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Behavior of Gas-Liquid Mixture in a Downward Orientation of Vertical Pipe

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Abstract

This paper describes the application of the erratic concept in the identification of two-phase gas-liquid flow patterns and transitions in a large vertical riser. The analyzed data in this paper were from the experimental conducted in the 4-inch diameter pipe. In the experiments, vertical gas-liquid two-phase flow was studied in a large cross-sectional area. The complete analyses covered the range experimentally attainable .

Usually, the flow pattern identification, and gas void fraction of two-phase flows are based on visual observation of phase distribution. While visual flow pattern identification may be sufficient for a number of instances, for many circumstances these methods are inappropriate or too biased. The objective of this study is to apply probability density function (PDF) and local distribution of averaged void fraction concepts, on experimental data of dynamic signals of gas-liquid two-phase flows, in an effort to identify and interpret the creation and transitions of flow pattern in downward flow. These methods will possibly give a favorable way in the identification of flow behavior. The plots of probability density function (PDF) confirm that, a bubbly to intermittent flow transition was occurring at all positions. The flow regime observed at the bottom region of pipe was accompanied by a wide base spanning from 0 to 0.6. The existence of large bubbles in a liquid phase contributes to the wide base of void fraction values. Annular flow was a dominant type in a downward flow, particularly when gas superficial velocity increased to higher rates. The achieved results were in good agreement when compared with data of local gas void fraction distribution, obtained from wire mesh sensor (WMS) technique.

Keywords: *Vertical gas-liquid flow, void fraction, wire mesh sensor, probability density function*.

1. Introduction

Gas liquid two-phase flows are extremely complicated because of their deformable interfacial structures and the compressibility of the gas phase. To deal with gas-liquid two-phase flow issues, it is vital to identify the flow patterns (also known as flow regimes). It is defined as the physical spatial distribution of two and/or multiphase in a pipe. Factors such as temperature, pressure, density, viscosity and surface tension, gas and liquid flow rates, gas void fraction, pipe orientation and its diameter, contribute to the formation of flow patterns. To identify the two-phase flow regimes, analysis the probability density function (PDF) and local distribution of averaged void fraction can be used.

It is well recognized that, vertical gas-liquid flows can be classified into bubbly flow where the tested gas velocity is relatively low and the gas phase moves in the pipe centre within a liquid as uniform discrete bubbles (Barnea, 1987; Taitel et al., 1980).

Increasing the gas velocity further will lead to create slug (or plug) flow, where the large bubbles coalesce and collide together. In most cases these bubbles are occupied a considerable area of the cross-section having bullet-shaped bubbles, named as Taylor bubbles (Nicholas, 2000).

Gradual increase of gas flow rate will lead to immediate deformation and breakdown of the Taylor bubbles to create a churn flow. In churn flow, a liquid phase exists as thin film around the liquid will fall into downward direction. This falling film will accumulate to form a bridge on the bottom of the pipe which can be lifted again by the continuous gas phase (Hewitt and Jayanti, 1993).

Higher flow rate of gas can contribute to formation of annular flow regime. This type is characterized by liquid film flows along the inner wall of the pipe, while gas phase (gas/liquid droplet mixture) flows in the pipe centre. When the liquid flow rate becomes high enough, the liquid droplets presented in the central zone of the pipe are agglomerated into large wisps, leading to creation of wispy annular flow. When gas flow rate increased to very high values, the liquid phase will be completely dispersed and mist flow can be formed as a result. This flow can only take place in a non-adiabatic system.

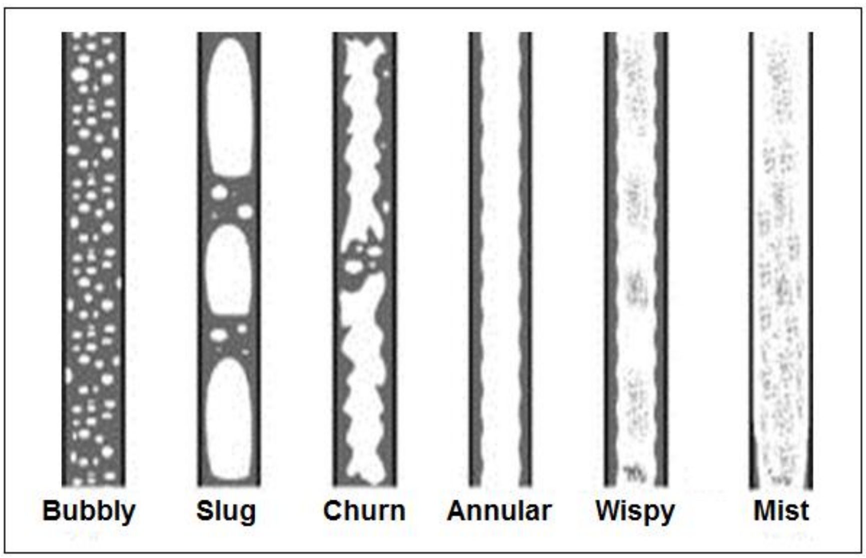


Figure 1 Gas-liquid flow patterns in vertical pipes (Cheng et al., 2008)

Olerni et al. (2013) were made a comparison between their work and other published studies in terms of gas void fraction distribution. They used a 16× 16 wire mesh sensor (WMS), as presented in Figure 2. This comparison was carried out for a range of gas flow rates, and for constant liquid velocity of 1.039 m/s. They revealed that their work was consistent with the previous studies. However, they observed that the gas fraction profile was not in complete agreement with the other investigators' work. This was attributed to dissimilarity between both studies in terms of sampling resolution of wire mesh sensor technique and inner diameter of the pipe.

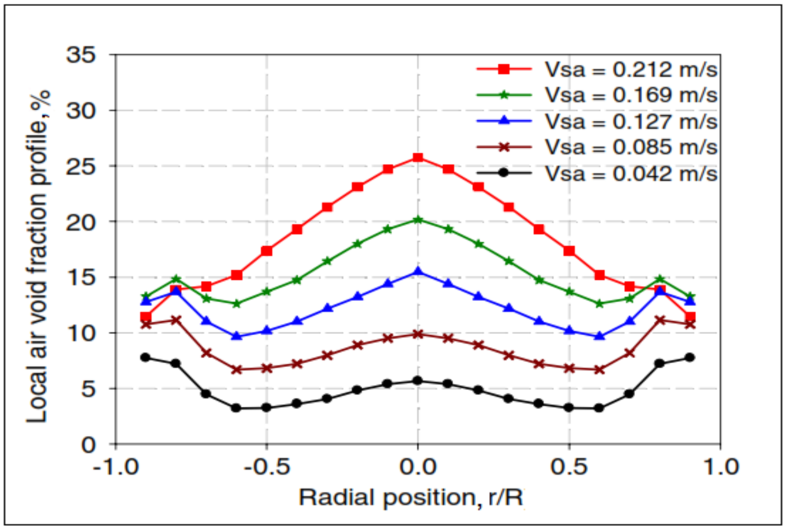


Figure 2. Local distribution of gas void fraction obtained from WMS for liquid superficial velocity of 1.039 m/s (Olerni et al., 2013)

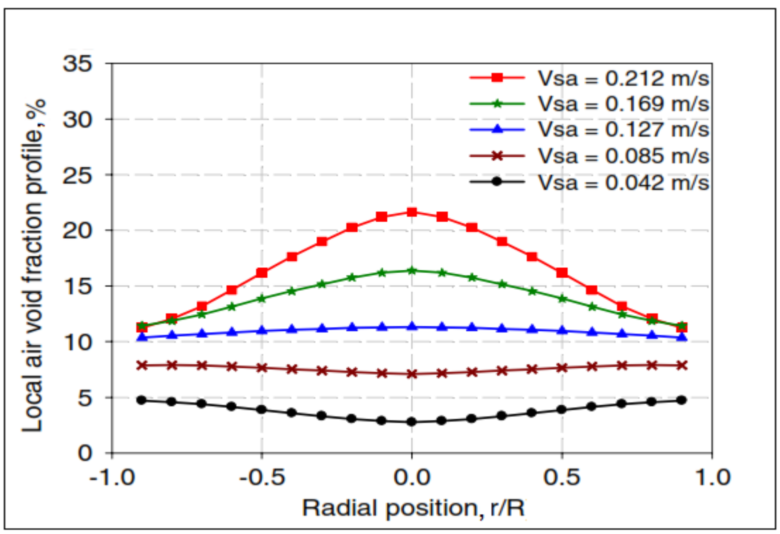


Figure 3 Local distribution of gas void fraction obtained from ERT for liquid superficial velocity of 1.039 m/s (Olerni et al., 2013)

Olerni et al. (2013) was also reported that, the void fraction profile shifted from wall peak to centre peak as the velocity of gas increased to higher amounts. Comparison was also carried out using an electrical resistance tomography (ERT) device, as shown in Figure 3. It was observed that, the ERT did not give clear details about the distribution of gas void fraction near the pipe wall. Also, they noted that the void fraction profile was different in both studies at relatively low gas velocity, which they attributed to the limitations in the back-projection algorithm used to create the images.

2. Description of the Experimental Facility

The test rig consists of four main areas, as shown in the schematic diagram of Figure 4. The middle sections of the test facility were made from a transparent Pyrex glass to keep track of the flow behaviour. The equipment also comprises one U bend at the bottom and two inverted U bends at the top, which were connected together by straight vertical pipes. Wire mesh sensor (WMS) device was installed at three locations of the vertical section, in order to identify the flow structures. The WMS employed in this study was made up of 32x32 wires, in other words transmitter and receiver wires in two planes. The axial arrangement connecting the wires is 2 mm and each one of these cross point of the wires stand for a recording point. More comprehensive description of WMS can be found in Almabrok, 2014.

Figure 4 Main parts of the test facility

3. Results and Discussion

The experiments were conducted for liquid superficial velocities of 0.48 and 0.7 m/s, while gas superficial velocity was covered a wide range, in order to extract any possible flow patterns that can be formed in a downward section of vertical pipes.

Investigation of flow regimes along downward flow was carried out by analyzing the PDFs' data, which were plotted against various velocities of gas with liquid velocities of 0.48 and 0.7 m/s, as presented in Figure 5. Different shapes of PDF were identified for different flow conditions; consequently various flow regimes were formed. Examining PDFs at the top position of the downward section did not show any discrepancies for liquid superficial velocities of 0.48 and 0.7 m/s. The plots presented similar flow regime varied from intermittent to annular. An intermittent flow was formed with the base spanning from 0.6 to 1. For liquid superficial velocity of 0.48 m/s, the maximum height of PDF for each particular gas flow rate was similar to that of liquid superficial velocity of 0.7 m/s. For the highest gas velocity, the annular flow regime with a narrow peak at high PDF of void fraction value was dominant for both velocities of liquid (i.e. 0.48 and 0.7 m/s). For liquid superficial velocity of 0.48 m/s, the flow regimes at the middle position were noted to be substantially different from those identified at the same position when liquid superficial velocity was 0.7 m/s. The dissimilarity was particularly noted when the flow in the intermittent region (for example, at gas superficial velocity of 0.25 m/s).

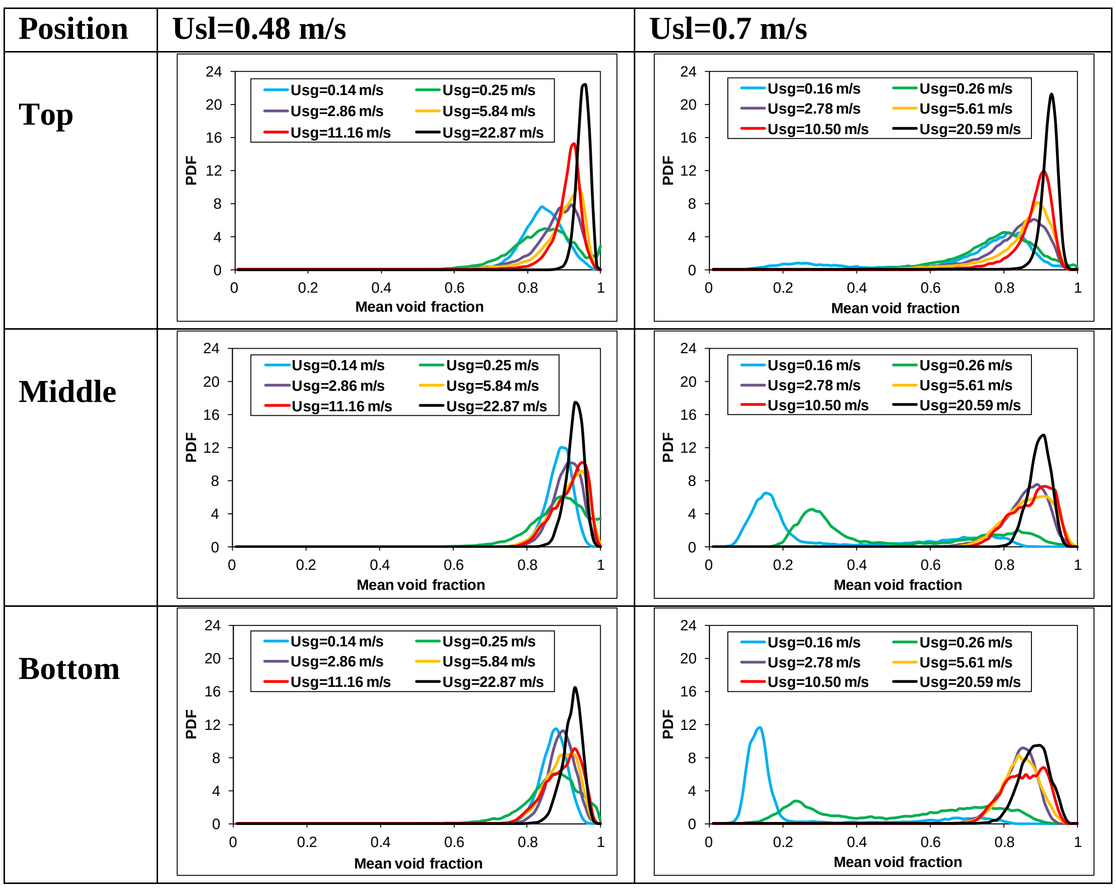


Figure 5 PDFs of the average void fraction at the top, middle and bottom positions of downward section

Analysis of PDFs' data at the bottom position for both velocities of 0.48 and 0.7 m/s shows considerable differences at the lowest flow rate, while they showed a similar tendency at the rest of flow rates. However, maximum PDF values were identified to be higher for liquid superficial velocity of 0.48 m/s. Comparison of PDFs' data at the top, middle and bottom positions confirms that, the PDFs at all positions do not show any significant differences for the lower liquid superficial velocity of 0.48m/s. It can be noted that, the intermittent flow was recognized by broadening the base values of void fraction. The PDF shape moved to a higher value of void fraction for the highest gas superficial velocity. On the other hand, for liquid superficial velocity of 0.7 m/s, significant differences observed between the three positions when low flow rate was applied. The dissimilarity between PDF curves of the three positions was based on the fact that, the flow starts to develop on entering the middle position and reaches full development on entering the bottom position.

Examining the local void fraction distribution in the downward section of the rig facility was also extended to include further flow conditions, as presented in Figures 6 and 7. It can be seen from the plots that, there are different distributions of void fraction for different gas velocities. Figures 6 and 7 show plots of local void fraction, against the wire positioned from the pipe wall towards the pipe centre and then from the pipe centre to the other side of the pipe wall. The data were obtained at the top, middle and bottom positions of the downward section. The behavior of the void fraction was obtained at eight gas superficial velocities, and at liquid superficial velocities of 0.48 and 0.7 m/s. In general, it was found that the void fraction gradually increases and varies as the gas flow rate increases to higher values. The plots of Figure 6 depict the void fraction behavior, from 90^o to 270^o positions, for liquid superficial velocities of 0.48 and 0.7 m/s. Both the 90^o and 270^o positions were located inside the quarter of the pipe's cross section in the same direction as the outer and inner curvature of the top bend respectively. The plots of Figure 6 show that, the void fraction observed at the middle position demonstrates evidence similar to that observed at the bottom position, however there was little difference. The profile of void fraction was symmetric at both positions (i.e. at the middle and bottom positions). On the other hand, an asymmetric profile of void fraction was identified at the top position. The void fraction profile at this position did not match those at the lower positions, due to impact of top bend on the fluid that flow in the 90^o side quarter of the top position. The bend impact was reduced when the flow reached the middle position.

For liquid superficial velocity of 0.7 m/s, the void fraction profile at the top position was also an asymmetric and different from those obtained at the middle and bottom positions. This was attributed to the bend effect observed at the top position. The void fraction profile at the lower (middle and bottom) positions was symmetric, implying that the bend effect was reduced when the flow reached the middle position of the downward section.

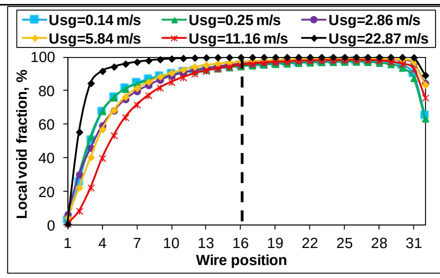
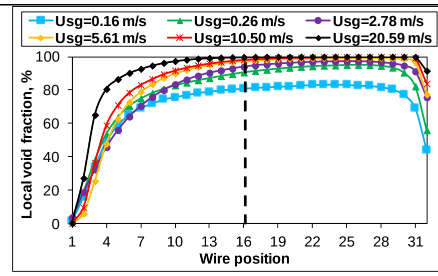
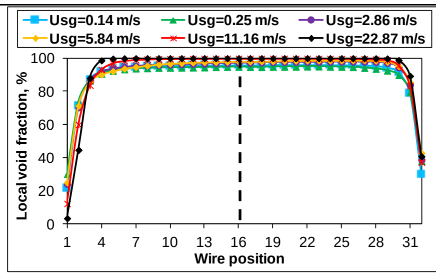
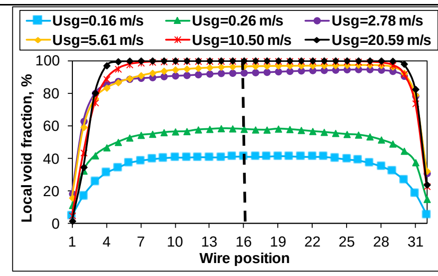
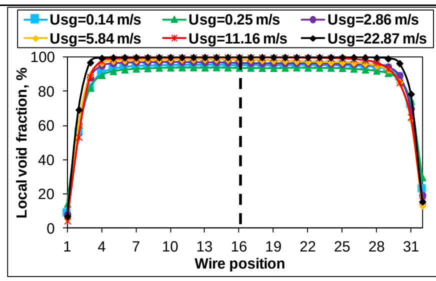
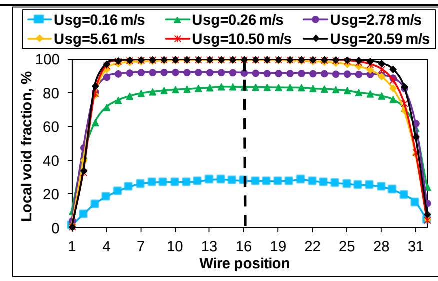
Axial position	Usl=0.48 m/s	Usl=0.7 m/s
Top		
Middle		
Bottom		

Figure 6 Local void fraction distribution from 90 to 270^{o} measured at the top, middle and bottom positions of downward section

Figure 7 depicts the local void fraction distribution along the wires located from 0^{o} to 180^{o}, for liquid superficial velocities of 0.48 and 0.7 m/s. Both the 0^{o}and 180^{o} positions were located in opposite quarters of the pipe's cross section (on the right and left sides of the 90^{o} position respectively). In general, it was observed that the peaks appeared in the centre of the pipe, and the gas void fraction exhibited greater peaks at higher gas superficial velocities.

It can be noted from this Figure that, the plots of liquid superficial velocity of 0.48 m/s have similar tendencies at the top, middle and bottom positions, indicating that the bend has no obvious impact at these locations of the pipe when this velocity of liquid was applied. For liquid superficial velocity of 0.7 m/s, different void fraction distribution was noted at the top, middle and bottom positions, as illustrated in Figure 7.

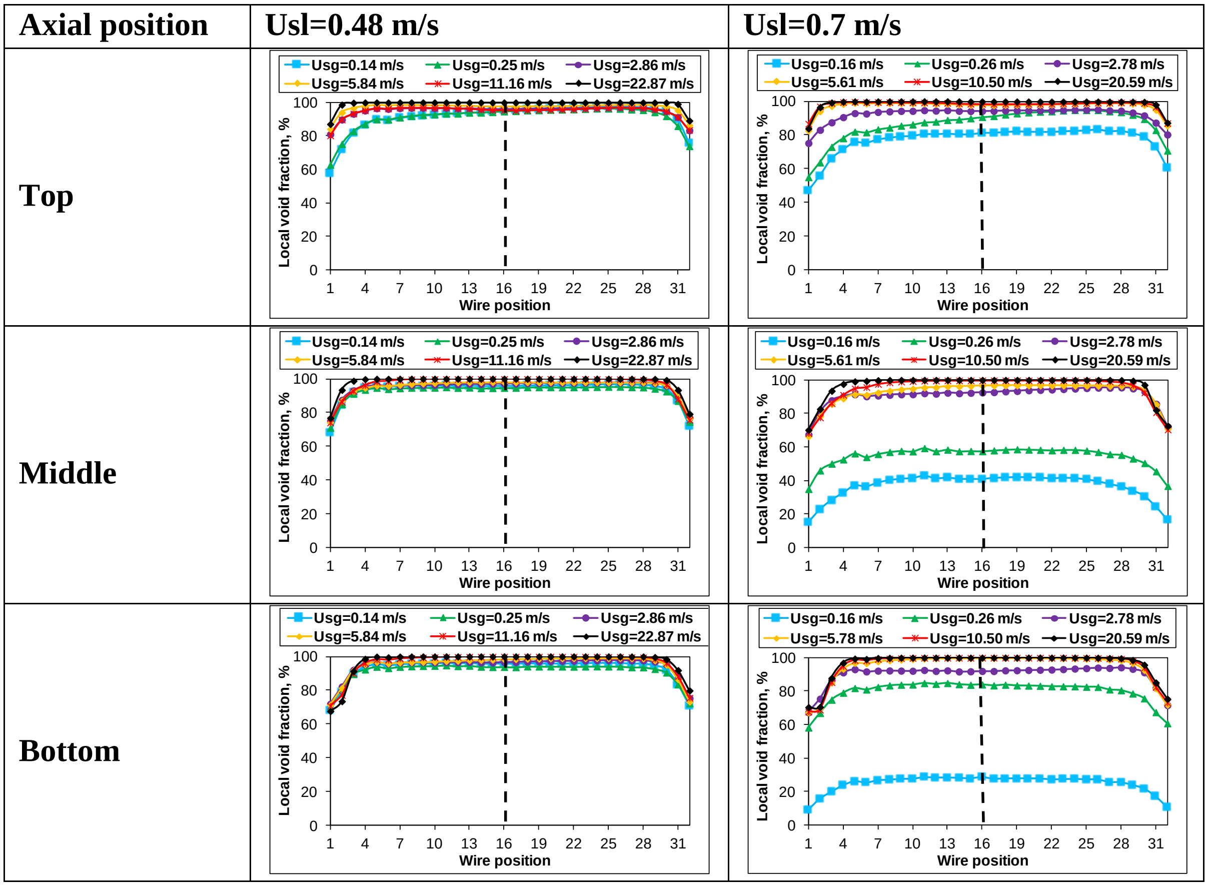


Figure 7 Local void fraction distribution from 0 to 180^o measured at the top, middle and bottom positions of downward section

4. Conclusion

In this study three flow regimes were identified in the downward pipe; these were bubbly, intermittent, and annular flow. In the bubbly flow pattern large bubbles with cap was occasionally formed. The flow structure at the top location of the pipe was significantly different from those observed at the middle and bottom regions, while the flow regimes at the middle and bottom regions were similar.

The local distribution of void fraction measured at the top region of downward section presented notably higher values at 270^o position, than that at 90^o position. This asymmetry was reduced as the fluid flows into the lower locations.

For most flow rates, the phase distribution was remarkably symmetrical at 0^o-180^o position. The cross-sectional phase distribution at the middle and bottom regions was similar, which indicate that the flow was fairly well developed on reaching the middle region of the downward section.

References

[1] A. A. Almabrok, “Gas - Liquid two-phase flow in up and down vertical pipes,” PhD Thesis, Cranfield University, 2014.

[2] Barnea, D. (1987). A unified model for predicting flow pattern transitions for the whole range of pipe inclinations. *International Journal of Multiphase flow*, 13, pp. 1-12.

[3] Cheng, H., Hills, J. H. and Azzopardi, B. J. (1998). A study of the bubble-to-slug transition in vertical gas-liquid flow in columns of different diameter. International Journal of Multiphase Flow, 24, pp. 431-452.

[4] Cheng, L., Ribatski, G., and Thome, J. R. (2008).Two-phase flow patterns and flow-pattern maps: Fundamentals and applications. Applied Mechanics Reviews, 61, pp.28.

[5] Hewitt, G.F. and Jayanti, S. (1993). To churn or not to churn. International Journal of Multiphase Flow,19, pp. 527-529.

[6] Kataoka, I. and Ishii, M. (1987). Drift-flux model for large diameter pipe and new correlation for pool void fraction. International Journal of Heat and Mass Transfer, 30, pp. 1927-1939.

[7] Nicholas P. Cheremisinoff (2000). Handbook of chemical processing equipment, Butterworth-Heinemann, USA.

[8] Olerni, C., Jia, J., Wang, M. (2013). Measurement of air distribution and void fraction of an upwards air-water flow using electrical resistance tomography and a wire-mesh sensor. Measurement Science and Technology, 24, pp.9.

[9] Taitel, Y., Barnea, D. and Dukler, A.E. (1980). Modelling flow pattern transitions for steady upward gas-liquid flow in vertical tubes. The AIChE Journal, 26, pp. 345-354.