HEFAT2010
7th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
19-21 July 2010
Antalya, Turkey

PHASE DISTRIBUTIONS OF AN AIR-SILICONE OIL MIXTURE IN A VERTICAL RISER

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ABSTRACT

This study is concerned primarily with the phase distributions of gas-liquid multiphase flows experienced in a vertical riser. Scale experiments were carried out using a mixture of air and silicone oil in 6 m long riser pipe with an internal diameter pipe of 67 mm. A series of pipe flow experiments were performed for a range of injected superficial air velocities over the range 0.047 to 2.836 m/ s, whilst maintaining the liquid superficial velocity of 0.047 m/ s. Measurements of radial time averaged void fractions across a pipe section located 5.15 m from the pipe flow injection were obtained using a capacitance wire mesh sensor (WMS). The data were recorded at a frequency of 1000 Hz over an interval of 60 seconds.

A comparison of the experimental data was performed against the mathematical model derived by [7] and used by [12] to investigate the flow structure of air - water mixtures in vertical risers:

$$\varepsilon_G = \bar{\varepsilon}\left(\frac{n+2}{n+2-2c}\right)\left(1-c\left(\frac{r}{R}\right)^n\right) \qquad (3)$$

It was concluded that, the [11] model was able to satisfactorily replicate the observed radial void fraction profile (mean relative error is within 5.7 %) at the higher gas superficial velocities.

It was found that the void fraction was strongly affected by the superficial gas velocity, whereby the higher the superficial gas velocity, the higher was the observed average void fraction.

Reasonably symmetric profiles were obtained when the air-silicone oil was fully developed, and the shape of the symmetry profile was strongly dependent on superficial gas velocity.

INTRODUCTION

Nassos and Bankoff [9] studied the slip velocity ratios in an air-water system under steady state and transient conditions. They proposed the following equation for the radial holdup profile

$$\varepsilon_G = \tilde{\varepsilon}\left(\frac{n+2}{n}\right)\left(1-\left(\frac{r}{R}\right)^n\right) \qquad (1)$$

where,
$\tilde{\varepsilon}$ is the radial chordal average gas holdup along the column diameter and the exponent n are parameters and $\frac{r}{R}$ is the dimensionless radial position. The value of n is indicative of the steepness of the holdup profile. When n is large the profile is flat, for small n the profile is steep. The steepness of the holdup profile is reflected in the intensity of liquid circulation. Later, [11] modified equation (1) as follows to include the possibility of finite gas holdup close to the wall

$$\varepsilon_G = \tilde{\varepsilon}\left(\frac{n+2}{n}\right)\left(1-c\left(\frac{r}{R}\right)^n\right) \qquad (2)$$

where,
c is an additional parameter which is indicative of the value of gas holdup near the wall. If c = 1 there is zero holdup close to the wall, if c = 0 holdup is constant with changing $\frac{r}{R}$.

Wu et al. [12] carried out work on predictions of radial gas holdup profiles in bubble column reactions using air and water as the operating fluid, employing gamma ray Computed

Tomography (CT). They used the following equation originally proposed by [7] for the radial holdup profile

$$\varepsilon_G = \bar{\varepsilon}\left(\frac{n+2}{n+2-2c}\right)\left(1-c\left(\frac{r}{R}\right)^n\right) \qquad (3)$$

Wu et al. [11] developed correlations for evaluating n and c based on the knowledge of the general operating variables and physical operating variables and physical properties of the system in order to estimate the gas holdup profile by equation (3). They found out that

$$n = 2.188\times10^3\ \mathrm{Re}_G^{-0.598}\ Fr_G^{0.146} Mo_L^{-0.004} \qquad (4)$$

$$c = 4.32\times10^{-2}\ \mathrm{Re}_G^{0.2492} \qquad (5)$$

Where,

$$\mathrm{Re}_G = \frac{DU_{SG}(\rho_L-\rho_G)}{\mu_L}, Fr_G = \frac{U_{SG}^{2}}{gD},$$

$$Mo_L = \frac{g\mu_L^{4}}{(\rho_L-\rho_G)\sigma_L^{3}}$$

$\bar{\varepsilon}_G$, cross-sectional mean gas holdup was evaluated from the experimental data.

Manera et al. [8] compared wire mesh sensors and conductive needle-probes for measurements of vertical two-phase flow parameters using air-water system. They found out that the WMS is a very good candidate for achieving a full mapping of interfacial area density and also for achieving a full three-dimensional reconstruction of gas bubbles. On the other hand, that the needle probe is less intrusive and yields fewer disturbances in the downstream flow.

Abdulkadir et al. [1] carried out experimental investigation of phase distributions of two-phase air-silicone oil flow in a vertical pipe using WMS. They found out that reasonably symmetric profiles were obtained when the air-silicone oil was fully developed and that the shape of the profile was strongly dependent on superficial gas velocity. They also found out that symmetric parabolic profiles can be represented as spherical cap bubble and slug flows and that flattened symmetric profile can be represented as churn flow.

This paper is therefore aimed at comparing experimental radial void fraction with [12] mathematical model. Experimental studies have been conducted on a vertical 67 mm internal diameter vertical riser. A wire-mesh sensor (WMS) was devised for air-silicone oil to measure cross-sectional void fraction and time averaged radial void fraction to provide some information on phase distributions in a quantitative manner. It consists of two planes of 24 stainless steel wires with 0.12 mm diameter, 2.78 mm wire separation within each plane and 2 mm axial plane distance. This determined the spatio/ temporal resolution of the sensor. Since the square sensor is installed in a circular tube, only 440 of the total 576 wire crossing points are within the radius of the tube. During the experiments, the horizontal transmitter lines are pulsed one after another. By measuring the signal of all crossing vertical receiver wires, the local capacitance around the crossing points in the mesh is known. This capacitance signal is a measure for the amount of silicone oil, and thus indicates the local phase composition in the grid cell. The data were taken at a data acquisition frequency of 1000 Hz over an interval of 60 seconds.

NOMENCLATURE

D	[m]	Pipe internal diameter
g	[m/ s^2]	Acceleration due to gravity
ρ	[kg/ m^3]	Density
σ	[N/ m]	Surface tension
μ	[kg/ms]	Viscosity
Re	[ ]	Reynolds number
Fr	[ ]	Froude number
Mo	[ ]	Morton number
U	[m/ s]	Superficial velocity

Special characters

$\bar{\varepsilon}$	[ ]	Cross-sectional average gas holdup
$\tilde{\varepsilon}$	[ ]	Radial chordal average gas holdup
ε	[ ]	Radial gas holdup

Subscripts

SG	Superficial gas
L	Liquid
G	Gas

EXPERIMENTAL ARRANGEMENTS

This section is aimed at presenting an outline of the construction of the experimental rig used to study gas-liquid flow behaviour in a vertical riser. An overview of the experimental facility is given below.

Overview of the experimental facility

All experiments were carried out on an inclinable pipe flow rig within the Engineering Laboratories of the Department of Chemical and Environmental Engineering at University of Nottingham. Details about the experimental apparatus have been previously reported [2], [4], [5], [6] and [1]. In brief, the experimental facility consists of a main test pipe section constructed from transparent acrylic glass. The 6 m test pipe section is of a 0.067 m internal diameter. The test pipe section

may be rotated on the rig to allow it to incline between -5 ^{o} to 90 ^{o} degree. For the experiments reported in this paper the rig test pipe section was mounted as a vertical riser.
The rig was charged with air-silicone oil mixture to study the flow regimes created by the circulation of various air – silicone oil mixtures created by the controlled pumped circulation of the oil from the reservoir and the compressed injection of air at the base of the inclined riser pipe. The resultant flow regimes created for the range of air-silicone oil injection circulation flow rates studied were recorded using wire mesh sensors (WMS) as shown in Figure 1. This technology, described by [3], [8] and [10], can image the dielectric components in the pipe flow phases by measuring rapidly and continually the capacitances of the passing flow across several

PROCESSING OF RESULTS

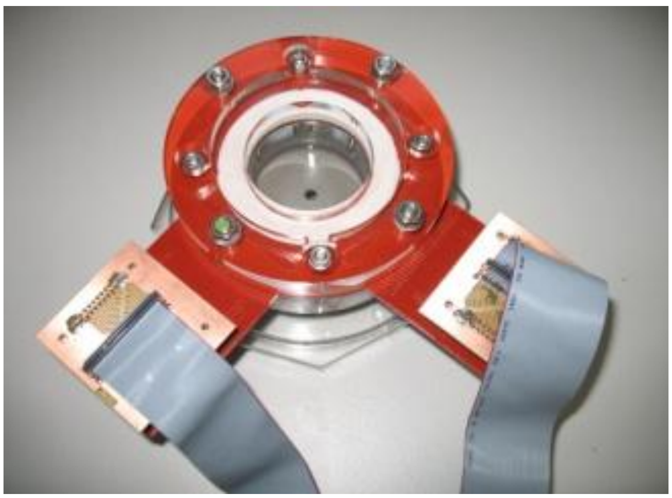


Figure 1 Wire mesh sensor (WMS)

In order to obtain quantitative information on the flow, both time and cross-sectional averaging of the void fraction data were used. The averaging was based on weight coefficients that define the contribution of each crossing point of wires (i, j) in the sensor matrix to the size of the domain, over which the averaging had to be done. Details about the definition and method of obtaining the weight coefficients ($a_{i,j}$) necessary to obtain a cross-section averaged void fraction can be found in [1].

Radial time averaged void fraction were calculated by averaging the local instantaneous void fractions over the measurement period and over a number of ring-shaped domains (m). Details can be found in [1].

TRENDS AND RESULTS

Comparison of time averaged cross-sectional void fraction distribution with superficial gas velocity

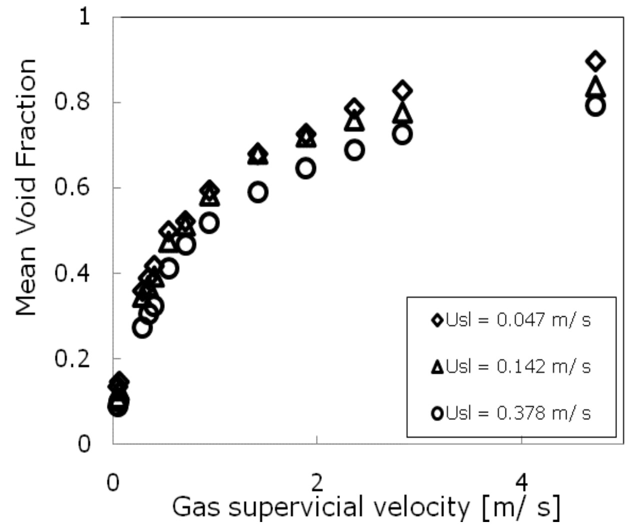


Figure 4 Variation of time averaged cross-sectional void fraction with gas superficial velocity

Figure 4 can be observed to show that all the plots of mean void fraction against superficial gas velocities followed the same trend. It is found that the time averaged cross-sectional void fraction increases with gas superficial velocity with liquid superficial velocity as a parameter. However, the cross-sectional average void fraction increases with a decrease in liquid superficial velocity.

Variation of c-parameter and steepness parameter with superficial gas velocity

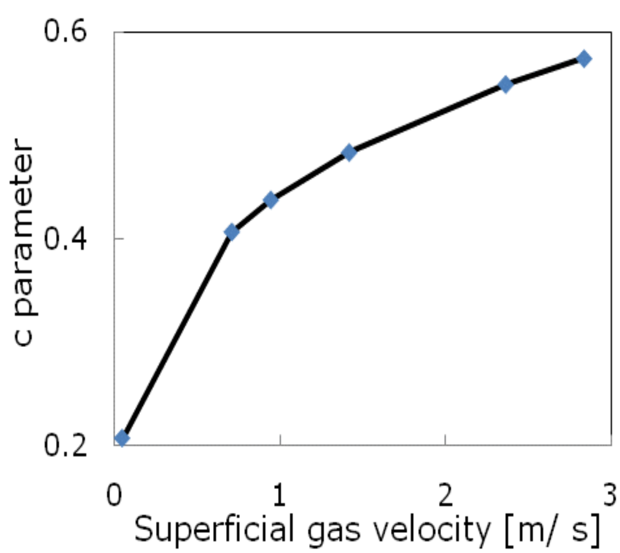


Figure 5 variation of c parameter with superficial gas velocity

The c-parameter is a parameter that defines the amount of gas near the wall. Here the influence of increasing gas flow rate on c parameter will be examined. It was found that that the c parameter increases from 0.207 to 0.575 with an increase in gas superficial velocity as shown in Figure 5. This means the amount of gas near the wall of the riser increases with an increase in gas superficial velocity.

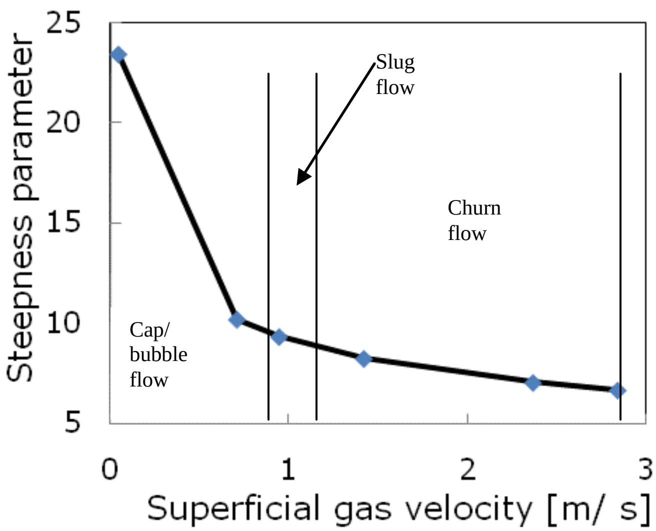


Figure 6 variation of steepness parameter with superficial gas velocity

When having a closer look at the variation in steepness parameter with superficial gas velocity (Figure 6), it can be observed that the steepness parameter decreases from 23.408 to 6.673 with an increase in gas superficial velocity. This means that high values of steepness parameter represent spherical cap bubble and intermediate values, slug flow. On the other hand low values represent churn flow. This therefore shows that the variation of steepness parameter with superficial velocity can be used to classify flow regimes.

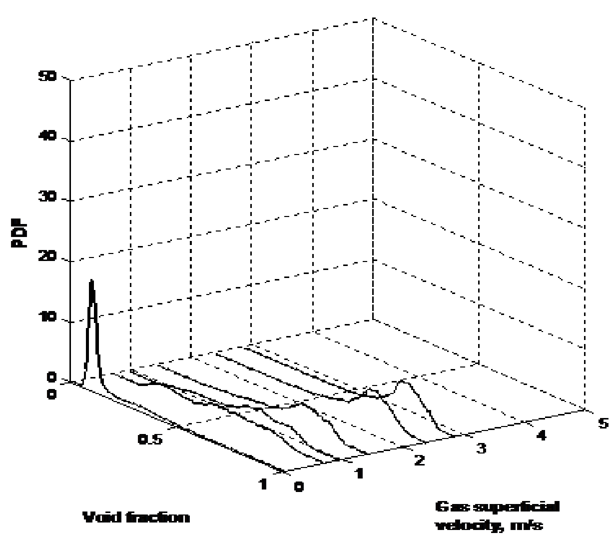
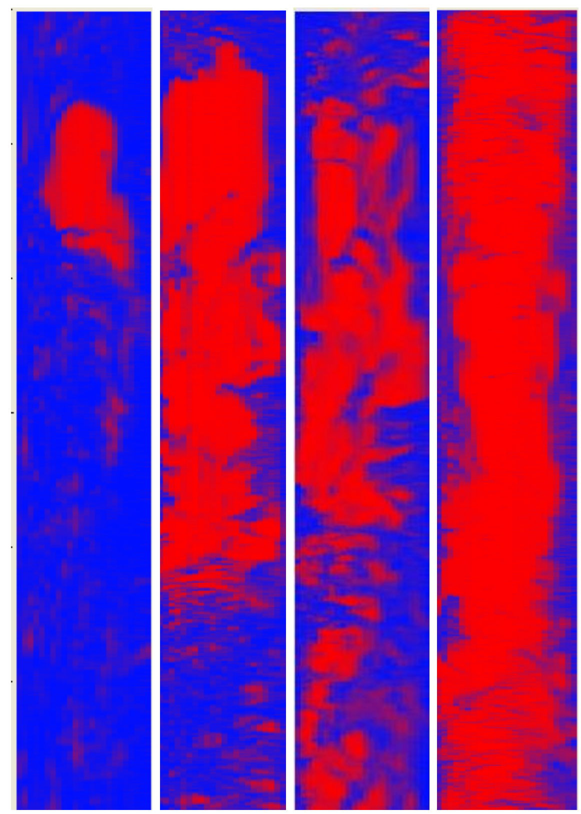


Figure 7 3-Dimensional probability density function of void fraction for WMS (U_{SL} = 0.047 and U_{SG} = 0.047-2.836 m/ s)

Figure 7 supports the observations made in figure 3 that as the superficial liquid velocity is maintained at 0.047 m / s and superficial gas velocity increased from 0.047 to 2.836 m/ s, there are increases in mean void fraction. This therefore brings about flow regime transition from spherical cap bubble to churn flow regime.



(a) (b) (c) (d)

Figure 8 Side view of the two-phase flow transition from spherical cap bubble to churn flow. Superficial liquid velocity of 0.047 m/ s and superficial gas velocity a) 0.047 m/ s b) 0.709 m/ s c) 0.945 m/ s and d) 2.836 m/ s. Sensor: Wire mesh, 24×24 sensitive points; time resolution: 1000Hz.

In figure 8 the side view is shown for different gas superficial velocities. At superficial gas velocity of 0.047 m/ s, there are still bubbles of large size, but not as big as the pipe diameter. When the air velocity is increased to 0.709 m/ s, coalescence starts leading to slug flow. At gas superficial velocity of 0.945m / s, the transition to unstable slug flow is complete. When the gas flow rate is further increased, the unstable slug flow transforms into churn flow.

Comparison of experimental time averaged radial void fraction with the [12] mathematical model

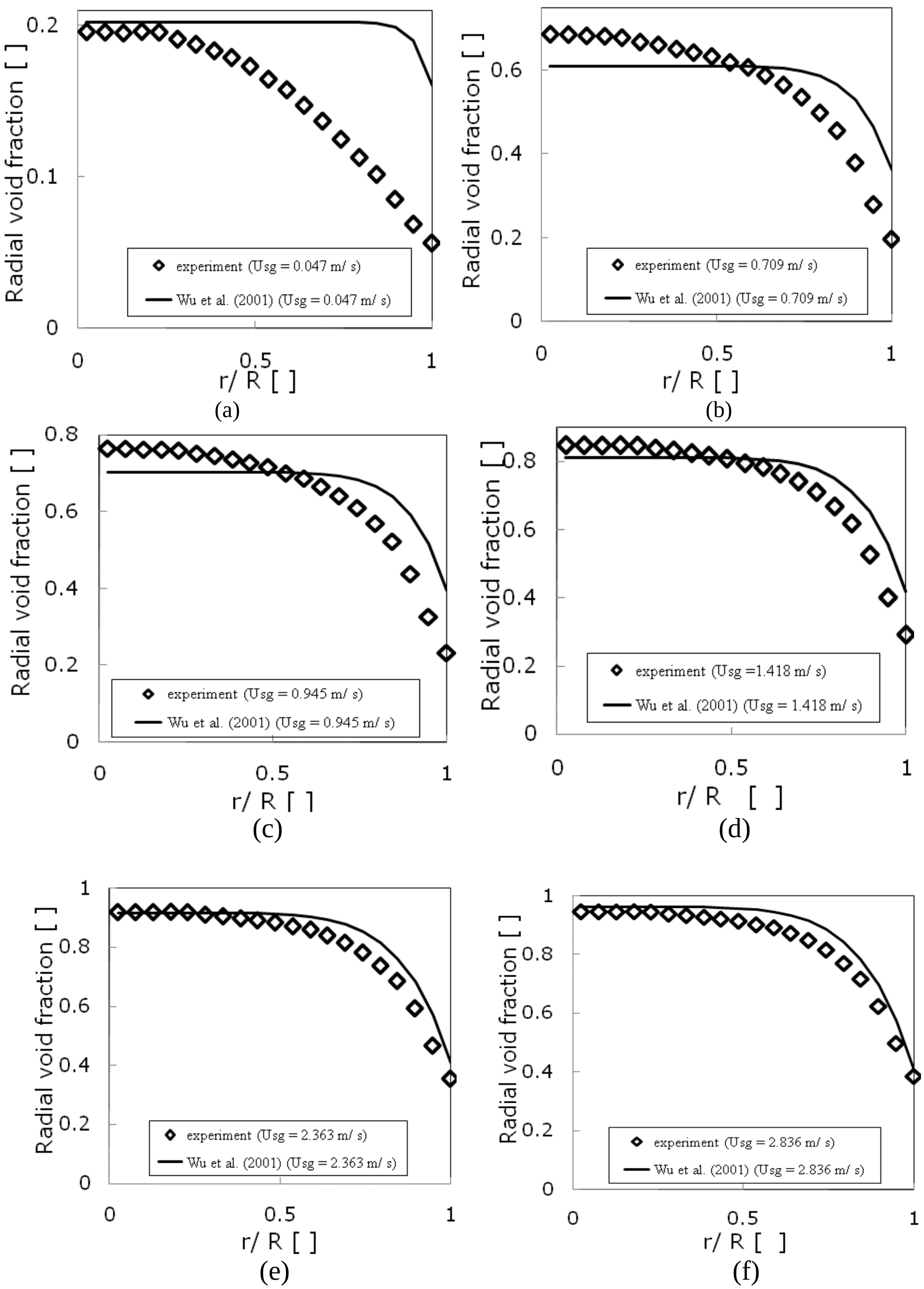


Figure 7 Comparison of experimental time averaged radial void fraction distribution with [12] mathematical model at superficial liquid and gas velocities of 0.047 m/ s and ($0.047 < U_{sg} < 2.836$ m/ s), respectively. The [12] model was recalculated using the physical properties of air and silicon oil. r/ R represent normalised pipe radius, r/ R = 0.5 represents centre of the pipe radius, r/ R = 1 represents pipe wall and r/ R = 0 is the radius of the pipe.

This section will aim to compare experimental data with [12] mathematical model. From an examination of the experimental data plotted on Figure 7 it is concluded that the radial void fraction increases with gas superficial velocity and that the shape of the profile is dependent on the gas superficial velocity. It is interesting however, to note that contrary to the results obtained by [12], the profiles for bubble and slug flows are parabolic and semi- flat parabolic whilst for churn flow flat parabolic as earlier reported by [1]. It can be observed that the [12] model is not suitable for replicating the observed radial void fraction at low superficial velocity.
The comparison between experiment and [12] model is very poor at superficial liquid and gas velocities of 0.047 and 0.047 m/ s respectively as shown in Figure 7a. The mean relative error is very high, about 47.3%. The experiment predicts the profile as parabolic while the [12] model predicts it as flat. The wide deviation could be as a result of this discrepancy.
For Figures 7b to 7f, the radial void fraction presents a semi-flat parabolic profile. Very good agreement is found for Figure 7f, with a mean relative error of 5.7 % while for Figure 7b a mean relative error of about 8.5 % is obtained between experiment and [12] model. For slug flow (Figures 7b and 7c) it has been found that the [12] model under predicts and over predicts void fraction before and after the centre of the radius of the pipe respectively. The effects disappearing with an increase in gas superficial velocity for churn flow as shown in Figures 7d to 7f. The under prediction and over prediction of the void fraction could be due to the fact that the model was originally developed for air-water systems.

CONCLUSION

The phase distribution of an air-silicone oil mixture in a vertical riser has been successfully carried out. The results show that:

- The cross-sectional void fraction was strongly affected by the superficial gas velocity, whereby the higher the superficial gas velocity, the higher was the observed average void fraction.
- The steepness parameter decreases with an increase in gas superficial velocity whilst the c-parameter increases with an increase in gas superficial velocity. The steepness parameter can be used to classify flow regimes; high steepness values represent cap/ bubble flow, intermediate values, slug flow and low values represent churn flow.
- The radial void fraction increases with gas superficial velocity and that shape of the profile is dependent on the gas superficial velocity. The profiles for cap/ bubble, slug and churn flows are parabolic, semi-flat parabolic, and flat parabolic profiles, respectively based on the radial void fraction distribution.
- The [12] model is most suitable for satisfactorily replicating radial void fraction profile at high gas superficial velocities (churn flow).

Acknowledgment

Abdulkadir, M., would like to express his sincere appreciation to the Nigerian government through the Petroleum Technology Development Fund (PTDF) for providing the funding for his doctoral studies. V. Hernandez Perez and S. Sharaf are funded by EPSRC under grant EP/ F016050/ 1.
“This work has been undertaken within the Joint Project on Transient Multiphase Flows and Flow Assurance. The Author(s) wish to acknowledge the contributions made to this project by the UK Engineering and Physical Sciences Research Council (EPSRC) and the following: - GL Industrial Services; BP Exploration; CD-adapco; Chevron; ConocoPhillips; ENI; ExxonMobil; FEESA; IFP; Institutt for Energiteknikk; PDVSA (INTEVEP); Petrobras; PETRONAS; SPT; Shell; SINTEF; Statoil and TOTAL. The Author(s) wish to express their sincere gratitude for this support.”

References

[1] Abdulkadir, M., Hernandez-Perez, V., Sharaf, S., Lowndes, I. S. and Azzopardi, B. J., 2010, Experimental investigation of phase distributions of two-phase air-silicon oil flow in a vertical pipe, ICFMHT 2010, International Conference on Fluid Mechanics, Heat Transfer and Thermodynamics, Cape Town, South Africa.
[2] Azzopardi, B. J., 1997, Drops in annular two-phase flow, International Journal of Multiphase Flow, Vol. 23, pp. 1-53.
[3] Azzopardi, B. J., Hernandez Perez, V., Kaji, R., Da Silva, M. J., Beyer, M., and Hampel, U., 2008, Wire mesh sensor studies in a vertical pipe, HEAT 2008, Fifth International Conference on Multiphase Systems, Bialystok, Poland.
[4] Geraci, G., Azzopardi, B. J., and Van Maanen, H. R. E., 2007a, Inclination effects on circumferential film distribution in annular gas/ liquid flows, AIChE Journal, Vol. 53, No.5, pp. 1144-1150.
[5] Geraci, G., Azzopardi, B. J., and Van Maanen, H .R .E., 2007b, Effects of inclination on circumferential film thickness variation in annular gas/ liquid flows, Chemical Engineering Science, Vol. 62, No.11, pp. 3032-3042.
[6] Hernandez-Perez, V., 2007, Gas-liquid two-phase flow in inclined pipes, a PhD Thesis, University of Nottingham, United Kingdom
[7] Luo, H., and Svendsen, H.F., 1991, Turbulent circulation in bubble columns from eddy viscosity distributions of single-phase pipe flow, Canadian Journal of Chemical Engineering, vol. 69, pp. 1389-1394
[8] Manera, A., Ozar, B., Paranjape, S., Ishii, M., and Prasser, H. –M., 2008, Comparison between wire-mesh-sensors and conducting needle-probes for measurements of two-phase flow parameters, Nuclear Engineering and Design, Vol. 239, pp. 1718-1724
[9] Nassos, G. P. And Bankoff, 1967, Slip velocity ratios in an air-water system under steady-state and transient conditions, Chemical Engineering Science, Vol. 22, No. 667
[10] Thiele, S., Da Silva, M. J., Hampel, U., Abdulkareem, L., Azzopardi, B. J., (2008), High-resolution oil-gas two-phase flow measurement with a new capacitance wire-mesh tomography, 5th International Symposium on Process Tomography In Poland, Zakopane, 25-26 August
[11] Ueyama, K., and Miyauchi, T., 1979, Properties and recirculating turbulent two-phase flow in gas bubble columns, A. I. Ch. E. Journal, Vol. 25, No. 258
[12] Wu, Y., Cheng Ong, B., and Al-Dahhan, M.H., 2001, Predictions of radial gas holdup in bubble column reactors, Chemical Engineering Science, vol. 56, pp. 1207-1210