Seeing Taylor bubble flow dynamic transient with bubble mapping method

Stella Iacovides, Mi Wang*, Qiang Wang

School of Chemical and Process Engineering, University of Leeds, Leeds, UK

*Email: M.Wang@leeds.ac.uk

ABSTRACT

The phenomenon of Taylor bubbles is usually created in gas-liquid flows and is commonly found in many chemical and process industries. Therefore, the visualisation and understanding of their flow dynamics is of crucial importance for the industries. Electrical Resistance Tomography (ERT) is generally used as non-intrusive method for the visualisation of multiphase flows. However, due to its low spatial resolution, the sharp interfaces as well as the small bubbles, are not able to be seen. A newly established method, called bubble mapping, enables three-dimensional visualisation of gas bubble size and distribution in gas-water flows. Bubble mapping (BM) is based on the transformation of the cross-sectional gas concentration tomograms to air bubbles. This paper specialises on the visualisation of the Taylor bubble and its dynamic transient. Taylor bubble has been generated using the University of Leeds facilities by applying low water superficial velocity and gas. Tomograms containing Taylor bubble and bubble transient are captured with ERT sensors. Based on the conductivity difference between water and gas, the bubble can be visualised. The performance of the bubble mapping method for visualise the size and shape of the Taylor bubble, as well as bubble flow dynamics, were explored, which would provide a potential to examine and reveal the transient dynamics of two phase flow in opaque pipe. .

Keywords Electrical Tomography, Taylor bubble, Visualisation, Transient Dynamics

Industrial Application e.g. Oil and gas, etc., or 'General'

1 INTRODUCTION

Multiphase flow can be simply defined as every mixture which contains more than one distinct phase flowing simultaneously in a system (Yeon & Tu, 2010). Such flows are very common in petroleum industries as well as in many other industries including pharmaceutical and food (NelTechnology). The dynamics of a multiphase flow in an industry, are significantly important since they determine the optimal design parameters and the operational conditions of the industry (Wang et al., 2016). Hence, multiphase flow characteristics, are of vital importance in each and every industry. The most important fact about the visualisation of multiphase flows is the understanding of the flow dynamics for safety, production and quality of each industry. One of common phenomenon that the industries have to deal with, is the Taylor bubbles which are usually produced under certain conditions during slug and plug flows.

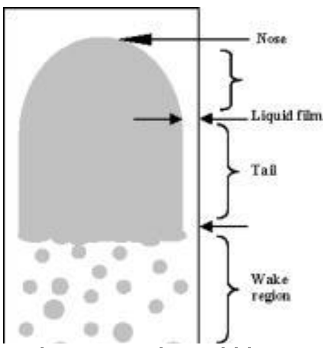

Figure 1: Taylor Bubble (Mandal et al. 2009)

For the last few years the Talyor bubble is the main topic for lots of research including theoretical, numerical and experimental studies. By definition, Taylor Bubbles are elongated gas bubbles that have been formed by coalescence of small bubbles (Mandal et al. 2009). As Figure 1 shows, Taylor bubbles are axis-symmetrical and consist of the nose (with a hemispherical shape), a cylindrical body, a tail which is characterised to be flat and the wake (Polonsky et al., 1999). They are usually characterised as bullet shaped bubbles. The liquid around the bubble moves downstream and usually has larger mean velocity than the liquid ahead of the bubble. As a result, the liquid film is injected into the liquid slung and produces a mixing zone, which is called wake region. It is usually a toroidal vortex shape and the flow is gradually re-established. (Mandal et al. 2009). The size of the Taylor bubble mostly depends of the cross section of the pipe and the fluid properties. It is a fact that, once the nose of the bubble is formed, the rest bubble size is independent with that (Mandal et al. 2009). Due to the importance of the Taylor bubble in industries, their three-dimensional visualisation and generally their multiphase flows have been studied for decades now. However, until now, three-dimensional visualisation of Taylor bubble in industrial opaque flows is still challenging.

The Electrical Resistance Tomography (ERT) is a non-intrusive technique which is normally used providing two -dimensional (2D) visualisation. For the visualisation of a multiphase flow there are several methods used nowadays including the colour mapping and surface extraction. However, using these methods the visualisation of flow patterns provide limited flow features. A newly established method called Bubble mapping can use the tomogram extracted from the ERT system to generate 3D images of multiphase flows to enhance the visibility of flow features. This technique is able to visualise various flow patterns for both vertical and horizontal pipes (Wang et al., 2016). In contrast with other techniques, it is able to reveal the small bubbles which are distributed and large bubbles with distinctive boundary in a water continuous phase of the flow. Bubble mapping method is able to define objects that are larger than 0.05 of the vessel size. This method is based on look up tables. For bubble mapping, look up tables are indexed by distribution and size of the bubbles, as well as by is surface algorithm. The first step of this new approach is the filtration of the data collected since abnormal numbers are usually appearing due to noises during the measurement. The spatial information is analysed to give the size of the small bubbles and the temporal information gives the actual superficial velocity of the gas phase and the data acquisition speed. For accurate visualisation, both spatial and temporal information are taken into account to define the dimensions of the interrogation Cell (IC). Once the IC is defined the next step is the creation of a new lookup table. This table is used to identify the small bubbles based on the translation of the concertation values which occupy fully or partially an IC. Threshold numbers are used for the calculations. In case where the gas volume fraction was more that 40% in an IC then it is assumed that a large bubble appears. When the concertation measurement is less than 5% then it is assumed that this is caused by noise error and is not taken into account. Once the small bubbles are identified and their size is measured, their position can be revealed. The next step of the bubble mapping method is to take into account the merged neighbouring bubbles and to form the large bubbles. When a cluster of cells with high gas is identified, it means that a large bubble is appearing in this area and therefore the boundary of the large bubble can be created. The final result of this method is a 3-Dimensional image. A comparison of the High-Speed camera, the Colour Mapping method and the bubble mapping method is illustrated in Figure 2 (Wang et all, 2016).

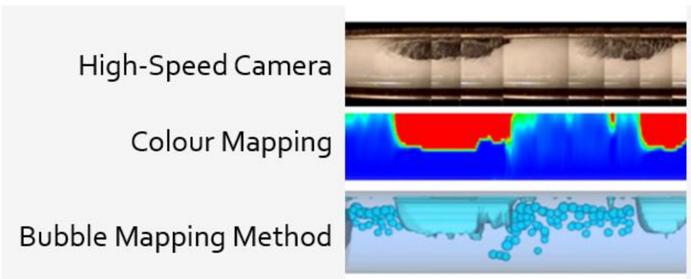

Figure 2: Comparison for High-Speed camera, Colour Mapping method and Bubble Mapping method for multiphase flow visualisation (Wang et all, 2016).

The main aim of this research is to visualise Taylor bubbles in 3D form and its transient dynamics using the bubble mapping method. During the experimental process evaluation, the newly design method for the visualisation of various flow regimes on both vertical and horizontal pipelines has been used. Once the accuracy of the software has been confirmed, Taylor bubbles have been generated and visualised during the experimental process. The capability of the software to visualise the transient dynamics of the Taylor bubble formation have been therefore checked and confirmed.

2 EXPERIMENTAL METHODOLOGY

The experiments were conducted with two steps. Firstly, an evaluation of the software capability by revealing flow regimes in existing flow data with the Bubble mapping method and then comparing the expected flow regimes according to the defined flow regimes maps in the recorded data, Then the new test focusing on reveal of the Taylor bubble formation was conducted.

The ERT system used in the study consists of a dual plane sensor, a data acquisition and finally a software to export the data as illustrated in Figure 3. The planes of the ERT sensor have a separation distance of 0.05m and 16 stainless steel electrodes distributed peripherally of each plane. Cross sectional images were produced by the ERT system, which presents the electrical conductivity of the flow on the cross section of pipe. The ERT measurements in this study were collected with the FICA tomography system which takes up to 800 frames of tomogram measurements per seconds (Wang et al, 2005) in the experiment. The final concertation tomograms were then exported using ITS P2000 data process software as the import data in the study (Industrial Tomography Systems, 2005).

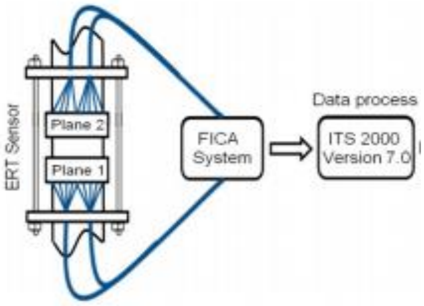

Figure 3: ERT System

In order to evaluate and check the capability of the bubble mapping method in visualising multiphase flows, concentration distribution tomograms have been used. The data used, has been collected from previous studies at the National Engineering Laboratory at Glasgow. Data from various flow regimes in the test matrix of the previous study have been chosen for the study.

For the bubble mapping method, the following data for visualisation have been added into the system.

- The start frame of the visualisation.
- The total frames required to be visualised.
- DAS; the number of frames that the ERT system collects per second (125 frames per sec.).
- Water threshold value; 0.05 has been used.
- Big bubble threshold value; 0.4 has been used.
- The pipe diameter; 5cm for University of Leeds' facilities.
- The total volume of the flow (calculated based on the superficial velocities and the diameter of the pipes).

Once these parameters were inputted correctly, the bubble method was used for the visualisation. The images being produced, based on the bubble mapping method, are subsequently compared with the videos or the expected flow regimes according flow regime maps in corresponding to flow conditions.

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The next step is to check the capability of this new method to reveal and visualise the transient dynamics of the Taylor bubble. Specifically, this part of the experimental process focused on the three-dimensional visualisations of the Taylor bubble. Knowing that Taylor bubbles are more likely to appear in a slug flow regime, the flow regime map (Figure 4) based on the University of Leeds facilities has been examined.

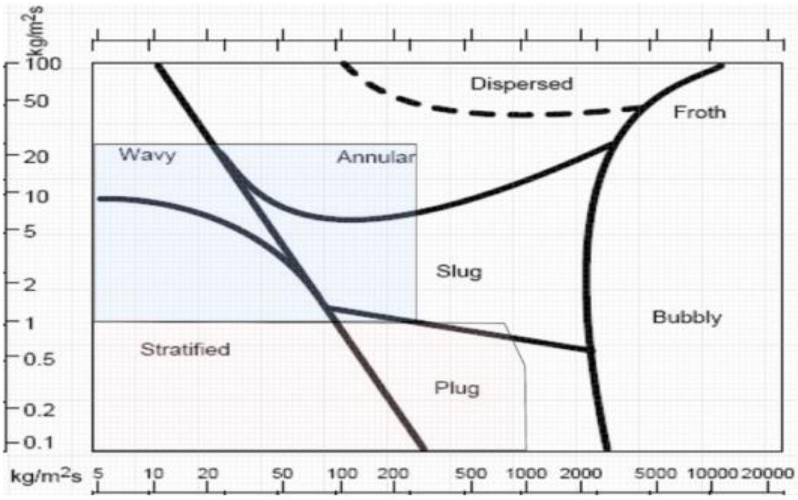

Figure 2: Vertical Flow regime map for UoL facilities (G21 manual)

Knowing that the density of the water is 997 kg/m3i and air density is 1.225 kg/m3, at room temperature, the test matrix to be used to carry out this project, need to be chosen. Five different tests have been done in order to get a fully developed Taylor bubble as Table 1 reveals.

Table 1: Test Matrices of the experiment done.

	Water Superficial Velocity (m/s)	Gas Superficial Velocity (m/s)
1	0.010	0.067
2	0.024	0.067
3	0.077	0.067
4	0.071	0.051
5	0.084	0.084

3 RESULTS - ANALYSYS

3.1. Evaluation of bubble mapping method

From the data used from previous studies, the visualisation of flow regime using the bubble mapping method was clearly confirmed. Figures 5 and 6, reflect the images that have been extracted using the bubble mapping method in contrast with an image collected form the high-speed camera. Figure 5 shows the 3D images extracted for the horizontal pipe. As the figure shows, the (a) stratified, (b) bubbly,

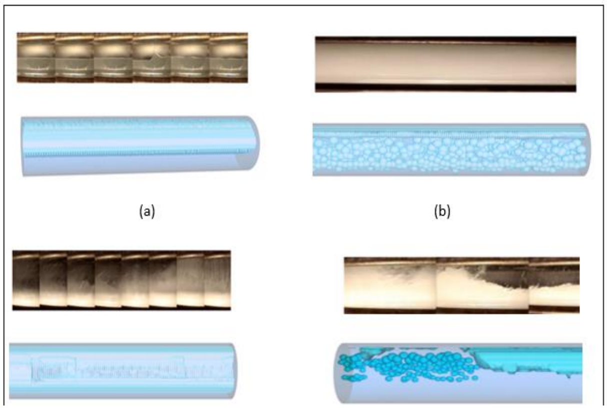

Figure 5: Visualization of horizontal flow regimes by bubble Mapping Method.

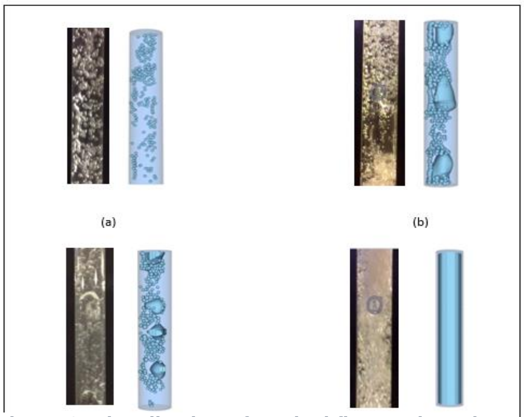

Figure 6: Visualization of vertical flow regimes by bubble mapping Method.

(c) annular and (d) slug flow regimes have been successfully visualised. Figure 6 illustrates the images extracted for the vertical pipe. As this figure shows, the (a) bubbly, (b) slug (c) plug and (d) annular flow regimes have been successfully visualised in a 3D form. Based on the text matrix of each data and the photographic recording during the experiments, the accuracy of this method has been therefore confirmed.

3.2 Tayor bubble visualisation and formation

The next and most important part of this research was to generate the Taylor bubble based on the flow regime map. The test matrices used are illustrated on Table 1. Figure 7 illutrates the results exctracted in order to generate the Taylor bubble. The numbers under each image indicateswith the flow condition in the test matrix given in Table 1.

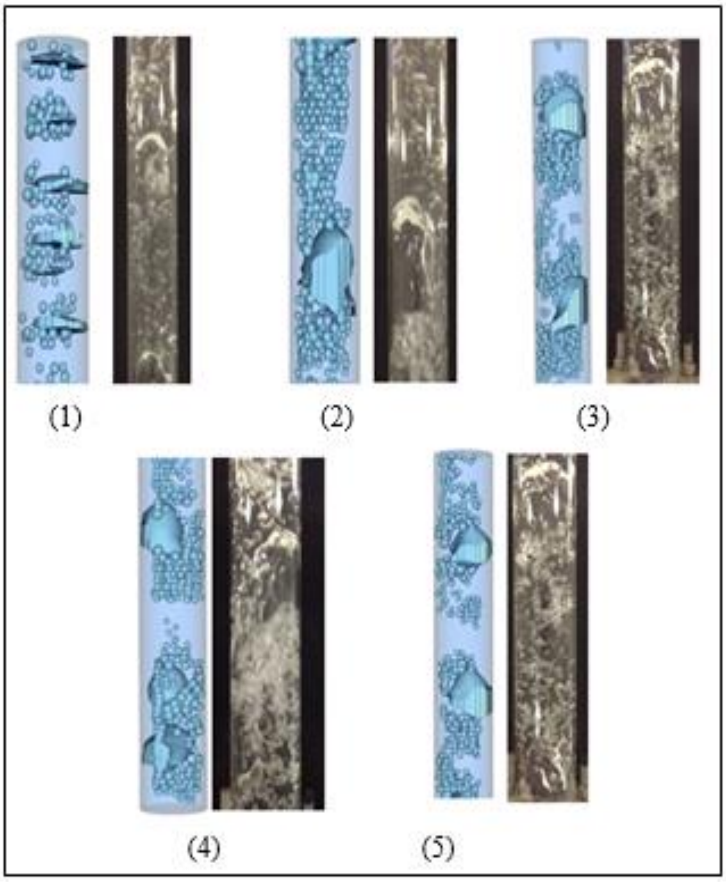

Figure 3: Generation and Visualisation of the Taylor bubble

In order to confirm once more that the bubble mapping has been visualised accurately, the mean gas concetration has been exported for certain number of frames which have been visualised during the experiment as Figure 8 shows.

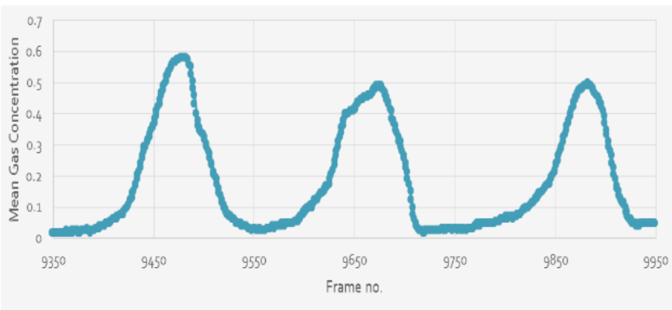

Figure 4: Comparison of the exported image with the mean gas concentration graph.

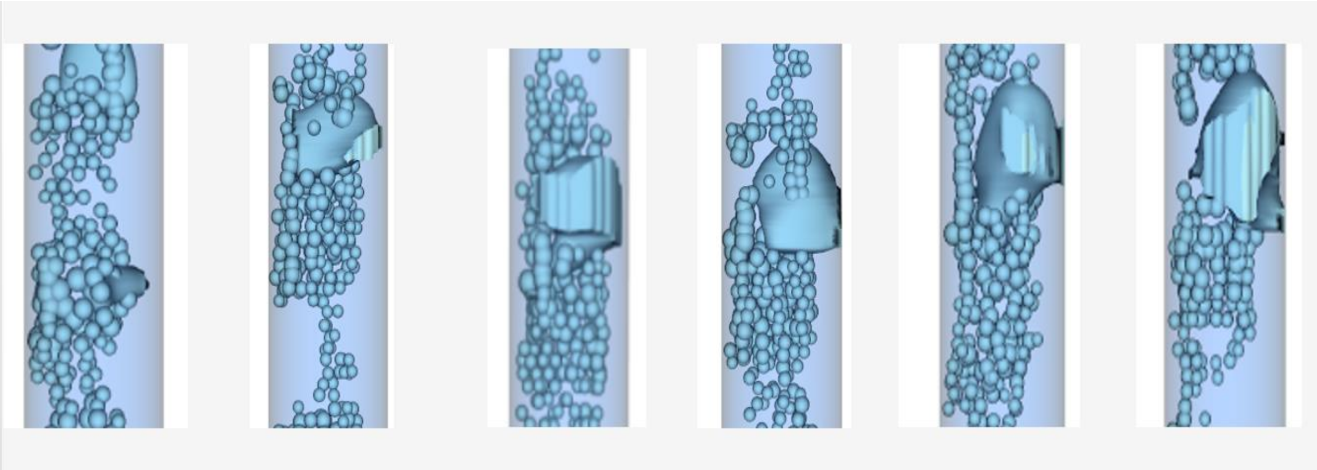

Figure 5: Transient dynamics of Taylor bubble

The transient dynamics of the Taylor bubble are then extracted by using the bubble mapping method. Figure 9 illustrates step by step the formation of the Taylor bubble. Similarly, with the bubble swarm, initially a cluster of small bubbles is created and the first bubble coalescence occurs, and hence the nose of the Taylor bubble starts to be formed. The coalescence of the small bubbles to generate the nose, occurs based on the bubble swarm. Due to the wake caused by the creation of the first bubble, the near to the wall bubbles, started to rise faster while the middle ones slower and merge with the nose of the bubble. Thereafter, the body of the bubble starts to be formed as also explained in the bubble swarming section.
For the generation of the body of the Taylor bubble, the drag and the buoyancy force are the forces affecting the shape and the velocity of the bubble. As the bubble starts to develop, as shown in Figure 9 (c), the bubbles in front of the Taylor bubble are coming together This is due to the increasing velocity of the Taylor bubble which occurs due to its high buoyancy force. The bubble swarming continues to occur as the Taylor bubble moves upward to the pipe as Figures 9 (e), (f), (g) reveal. Finally, a fully develop Taylor bubble is generated. The tail and the wake of the bubble which are clearly shown on Figure 9 (g) are generated as a result of the backflow which occurs due to drag force which drags the liquid downwards at the area of the body of the Taylor bubble.

4 CONCLUSIONS

Undoubtly, the understanding of the Taylor bubbles is of vital importance in industries since it can cause pressure drop and subsequent damages to a plant. The visualisation of multiphase flows in an opaque environment is of vital importance since transparent pipes are difficult to be installed in industries whilst the fluids used are mostly blur. Using Electrical Resistance Tomography (ERT) and a new methodology for data processing, called Bubble Mapping, a clear image of the transient dynamics of the taylor bubble has been visualised for the first time ever. The combination of these methods overcome, the ERT’s main limitation of low spatial resolution. Using the flow loop of the University of Leeds, a Taylor bubble has been generated by subsequently achieving its successful visualisation, for the first time in an opaque pipe. This article expresses in detail how the Taylor bubble has been generated and visualised on a step by step process with tomograms. The visualisation of its transisient dynamics reveals how the drag and byoyancy forces applied during the formation of a fully developed Taylor Bubble. The visualisation of a taylor bubble is therefore now possible and is expected to provide a solution to several industries as this can prevent potential plant damages .

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