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DESTABILISATION OF A HOMOGENEOUS BUBBLY FLOW IN AN ANNULAR GAP BUBBLE COLUMN

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Abstract: Experiments have been conducted to measure gas void fractions, α, in vertical upward, two-phase flows contained within the annular gap between two concentric tubes. A porous sparger was used, which would normally have produced a homogeneous bubbly flow at low gas superficial velocities, j_g, in an open tube. For a given j_g, α in the annular gap was found to decrease as the diameter ratio of the two tubes approached unity (*i.e.* for narrower gaps). Moreover, α could be significantly lower than that obtained in an open tube at the same j_g. Two proposed explanations were that, within the annular region, (i) large bubbles were generated which destabilised the flow, and (ii) α distribution parameter C_0, in open tube was different to that in an annular gap, which results in a different mean α. To investigate this phenomenon, further experiments in an open tube were conducted in which a small

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orifice was drilled in the centre of the plastic sparger. This orifice produced a stream of large bubbles that rose rapidly through the smaller bubbles produced by the porous sparger. The effects of the orifice diameter on the gas α and two-phase flow regime were studied using a two-needle conductivity probe to obtain measurements of the local α, bubble size and velocity distributions. For the largest orifice diameter used (3 mm), the flow was heterogeneous at very low j_g, showing that a single stream of injected bubbles were capable of destabilising the homogeneous bubbly flow produced by the porous sparger.

Keywords: local void fraction, void fraction profile, orifice, drift flux method, dual conductivity probe.

1. INTRODUCTION

Two-phase flow is of interest in a wide variety of industrial processes. An important variable in two-phase flow is the void fraction, α, which is used to define both the occurrence of two-phase flow, and the prediction of process pressure drop and heat transfer coefficient. These factors are crucial in the design of industrial process units, e.g. bubble column reactors, aeration tanks, and gas-liquid reactors, etc. Two-phase gas-liquid flow is a vital phenomenon that is harnessed in numerous forms within the chemical and process industry. It is commonly found in evaporators, condensers, and gas-liquid reactors. Moreover, the applications involves cases where gas is bubbled through reacting liquids to control temperature, in nucleate and other boiling regimes,

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as well as in steam production, and wastewater aeration (Coulson and Richardson, 1999). Typically, two-phase flow behaviour drives the design of related process components. Slow chemical process reactions such as oxidation, chlorination, alkylation and many others, which are utilised in the chemical and bio-technological industries, commonly use gas-liquid bubble columns. These columns possess numerous advantages in terms of their simplicity, absence of mechanical moving parts, as well as efficient heat and mass transfer properties, when compared to other types of multiphase reactors (Vijayan et al, 2007). Two-phase liquid-gas flow is distinguished by being of great utility, yet is an area of significant difficulty. This is due to the complexity of the flow patterns of the two fluid phases within the containing component, pipe or otherwise. A number of factors, e.g. internal dimensions of the pipe work, fluid physical properties, flow rates or superficial velocity, exert considerable influence and determine the flow regime.

In bubble columns with no liquid flow, three basic flow regimes occur: the homogeneous, the heterogeneous and the transition regimes, Deckwer, (1992), Kastanek et al., (1993), Molerus, (1993), Zahradnik et al., (1997). The homogeneous regime is known as the dispersed, uniform, bubbly flow regime. As the coalescence of bubbles increases large bubbles form and this leads to the heterogeneous regime.

For such system, the drift-flux model was proposed by Zuber and Findlay (1964). This popular model predicts gas hold-up over a range of two-phase flow regimes. It may be written as

$$\alpha = \frac{j_g}{C_0 j_g + v_t} \qquad (1)$$

The model contains two adjustable parameters, the single bubble rise velocity, v_t and the distribution coefficient, C_0. The model has been fitted to the experimental data sets for (i) open tube and (ii) the annular column, figure 1. It shows a comparison between the gas hold-up in an open tube and annular gap column, at the same j_g. At low gas flow rates in the open tube column, uniformly sized bubbles were generated by the sparger. As the gas flow rates increased, the bubble concentration increased inside the column—the flow remained homogeneous. At j_g of about 0.12 m/s, the bubbles reached a maximum concentration at $\alpha = 0.4$ and then start to coalesce. With increasing jg, the transition from homogeneous to heterogeneous flow occurs and α falls.

The results obtained from the annular gap column show that at low j_g, small bubbles were produced. Increasing j_g caused these bubbles to merge and form bigger bubbles which destabilised the flow.

For annular channels, Griffith (1964); Hasan and Kabir (1988a,b); Kelessidis and Dukler (1989); Hasan and Kabir (1991) experimentally verified the theoretical contention of Radovich and Moissis (1962). This holds that α, of about 0.25 in vertical pipes triggers the transition from bubbly to slug flow.

Figure 1

2. EXPERIMENTAL

2.1   *Open tube and annual gap rig set up*

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The experimental set-up is illustrated in Fig. 2. The column consists of a vertical 10.2 cm internal diameter (i.d.) pipe made of transparent QVF® glass with a height of about 225 cm. The column is equipped with an appropriate rotameter and digital pressure gauge; a pressure correction was made to the rotameter reading. Compressed air was injected through a sintered plastic sparger, with a 10 cm diameter and a permeability of 5.3×10^{-14} m^2, installed at the bottom of the column. The sparger produced a uniform distribution of bubbles and no large bubbles and slugs were observed moving up the empty column, at low j_g.

Annular gap experiments were conducted by using different inner tube sizes placed concentrically in the column, 2.5, 3.8, 5.1, 7.0 and 7.6 cm (o.d.) tubes denoted as 1, 1.5, 2, 2.75 and 3 inch respectively. The purpose of these experiments was to study the transition (from homogeneous to heterogeneous flow) occurring in air-water systems. The experiments were conducted at the same j_g that were used in open tube. The annular gap has a smaller cross-sectional area than the open tube, hence the gas flow rates were adjusted appropriately.

Figure 2

Overall gas hold-ups (averages for the whole column) were obtained by recording the volume change on aeration at a given j_g, Δ volume method:

$$< \alpha > = \frac{volume\ of\ gas}{volume\ of\ (gas\ +\ liquid)} \qquad (2)$$

2.2   Probe design and dimensions

The impedance method, using one or more electrodes, is a popular method that has been used under different two-phase flow regimes by many researchers. The electrical conductance of the gas-liquid region surrounding the electrodes is measured. The relationship between α and the difference in impedance between the gases and liquids in two-phase flow, as measured by the electrodes, is exploited in this method. Employing a single resistivity probe, Angeli & Hewitt (1999) and Julia *et al.* (2005), measured the α in gas-liquid flow. However, the bubble velocity, α and bubble size in two-phase experiments may also be measured using a double sensor probe.

Fig. 3 illustrates the conductivity probe which consists of two electrodes that produce a weak current and measures the resistance of the solution to the passing of the current, which is proportional to the number of electrons that run between the electrodes. An alternating current is used to prevent electrolysis. The sensing stainless steel needle of the probe was electrically insulated and made non-wetting and non-conductive by the application of a varnish except at the needle tip. This needle tip was able to pierce, with minimum deformation, the fast-moving small bubbles at the point of impact, leading to a fast signal response to sense a local bubble interface. The probe operated like an electrical switch: when the tip was in contact with the liquid phase—closed circuit—and gas phase—open circuit. The tip reacts as live (+ve) current and the case as earth (-ve) in this circuit. Depending on the bubble sizes in a two-phase flow system, a suitable axial distance, around 5 mm, between the two

needle tips was selected to measure the size and velocity of bubbles with reasonable accuracy.

The conductivity probe signals were digitally processed to yield local α measurements; the distribution of α was obtained by traversing the probe across the column diameter, or radially along the annular gap. Mean α were obtained by volume-averaging the local α profiles.

3. RESULTS AND DISCUSSION

3.1 *Mean void fraction,* α

A comparison between the gas hold-up in open tube and in different annular gap is illustrated in Fig. 4. Both volume variation and conductivity probe methods confirm that the α in the open tube is high compared to annular gap. This is either because large bubbles have been generated in the annular gap, which led to heterogeneous flow, or α profile has changed — the latter would affect the distribution parameter, C_0, in Zuber and Findlay's (1965) drift-flux model. The geometry of the annular gap also affects the mean α: Fig. 4 shows that when the inner tube size increases, then a lower mean α results.

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The first mechanism by which the mean α might be lowered in an annular gap column was investigated, namely that the formation of large bubbles might destabilise the flow and force an early transition to the heterogeneous regime. A single orifice with a diameter between 0.6 – 3 mm was drilled in the centre of the porous sparger, generating a stream of large bubbles in the empty bubble column geometry. Fig. 5 a) and b) represent the results obtained from volume change and electrode methods respectively; for the latter, mean α were obtained by volume-averaging the local α distributions. From Fig. 5, the conductivity probe mean α agree fairly well with the volume variation results. Any discrepancies are due to (i) the volume change method measures the mean α over the whole bed, whilst the conductivity probe averages over a horizontal plane, assuming axisymmetry and (ii) some small bubbles may bypass the conductivity probe. In the open tube normal sparger (NS results), it was observed that at low j_g small and uniform bubbles, in homogeneous flow, were generated by the sintered plastic sparger which had no orifice. When the sintered plastic sparger was drilled with a small hole size diameter e.g. 0.6 mm, it was expected to generate large bubbles, which should destabilise the homogeneous flow, however, this expected scenario actually did not occur in these experiments; the small orifice diameter did not generate large enough bubbles to disturb the homogeneous flow (data not shown). The literature suggests that the orifice size has to be greater than 1 mm to generate heterogeneous flow at all j_g. The effect of large bubble generation from the orifice starts to take place at a diameter of 2 mm; these bubbles should rise much faster than the smaller spherical bubbles produced by the sintered sparger. The results show that large orifice size generates large bubbles which destabilise the homogeneous flow.

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Figure 5

Zuber and Hench (1962) carried out experiments at the same values of overall flow rates with a range of perforated plates as air dispersers; see table 1. From their experiments, as the hole size in the gas distributor plate decreased, higher gas hold-ups were generated, forming a homogeneous regime. So the orifice diameter plays a role in determining the gas hold-up, by destabilization of the homogeneous regime. The present results agreed with Zuber and Hench's (1962) results, as the sintered plastic sparger generated small and uniform bubbles (homogeneous regime) with high gas hold-up, behaving in the same way as the minimum orifice diameter, 289, used by Zuber and Hench (1962). On the other hand, as the orifice diameter increased, the flow tends to form a heterogeneous regime. Fig. 6 presents the current study results compared to Zuber and Hench's (1962) results. Large orifice would generate large bubbles, which rose much faster than the smaller spherical bubbles produced by the sintered sparger. These large bubbles would sweep the smaller bubbles into their wake, causing coalescence and hence transition to the heterogeneous regime occurs.

Table 1 Gas distributor configurations used by Zuber and Hench (1962)

No. of orifices	Diameter (mm)	Square array spacing (mm)
1	4.06	-
49	4.06	6.25
100	1.52	9.5

| | 289 | 0.41 | 6.25 |

3.2   Void fraction Profile

Fig. 7 represents the relationship between the local α and radial position in the column at different j_g for the open tube_NS. At low j_g the results show almost uniform α distributions across the column. However, most of the bubbles tend to travel in the centre of the column at high j_g and few bubbles travel towards the wall. This can be noticed from the local α distribution.

Figure 6

Figure 7

The void fraction profiles with respect to electrode radial position in an annular gap column are represented in Fig. 8. Void fraction profile in annular gap behaves slightly different than in open tube, since the inner tube placed at the centre of the column, bubbles tend to travel through faster region (at around r = 0.03 m). However, the local α becomes small at the inner tube wall for low j_g..

Figure 8

4.   CONCLUSIONS

Two main effects have been considered in this study, which reduce α in annular gap columns compared to empty bubble columns, at the same j_g destabilisation of the homogeneous flow by large, fast rising bubbles and changes to α profile, which affects the distribution parameter C_0 in the drift-flux model. Separate experiments confirm that bubbles formed from a large diameter orifice (> 2 mm) orifice reduce the mean α by destabilising the homogeneous flow. The present results also agreed with Zuber and Hench's (1962) findings, who found lower mean α when using large orifice diameter spargers. Void fraction, α distribution results also showed that the profile shape was not constant and varied with both j_g and the annular gap geometry.

NOMENCLATURE

Notations

C_0 distribution parameter

j_g Gas superficial velocity, m/s

v_t Rise velocity, m/s

Greek letter
α   void fraction
Abbrevation
NS   Normal sparger which has no orifice

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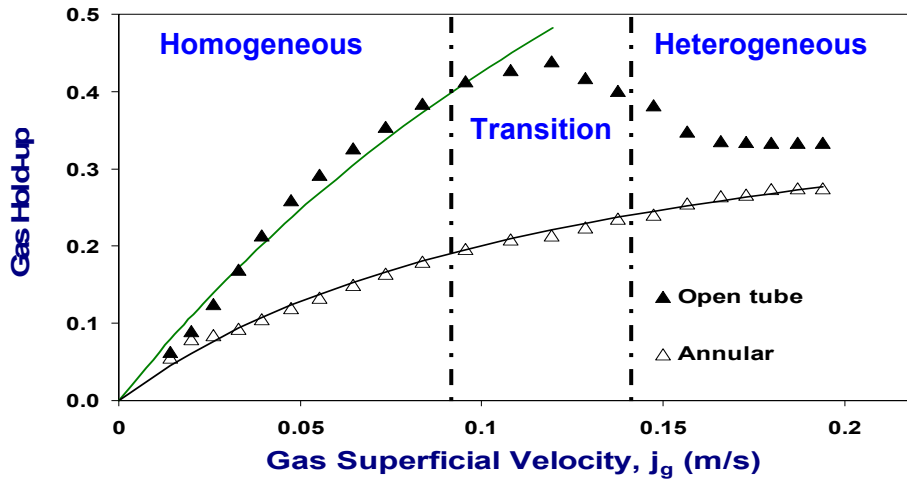
Fig. 1 Gas hold-up behaviour in open tube and annular gap for completeness, state that this is air – tap water and gives the inner diameter of the outer column and the outer diameter of the inner (concentric) column. Gas α obtained from change of level in the bubble column on aeration.
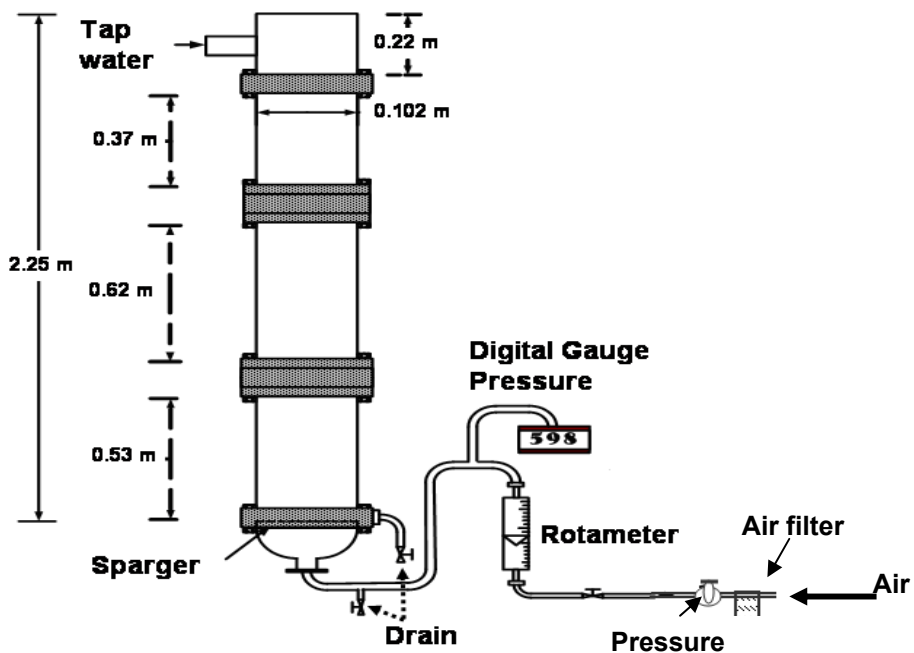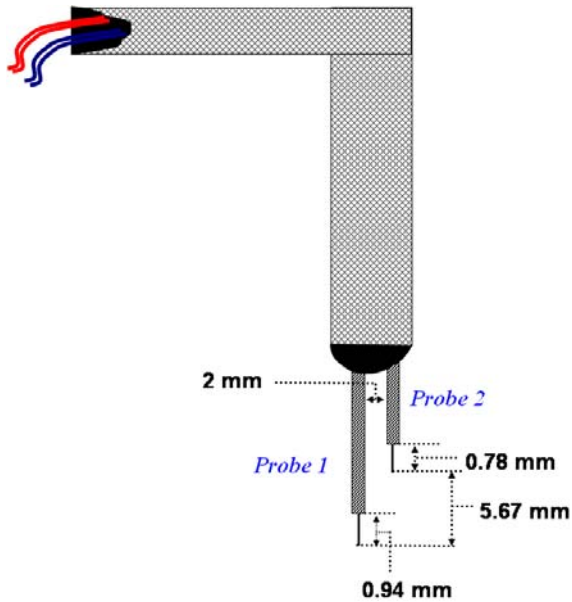
Fig. 2 Experimental set-up
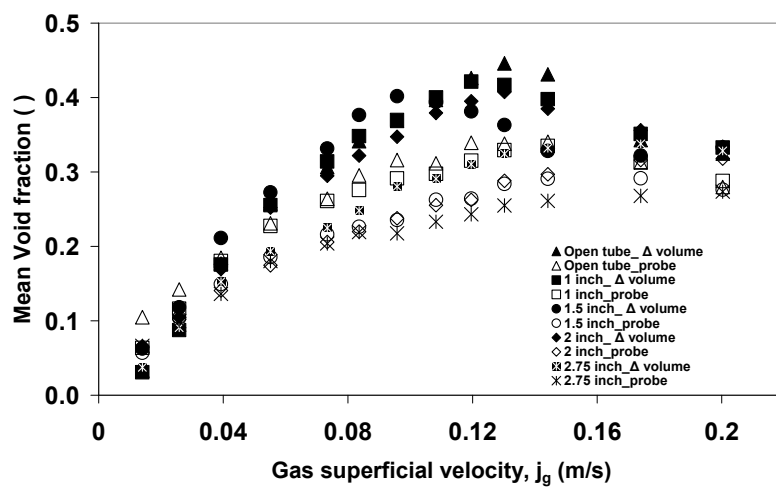

Fig. 3 Design and geometry of the two-point

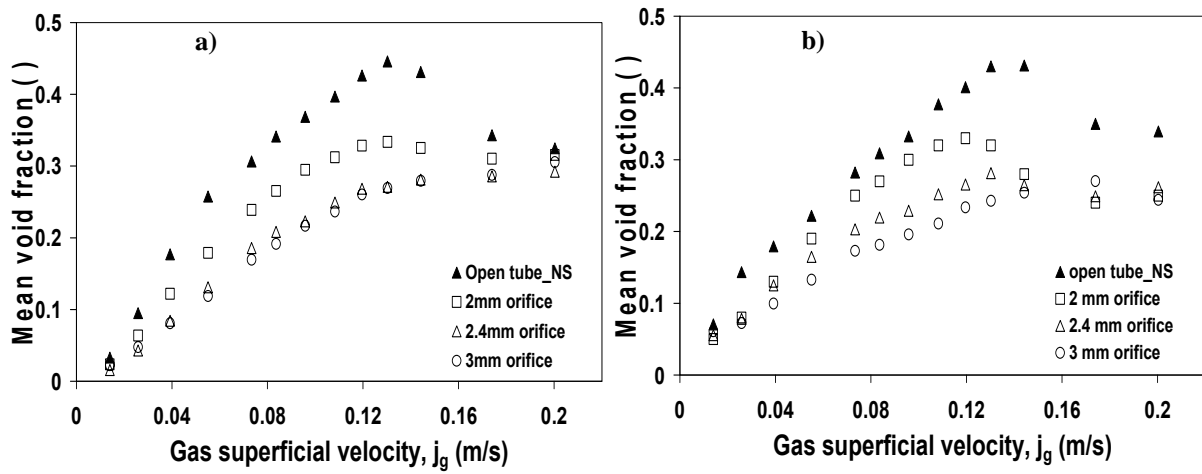Fig. 4 Mean α in annular gap compared to the open tube results

Fig. 5 Mean α with respect to j_g, comparison between plastic sparger "no orifice" (NS) and plastic sparger with different orifice sizes; a) Δ volume method, b) conductivity probe method.
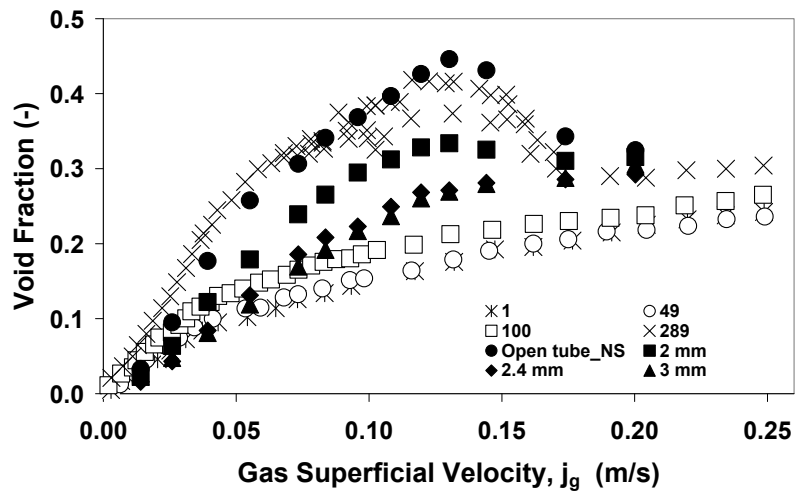

Fig. 6. Mean α for normal sparger (NS) and spargers with different orifice hole sizes; comparisons with Zuber and Hench's (1962) results (see table 1)
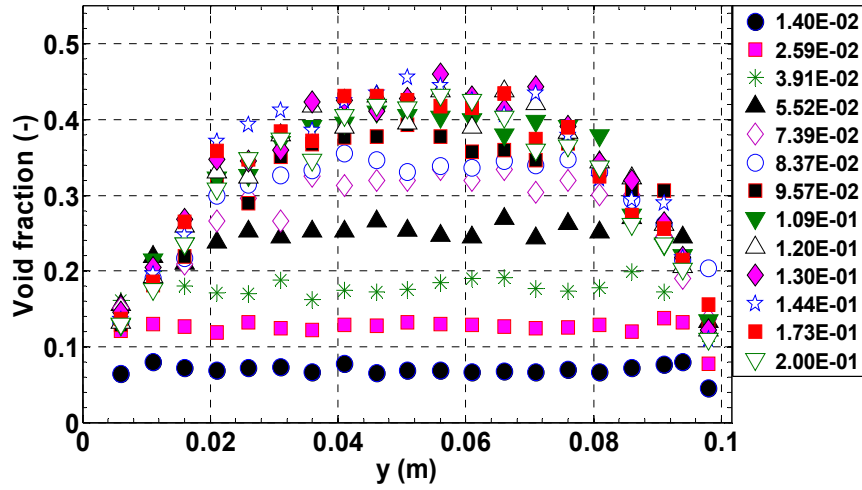
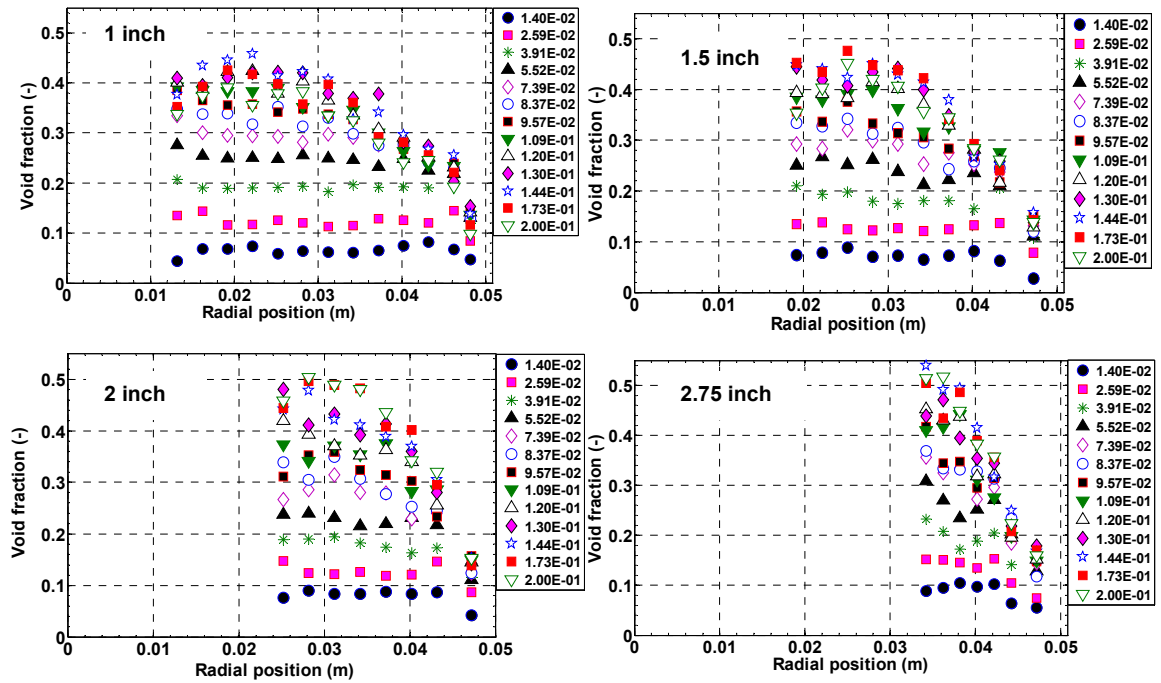Fig. 7. α profile for open tube-NS at different j_g.

Fig. 8 Void fraction profile respect to radial position for annular gap, different inner tube sizes.