flux model, the graph shows coincidence with the theoretical equation and data obtained from the experiments. The points well fit with drift model when the distribution parameters, C_0 is assumed to be 1.12 and the rise velocity v_t is equal to 0.11 m/s. At the same gas superficial velocity, the void fraction in empty 4" column is more than in 4" with 2" tube. This is due to the flow area relationship between the two conditions. The 2" tube occupies 35 % of the area inside 4" column. This also can be applied in the airflow needed to achieve the desired gas superficial velocity.

CONCLUSION

The impedance method can be very effective in determining the void fraction in two-phase flow. Good measurement repeatability and general feasibility for ring electrodes were confirmed particularly when the electrodes normalized with pure water. There is an inverse relation between void fraction and conductivity and proportion with the difference of conductivity (water and aerated water). The measured average void fraction compares favourably with data in the literature. The results obtained from this project showed that theory developed by Maxwell (1881) and Bruggeman (1935) for dispersed flows can easily be adapted to describe the electrical behaviour of the ring electrodes analysed in this project. The results show that there was no α profile in the column, hence there isn't really any need for a number of pairs of electrodes. They should all measure about the same α.

The sensitivity of the drift-flux methods has been investigated in the liquid level experiments, which are carried out in vertical upward bubbly pipe flow. The

experimental data showed that, there is good agreement between measured void fraction and the predicted void fraction obtained from Zuber and Findley (1965) equation. The liquid height does not affect in void fraction, so long on the actual airflow remains constant. The airflow was correlated through all the experiments to avoid the errors that may effect on the results.

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NOMENCLATURE

G_E	Conductivity of the mixture, S
G_L	Conductivity of pure liquid, S
G_E^*	Normalized conductance
H_L	Volume fraction occupied by the liquid
α	Void fraction
C_0	Phase distribution parameter
u_{sg}	Superficial velocity of gas, m/s
v_t	Rise velocity, m/s
Q	Volumetric flux of the phase flow, m^3/s

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