IV Journeys in Multiphase Flows (JEM 2017)
March 27-31, 2017, São Paulo, SP, Brazil

Paper ID: JEM-2017-0037

METHODOLOGY TO DETERMINE TYPICAL BUBBLE SHAPE IN INTERMITTENT FLOW FROM WIRE-MESH SENSOR DATA

Eduardo Nunes dos Santos[1]**,** e.n.santos@ieee.org
Rômulo L. P. Rodrigues[2]**,** romuloluisrodrigues@hotmail.com
Rigoberto E. M. Morales[2]**,** rmorales@utfpr.edu.br
Daniel R. Pipa[1]**,** danielpipa@utfpr.edu.br
Marco José da Silva[1]**,** mdasilva@utfpr.edu.br

[1] Federal University of Technology – Paraná, UTFPR – Department of Electrical Engineering (CPGEI)
[2] Federal University of Technology – Paraná, UTFPR – Department of Mechanical Engineering (DAMEC)

Abstract. *Wire-mesh sensors are flow imaging devices which produce three-dimensional data of void fraction distribution at high resolution thus being an appropriate tool to investigate two-phase gas-liquid flows. Slug flow is typically found in petroleum production lines. This type of flow is characterized by the intermittent occurrence of gas bubbles and liquid slugs along the pipe. An important issue of these flows is the existence of a variety of regimes, depending on the flow rates of gas and liquid. The quantitative and qualitative information about shapes of the bubble nose and tail allows to study and to model the flow characteristics in order to increase safety and profit margins in operation of pipelines. In this paper we describe a methodology to determine typical bubble shape of gas-liquid slug flow, which are based on ensemble mean and median approaches, for a set of identified bubbles in a given experiment. Results show that both approaches produce similar estimations, however since median is a type of robust estimator, contours of bubbles are better defined. Three-dimensional images of typical bubbles, for five different operational conditions, are generated and reveal some details about bubble shape.*

Keywords: *two-phase flow, wire-mesh sensor, bubble identification, robust estimation.*

1. INTRODUCTION

Flows involving the simultaneous transport of gas and liquid in pipes are present in many industrial applications, among them in food, nuclear, aerospace, geothermal and petroleum industry, just cite a few. In the last decades, an intense effort has been devoted to the study and modelling of the flow characteristics in order to increase safety and profit margins in pipeline operations. An important characteristic of two phase flows is the existence of a variety of flow regimes, depending, among other variables, on the flow rates of each phase. A specific case of two-phase flow very common in oil and gas production lines is the slug flow regime (also classified as intermittent flow) (Al-Hadhrami *et al.*, 2014), which consists of liquid slugs alternating with elongated gas bubbles. Understanding slug flow is made difficult by its transient nature and the multi-dimensional fluid dynamic process that characterizes it (Havre *et al.*, 2000).

The quantitative and qualitative information about shapes of the bubble nose and tail are important to understanding the dynamic of such flows and also for supporting the development of flow models. In addition, experimental data obtained in controlled conditions (e.g. pilot plants) can be used as database for validation of computer simulations, which in turn may provide better tools for designing new and improved facilities and plants, eventually increasing safety and efficiency in operation of pipelines. Therefore, measurement and imaging of two-phase flows has received much attention in past. Hence, several flow imaging modalities have been developed, tested, and applied, ranging from high-speed cameras and image processing algorithms (De Oliveira *et al.*, 2015; Pipa *et al.*, 2014) to complex tomography systems (Li *et al.*, 2013; Frøystein *et al.*, 2014; Hu *et al.*, 2014; Thorn *et al.*, 2013).

2. MATERIALS AND METHODS

2.1 Wire-mesh sensor

Wire-mesh sensors are imaging instruments that have been used widely for gas–liquid and liquid–liquid two-phase flow measurements. It provides flow images at high spatial and temporal resolutions and it has been applied by many researchers for multiphase flow imaging. The sensor consists of two electrode planes spanned in the cross section of the pipe. Each plane of parallel stainless steel wires (transmitter and receiver) has an angle of 90° to each other and are separated by a small axial distance, forming a grid of electrodes. The associated electronics measures an electrical property (resistance or capacitance) of the flowing media in the gaps of all crossing points at high repetition rate. Based on raw data and knowing the electrical properties of substances involved, is possible to determine instantaneous phase distribution of a two-phase mixture over the cross-section (Prasser *et al*., 1998).

In capacitance wire-mesh sensor, a sinusoidal alternating voltage is applied for excitation and the receiver circuit must encompass a demodulation scheme, for details see: (Da Silva *et al*., 2007). Since the gaseous and liquid phases present different electric permittivity, the obtained sensor readings are an indication of the phase present at each crossing point. Images of cross sectional distribution of phases at high repetition rates (up to Kilohertz range) are achieved by a multiplexed probing-sensing schema.

2.2 Data processing

A 3D-fill algorithm was developed using a threshold segmentation method and the bubbles identification in the gas fraction distribution $\alpha\ (i, j, k)$ was carried out upon the three-dimensional data array measured from wire-mesh sensor in which the values are proportional to the gas volume fraction. Previous works have been used similar approach [20, 23-24] whereby a 3D-fill recursive algorithm using 6 neighbours in the 3D voxel space is used. In this work we present a 3D-fill non-recursive algorithm that uses 26 neighbours to better extract the characteristics of spatial data. Using a non-recursive technique allow us to decrease the processing time and overcome stack overflow issues due the excessively deep or infinite recursion. For the process of bubble identification, the following steps are applied:

- Binarization of the three-dimensional gas-fraction (void-fraction) matrices by thresholding the voxel of a given 3D data in order to classify into two groups (gas bubbles and liquid water).

- Identification and labelling of bubbles, i.e. assigning each bubble a unique label of the array of measured local instantaneous gas fractions.

In the binarization process the threshold is a crucial parameter for correct identification of bubble, allowing the distinction of one phase from another, and a joining scheme to connect regions and identify bubbles. If the value chosen is low, it is possible that some of the bubbles will be artificially divided or smaller bubbles may be ignored, if the threshold chosen is high, neighbouring bubbles can be identified as one bubble despite of the fact that the gas fraction gradient may suggests independent bubbles. In general, the choice depends from the noise level of the sensor raw signal.

In the identification process, a recursive fill algorithm analyses 26 neighbours (voxels share one faces, one edge and one vertex) to better extract the characteristics of spatial data, which is required to identify small bubbles in the 3D voxel space. As the bubbles are found the constituting voxels get labelled with the same identifier number. Figure 1 depicts the identified bubble as voxels grouping within the 3D-space.

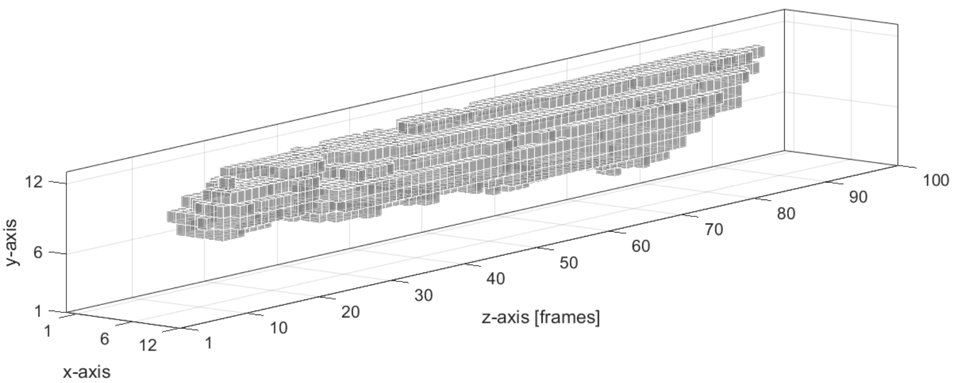

Figure 1. Identified voxels representing the bubble in the 3D-space.

In order to estimate the 3D bubble shape, the temporal index needs to be rescaled with the velocity of each individual bubble. Thus, a linear interpolation in z-axis is necessary to convert frames unity to m. In this work, each frame was convert to 2.1 mm of resolution in order to keep the aspect ratio with the x- and y-axis. Afterwards, the bubbles are aligned from their nose tips and arranged as

$$b_n\left(i, j, k'\right) \tag{1}$$

where n is the index of the bubble, i and j are the wire indices, $1<k'<K$ is a rescaled temporal index and K is typically the length of the longest bubble found in an experiment. As an illustration, $b_1(i, j, 1)$ and $b_2(i, j, 1)$ represent the cross sections adjacent the nose tips of bubbles 1 and 2 respectively (Figure 2).

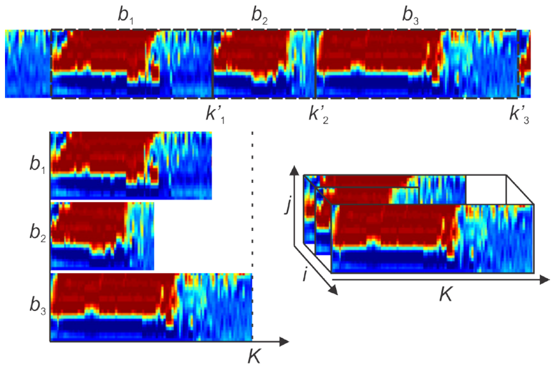

Figure 2. An example of bubble arrangement for three bubbles.

This arrangement allows to calculate a voxel-wise 3D averaged bubble as

$$\bar{b}(i,j,k') = \frac{1}{N}\sum_{n=1}^{N} b_n(i,j,k'). \tag{2}$$

Similarly, we can replace the mean operator by the median, yielding

$$\tilde{b}(i,j,k') = \mathrm{MEDIAN}_n\left(b_n(i,j,k')\right), \tag{3}$$

where $\mathrm{MEDIAN}_n(.)$ is an operator that calculates the median along the index n.

3. RESULTS

From the data set (46 measurements), five measurements were chosen to represent the main results and validation of the technique, including both non-aerated and aerated slug flows. Figure 3 shows the results of mean and median approaches for different flow conditions, namely different pairs (j_L = 1.5 m/s, j_G = 0.5 m/s to 1.5 m/s). Since alignment is performed from nose tips, both mean and median approaches generate rather sharp images around the front of bubbles. However, the tails are visibly blurrier in the mean images. In contrast, the median images show better-defined contours at the tails, with clearer edges.

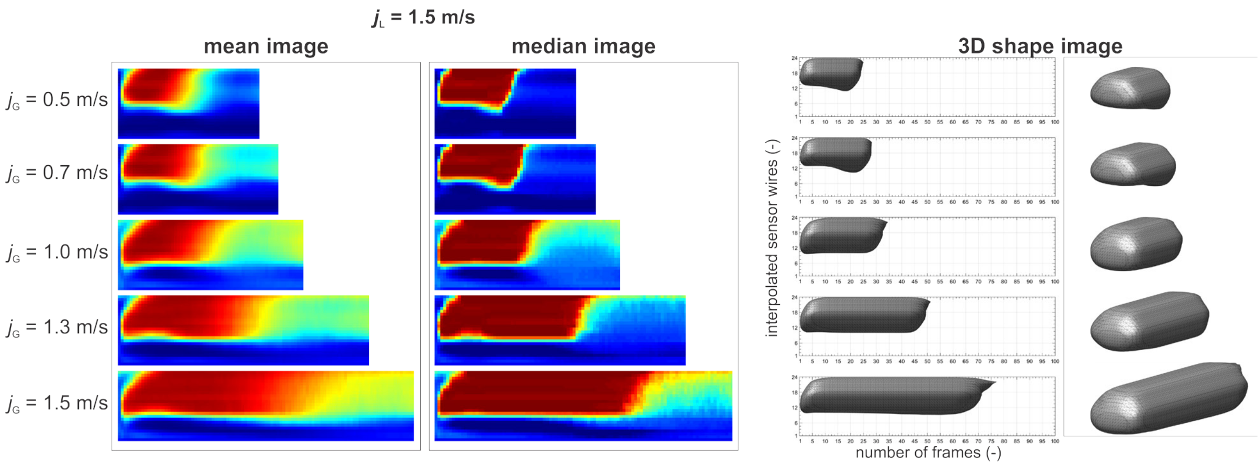

Figure 3. Results of mean and median approaches for different flow conditions. 3D superficial shapes of typical bubbles, obtained from isosurfaces of median image (liquid superficial velocity constant j_L = 1.5 m/s and gas superficial velocity varying from j_G = 0.5 m/s to 1.5 m/s).

The rationale for this difference is that the median is a more robust estimate than the mean since the mean is an unbiased estimator which is influenced by the variation of the bubbles size, where extreme values do not affect the median and its result is necessarily an element of the data set, the same not being true for the mean. This results in smooth transitions in the tails of mean estimates, whereas median estimates favour sharpness.

Figure 3 also shows the superficial shapes of typical bubbles, obtained from isosurfaces of median image. The obtained estimation from ensemble mean is, in turn, better suited for the purpose of analysing the amount of small bubbles dispersed in the slug body. Systematic studies of gas bubble shape as well as the liquid slug with and without aeration can be performed with the developed methodology.

4. CONCLUSIONS

Three-dimensional data of two-phase flow generated from wire-mesh sensors contain high degree of details and may need to undergo some type of data reduction in order to provide useful information about flow phenomena. This work investigated the use of two approaches to estimate the typical bubble shape in gas-liquid slug flow. Ensemble mean and ensemble median were applied to a set of identified bubbles allowing to observe, quantitatively, changes of the bubble shape. Results show that both approaches produce similar estimations, however since median is a type of robust estimator, contours of bubbles are better defined. Three-dimensional images of typical bubbles were generated and reveal some details about bubble shape. The bubble size was also evaluated by validating the bubbles velocity and superficial gas velocity. Further studies of gas bubble shape as well as the liquid slug shape can be performed with the developed methodology.

5. ACKNOWLEDGEMENTS

The author Eduardo thanks the financial support from the National Agency of Petroleum, Natural Gas and Biofuels - ANP - Financier of Studies and Projects - FINEP - Ministry of Science and Technology - MCT - through the Human Resources Program of ANP for the Oil and Gas Sector (PRH-ANP/MCT) and Program for Formation of Human Resources (PETROBRAS) under PRH10-UTFPR.

6. REFERENCES

Al-Hadhrami L.M., Shaahid S.M., Tunde L.O., Al-Sarkhi A. Experimental Study on the Flow Regimes and Pressure Gradients of Air-Oil-Water Three-Phase Flow in Horizontal Pipes. *Sci. World J.*, vol. 2014, pp. 1–11, 2014.

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

De Oliveira W.R., De Paula I.B., Martins F.J.W.A., Farias P.S.C., Azevedo L.F.A. Bubble characterization in horizontal air–water intermittent flow. *Int. J. Multiph. Flow*, vol. 69, pp. 18–30, Mar. 2015.

Frøystein T., Kyandal H., Aakre H. 2005 Dual energy gamma tomography system for high pressure multiphase flow *Flow Measurement and Instrumentation* 16 99-112

Havre K., Stornes K., Stray H. *Taming Slug Flow in Pipelines*. 2000.

Hu B., Langsholt M., Liu L., Andersson P., Lawrence C. 2014 Flow structure and phase distribution in stratified and slug flows measured by X-ray tomography *International Journal of Multiphase Flow* 67 162–79

Li Y., Yang W.Q., Xie C.G., Huang S.M., Wu Z.P., Tsamakis D., Lenn C. 2013 Gas/oil/water flow measurement by electrical capacitance tomography *Measurement Science and Technology* 24 074001

Pipa D.R., Zibetti M.V.W., Morales R.E.M., Da Silva M.J. Typical bubble shape estimation in two-phase flow using inverse problem techniques. *Flow Measurement and Instrumentation*, v. 40, p. 64-73, 2014.

Prasser H-M., Böttger A., Zschau J. A new electrode-mesh tomograph for gas-liquid flows, *Flow Measurement and Instrumentation*. 9, pp. 111-119. 1998.

Thorn R.G., Johansen G.A., and Hjertaker B.T. 2013 Three-phase flow measurement in the petroleum industry *Measurement Science and Technology* 24 012003

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.