International Journal of Engineering Research
Sirte University
Faculty of Engineering

IJER@su.edu.ly

Special Issue, Oct. 2022

Identification of Gas Void Fraction and Flow Patterns in Upward Direction of Vertical Pipes

Almabrok A. Almabrok[1], Faraj A. AlTaher[2]*

[1]Department of Petroleum Engineering, Faculty of Engineering, Sirte University, Libya

[2]Department of Chemical Engineering, Faculty of Engineering, Sirte University, Libya

Corresponding author: Email: almabrok.abushanaf@su.edu.ly

Abstract

Experiments on gas-liquid two-phase flow were conducted at three positions of upward section in a vertical pipe with diameter of 101.6 mm. In this study, probability density functions (PDFs) and local distribution of gas void fraction were applied to identify the possible flow patterns that can be formed in a vertical upward orientation. It was observed from the shape of PDFs that bubbly, intermittent and annular flows are the dominant types. These flow structures were significantly influenced by gas and liquid superficial velocities. Bubbly flow was formed at low gas flowrates, which was characterized by discrete bubbles distributed in a liquid continuum. The bubbles were uniformly distributed in the pipe center with similar shape and size. Intermittent flow was formed due to gradual increase of gas flowrate, where large bubbles tend to collide and coalesce with the smaller ones. The bubbles are noted to occupy the greater part of the pipe's cross-section. Fluctuations of gas flowrate led to distortion and breakdown of the large bubbles immediately. Further increase of gas flowrate was attributed to formation of annular flow regime. In this type, the liquid phase flows along the pipe walls in the form of liquid film, while the gas phase flows in the center of the pipe. Further attempts were also performed by examining the local distribution of gas void fraction which confirmed the achieved above-mentioned results.

Keywords: *PDFs, Local Distribution, Bubbly, Intermittent, Annular*

1. Introduction

The void fraction is defined as the fraction of cross-sectional area occupied by the gas phase. Void fraction is nonetheless not simply depending on the amount of input mass flowrates. The measurements and determination of gas void fraction in two-phase flow is very vital in a variety of engineering purposes. Various techniques have been used for such measurements, and comprehensive evaluations were given by Hewitt (1) and of late by Leblond and Stepowski (2). They used impedance and local probes to measure average and local void fraction, respectively.

It is very essential to observe flow regimes with the intent of improving safety and wide-ranging performance in industrial systems of petroleum processing systems. Several researchers have been working on developing factual methodologies for two-phase flow regime identification, and have evaluated different methods for the determination of void fraction. Malnes (3) carried out an experimental work for local distribution of void fraction at lower and higher positions along the pipe (Figure 1). The experimental measurements were carried out for a bubbly flow regime. He observed that the void fraction varies over the given range of gas superficial velocities. Higher void fraction was observed closer to the pipe wall than at the pipe center, for lower and upper measuring points, as shown in Figure 1. Nevertheless, a center peak was observed for the upper measuring point when the gas velocity increased to higher values.

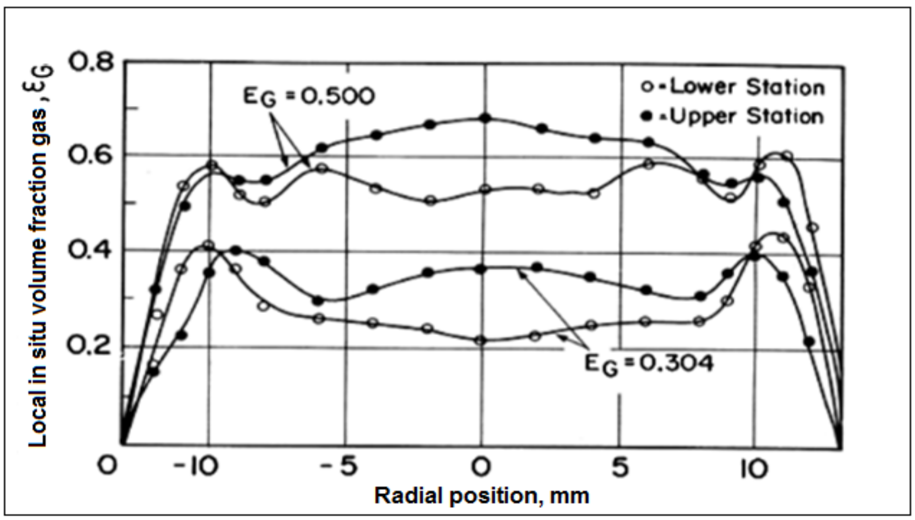


Figure (1): Distribution of gas void fraction in bubbly flow region (Malnes, 1966)

Observations by Wang et al (4) revealed that wall peaks occurred for the fluid flows in an upward orientation, while a core peak was observed in the case of downward orientation. Likewise, Serizawa and Katoaka (5) conducted an experimental study of local void fraction distribution in the region of bubbly flow (Figure 2). They reported in their findings that the gas distribution showed different profiles for different gas and liquid flowrates, which was in tandem with the observations of Malnes and Wang et al.

Furthermore, Serizawa and Katoaka observed that the void fraction values on the pipe wall became higher (wall peak) than at the opposite side of the pipe's cross-section, at a higher gas velocity that moves to the direction of the pipe wall. Intermittent and slug peaks were formed on a steady increase of the gas flowrate. Additional increases in the gas flowrate led to higher void fraction in the pipe center (classified as center peak). The experimental work conducted by Liu and Bankoff (6) demonstrated that the gas void fraction distribution is fractional, based on the shape and size of the bubble, mostly for low liquid velocities. The observed wall peak was attributed to the influence of bubbles that moved close to the pipe's wall.

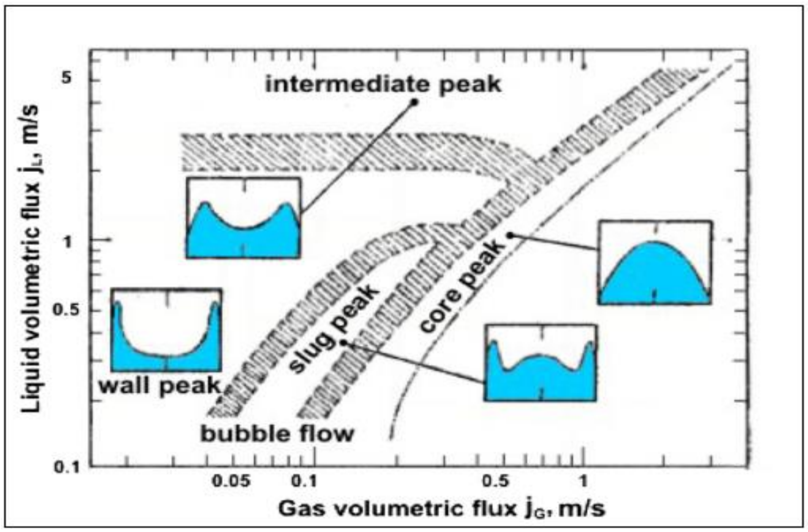


Figure (2): Patterns of gas void fraction distribution (Serizawa and Katoaka, 1988)

To identify gas-liquid two-phase flow regimes in a factual way, Jones et al (7) were among the first to use a non-visual approach, based on X-ray void fraction measurements. In their approach they measured void fluctuations in air-water upward flow in a narrow rectangular channel (05 x 64 mm).

The probability density function (PDF) of void fluctuations was successfully used to identify bubbly, slug and annular flow regimes. Their PDF distributions in the work showed a single peak at low void fraction for bubbly flow, a single peak at high void fraction for annular flow, and two peaks for slug or intermittent flow, a particular characteristic of bubbly flow and the other characteristic of annular flow.

Matsui (8) used statistical properties of PDF of pressure and differential pressure to identify flow regimes of nitrogen gas-water mixtures at four positions along a vertical pipe. He reported that the shape of PDF depends on the flow regime types and the pressure fluctuations were due to flow configuration.

2. Brief Description of The Test Facility

This unique configuration of the facility, presented in Figure 3 comprises fluid supply section, metering sections, test section, and fluid separation section. The experimental rig is made of a transparent Pyrex glass with one U-shape bend at the bottom and two inverted U-shape bends at the top. The rig comprises various vertical transparent sections in order to visualize the possible flow structures. More details about this facility were presented by Almabrok (9).

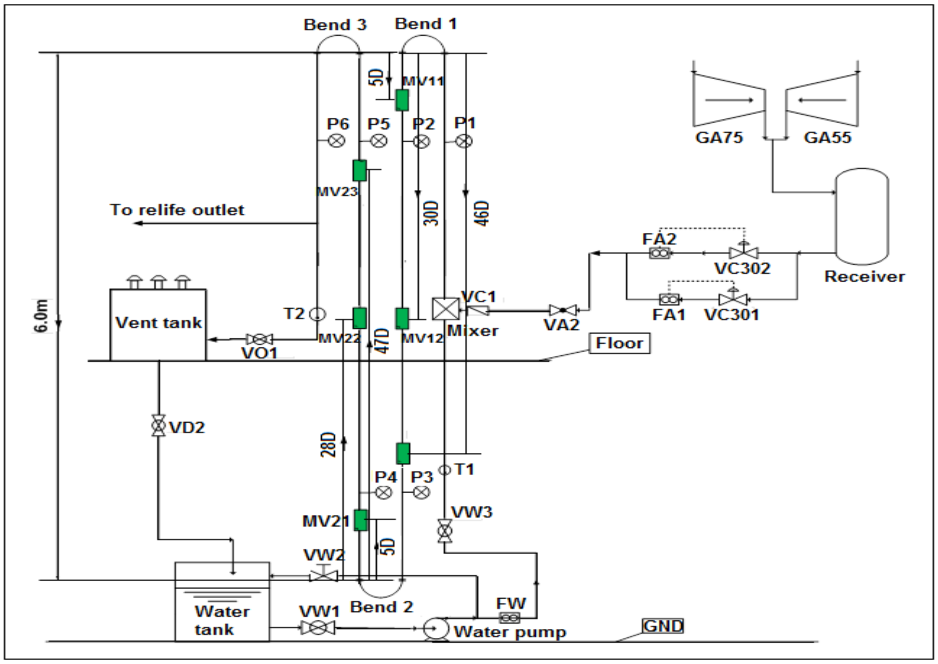


Figure (3): Schematic of The Test Facility

3. Description of The Instrument

The wire mesh sensor (WMS) used in this study was made up of 32x32 wires (i.e., transmitter and receiver wires) in two planes. Figure 4 (a, b) presents the theory in a more comprehensive picture. The axial arrangement connecting the wires is 2 mm and each one of these cross points of the wires stand for a recording point. Figure 4b shows that the sender wires are in the 0^{o}-180^{o} direction and the receiver wires are in the 90^{o}-270^{o} direction. With this arrangement the void fraction distribution at both directions (i.e., 0^{o}-180^{o} and 90^{o}-270^{o}), can be easily estimated from the cross-sectional distribution of the gas void fraction, which is used to determine the extent of the phase distribution asymmetry over a cross-section at the measuring position of the pipe. Details of WMS technique are described by Da Silva et al (10).

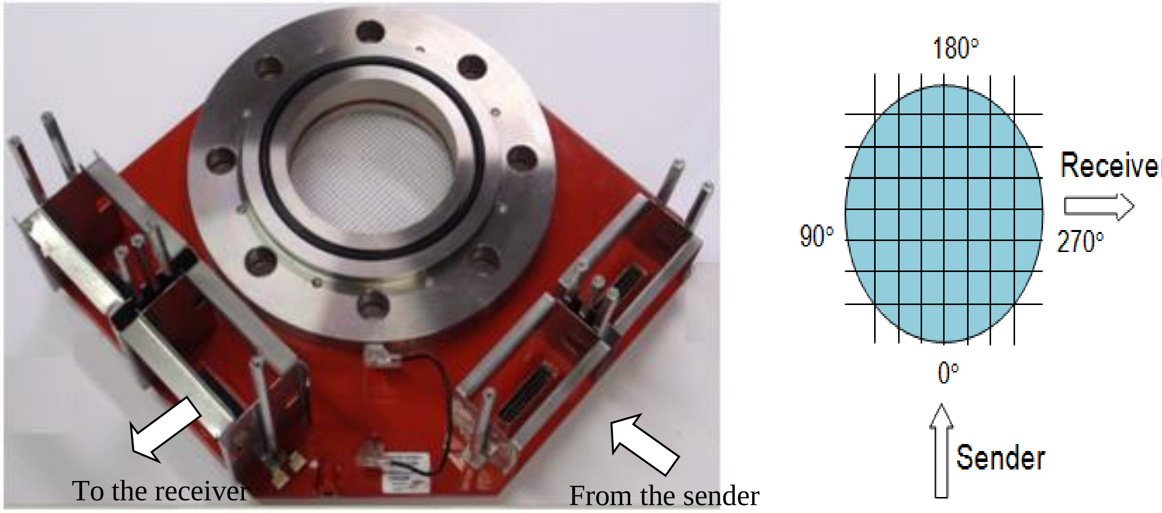


Figure (4) (a and b): Presented the WMS and Its Cross Section, Respectively

4. Results and Discussion

Figure 5 shows the PDFs' data at top, middle and bottom positions of the upward section for a wide range of gas velocities, and liquid superficial velocities of 0.48 and 0.7 m/s. It can be seen that the shapes of PDFs were consistent with a striking similarity at all positions when similar flowrates were applied. Bubbly flow with a long tail extended to high values of void fraction, was noted at gas and liquid velocities of 0.14 and 0.48 m/s, respectively. In general, the PDFs show similar shapes for all positions when liquid superficial velocity of 0.48 m/s. Similarly, the shape of the PDFs did not change even for higher liquid superficial velocity of 0.7 m/s. However, the extracted PDFs' data for liquid superficial velocity of 0.7 m/s and gas superficial velocity of 0.16 m/s, showed a bubbly flow regime at the three positions.

The transition from bubbly to intermittent flow occurred and presented a similar shape of PDFs at all positions for higher gas velocity of 0.26 m/s. When gas superficial velocities increased to 2.78 and 5.61m/s, an intermittent flow with a wide base was identified for both liquid superficial velocities of 0.48 and 0.7 m/s. The broad base of gas void fraction was due to the existence of continuous large bubbles in the liquid body. For the highest flowrates, annular flow with a single peak at high values of gas void fraction was recognized at all positions

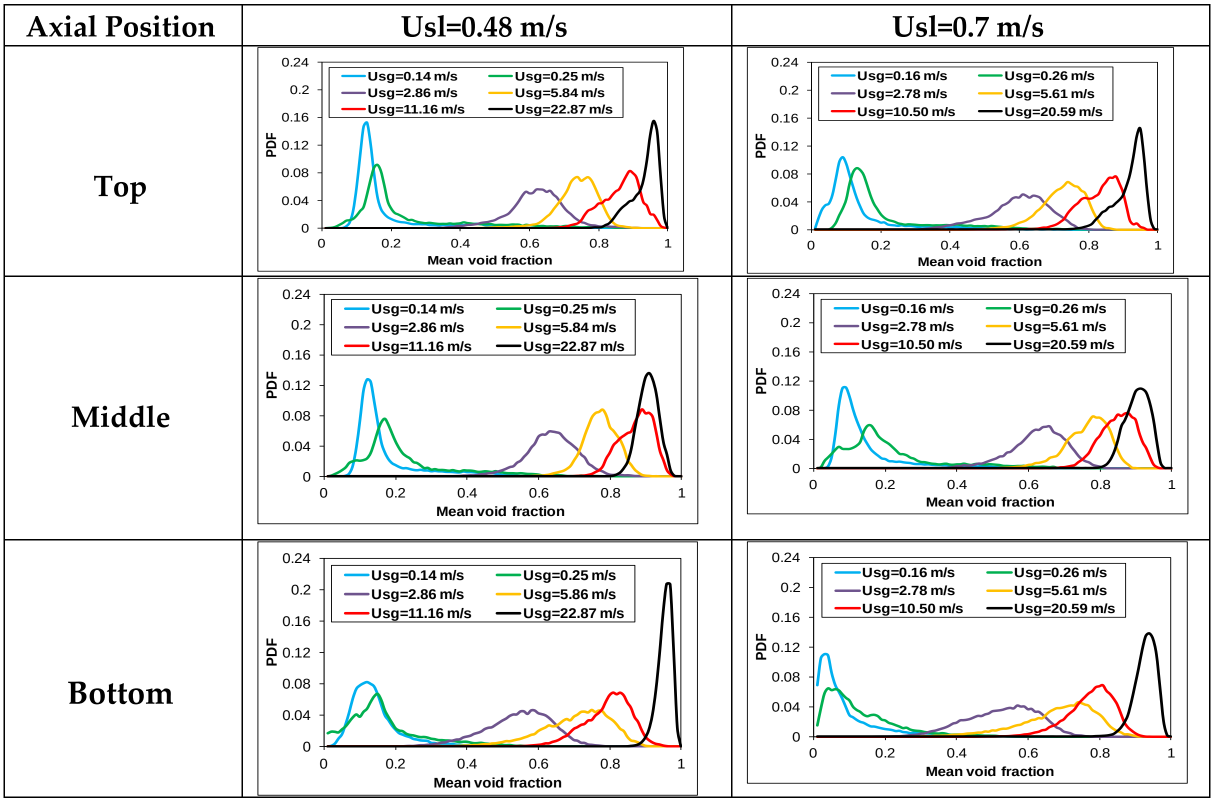


Figure (5): Shows Variation of Probability Density Functions Along Upward Section

Local void fraction distribution at different positions of the upward section was also analyzed for liquid superficial velocities of 0.48 and 0.7 m/s with a number of gas superficial velocities, as illustrated in Figures 6 and 7. The plots in Figure 6 represent the distribution of void fraction from 90º to 270º positions, while Figure 7 shows the void fraction distribution from 0º to 180º positions It is important to note that, the 90º position corresponds to the outer pipe wall, and the 270º position corresponds to the inner wall.

Both the 90º º and 270º positions are respectively located on the upward section, close to the outer and inner curvatures of the bottom bend. The 0º and 180º positions are located on the right and left positions of 90º, respectively. Figure 6 shows a symmetrical void fraction profile at all positions and overall flow conditions. It can be seen in all plots that, the void fraction increases in a parabolic manner when the gas superficial velocity ranged from 0.14 to 5.84 m/s (for liquid superficial velocity of 0.48 m/s), and also when the gas superficial velocity ranged from 0.16 to 5.61 m/s (for liquid superficial velocity of 0.7 m/s). The void fraction values at these positions significantly increased towards the pipe center, where the void fraction is at maxima. This then gradually decreased to exhibit minima in the pip wall.

As a gas superficial velocity increased further, the void fraction profile was still uniform with minima appearing on the pipe wall. However, the maxima of void fraction appeared along wire 5 towards wire 28 when highest gas superficial velocity was applied. As a result, the void fraction profile exhibits a flat shape along all positions.

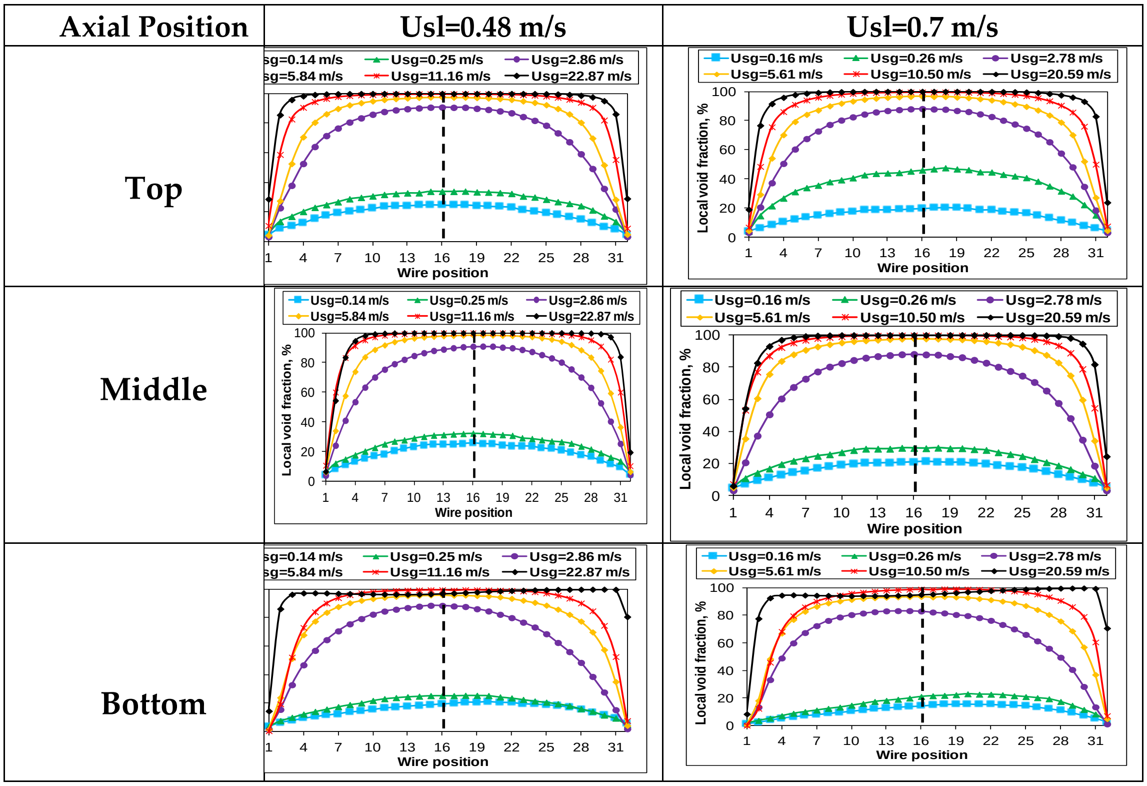


Figure (6): Depicts The Local Void Fraction Distributions From 90 to 270^{o} Measured at The Top, Middle and Bottom Positions of The Upward Section

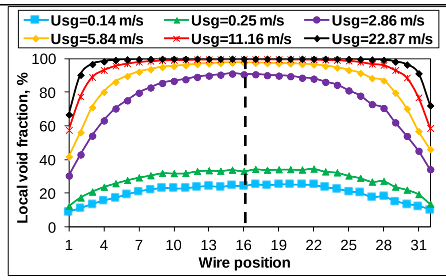
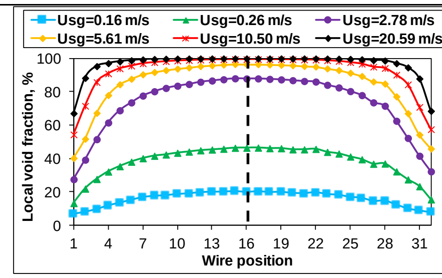
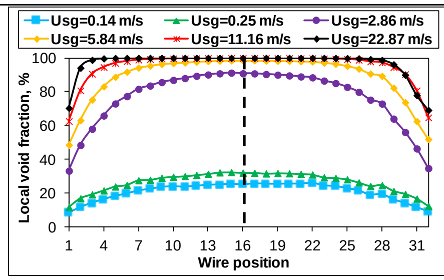
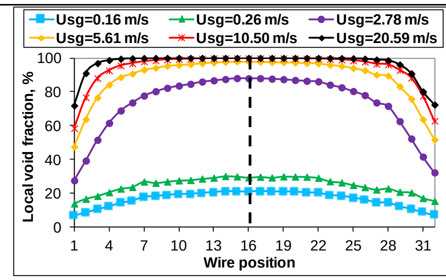
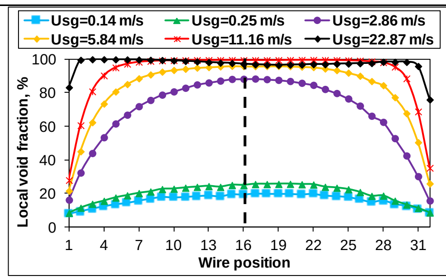
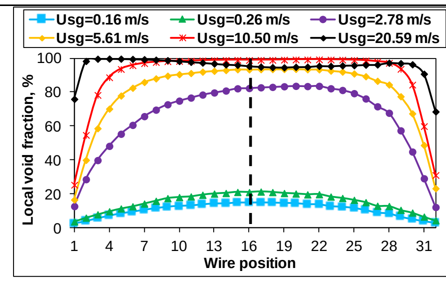
<table>
<tr><th>Axial Position</th><th>Usl=0.48 m/s</th><th>Usl=0.7 m/s</th></tr>
<tr><td>Top</td><td>
</td><td>
</td></tr>
<tr><td>Middle</td><td>
</td><td>
</td></tr>
<tr><td>Bottom</td><td>
</td><td>
</td></tr>
</table>

Figure (7): Depicts The Local Void Fraction Distributions From 0o to 180o Measured at The Top, Middle and Bottom Positions of The Upward Section

Conclusions

The following conclusions were drawn from this study:

a) It was observed from the shapes of PDFs that the flow structure varied due to obvious impacts of gas and liquid superficial velocities.

b) The flow patterns at three positions of the upward section were bubbly, intermittent and annular.

c) The profile of gas void fraction was noted to be symmetrical throughout the flow path and increased towards the pipe center.

d) The void fraction values were at maxima in the pipe center, which was increased in a parabolic manner, particularly for low gas superficial velocities.

e) The void fraction was decreased gradually to exhibit minima in the pipe wall.

References

[1] *Hewitt GF. Measurement of Two-Phase Plow Parameters. Academic Press, London. ISBN: 0-12-346260-6. 1978.*

[2] *Leblond, J. and Stepowski D. Some non-intrusive methods for diagnostics in two-phase flows. Multiphase Science and Technology, Vol. 8, Begell House, New York. 1995.*

[3] *MALNES d. Slip ratios and fraction factors in the bubble flow region in vertical tubes. 1966.*

[4] *Wang SK, Lee SJ, Jones OC, Lahey RT. 3-D turbulence structure and phase distribution measurements in bubbly two-phase flows. International Journal of Multiphase Flow. 1987; 13(3): 327–343.*

[5] *Serizawa A, Kataoka I. Turbulence suppression in bubbly two-phase flow. Nuclear Engineering and Design. 1990; 122(1-3): 1–16.*

[6] *Liu TJ, Bankoff SG. Structure of air-water bubbly flow in a vertical pipe—II. Void fraction, bubble velocity and bubble size distribution. International Journal of Heat and Mass Transfer. 1993; 36(4): 1061– 1072.*

[7] *Jones O. & ZN. The interrelation between void fraction fluctuations and flow patterns in two-phase flow. Int. J. Multiphase Flow 2,. 1975; 273- 306.*

[8] *Matsui G. Identification of flow regimes in vertical gas-liquid two-phase flow using differential pressure fluctuations. International Journal of Multiphase Flow. 1984; 10 (6): 711–719.*

[9] *Almabrok A. Gas-liquid two-phase flow in up and down vertical pipes. PhD Thesis, 2014. Cranfield University, UK.*

[10] *Da Silva, M.J., Schleicher, E. And Hampel, U. (2007). Capacitance wire-mesh sensor for fast measurement of phase fraction distributions. Measurement Science and Technology, Vol. 18, pp.2245-2251.*