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STUDY OF THE VELOCITY OF ELONGATED BUBBLES IN TWO-PHASE SLUG FLOW IN A HORIZONTAL PIPELINE

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Abstract. *Geometric distribution are assumed by different two-phase flows, named flow patterns depending on liquid and gas velocity, pressure, fluid properties, among others. The gas-liquid two-phase flow is subject of several studies due the wide frequency on industries, using as example the slug flow which has as mainly characteristic the phases that are distributed in an elongated bubble and a liquid piston. Several theoretical models have been proposed, which need additional correlations for the resolution of the model equations. One of the most used correlations are given for the bubble front velocity that has been analyzed by several authors. The objective of this work is to analyze the bubble front velocity behavior due the velocities in a horizontal pipeline of 25.8mm of internal diameter and 11m of length seeking expand knowledge in this type of flow and compare the results obtained from experiments with correlations obtained from the literature. The results indicate divergence with other correlations, mainly for low flow rates. Finally, his work can be used as a database for analysis of two-phase flow models.*

Keywords: *multiphase flow, pipe, bubble, pressure drop*

1. INTRODUCTION

Two-phase flow can be defined as a flow involved by two phases in an interface, at least one of the phases have to be a fluid, whether liquid or gas. The other phase should also consist of a fluid or solid particles in the flow. The research field of a two-phase gas-liquid flow includes various areas in a series of different technologic contexts having as some applications, oil extraction, cooling of reactors in nuclear power plants, among others.

Two-phase flow can appears in different geometric distributions denominated flow patterns, depending geometric parameters and fluid properties. One of the main flow patterns is slug flow, consisting on an elongated bubble and a liquid slug in an intermittent passage. One of the most important parameters to modeling and analyze slug flow is the bubble velocity.

The main characteristics of slug flow is that their phases are distributed in an intermittent sequence of gas bubbles and liquid pistons. The most of the works in the literature were based on the superficial velocities of liquid and gas, defined as

$$J_L = \frac{Q_L}{A}; \quad J_G = \frac{Q_G}{A}; \quad J = J_L + J_G \tag{1}$$

where J_L, J_G and J are the superficial velocities of liquid, gas and mixture, respectively. Q_L and Q_G are the liquid and gas flow rates, respectively.

The flow patterns of two-phase gas-liquid flow can be obtained for different conditions or fluid properties. This classification is denominated flow map. The flow map of Taitel & Dukler (1976), as shown in Fig. 1, is one of the most used flow maps for the researchers.

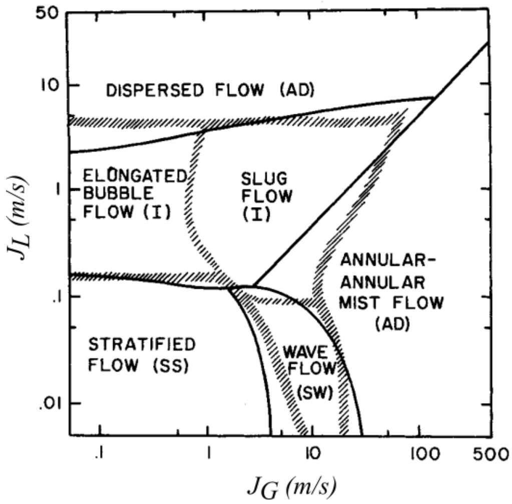

Figure 1 – Flow map for two-phase gas-liquid flow proposed by Taitel & Dukler (1976)

The liquid and gas flow rates can be measured with different sensors. One of them is the rotameter, – used in this work – based on the balance of buoyancy, drag and gravity forces (Vicencio, 2013).

To calculate the main parameters of flow, various theoretical models has been proposed, but all of them need some correlations to solve the system of equations resulting from momentum and mass balances.

One the most important constitutive relation is for the bubble front velocity. The most used expression is given by Nicklin et al (1962). These expression has been usefully by several authors, giving no great divergences between them.

Thus, in this work, an experimental study was carried out using combinations of liquid and gas flow rate between 10 and 30 LPM for liquid, and 5-40 LPM for gas. The objective of this study is to understand the physical of the problem and to compare the data obtained in this work with other works of the literature.

2. METHODOLOGY

One of the more utilized correlations is given by Nicklin et al. (1962),

$$V_D = C_0 J + C_\infty \sqrt{gD} \tag{2}$$

where C_0 is the average coefficient of movement of the bubble, V_D is the drift velocity.

The drift velocity can be considered as the velocity that the bubble is propagated in the pipe, and was described by Nicklin et al. (1962) as

$$V_D = C_\infty \sqrt{gD} \tag{3}$$

where C_∞ is a constant to be determined. Several author calculate values of C_∞, some of them are shown in Table 1. It should be noted that there are no great divergences between the values of the constants.

Table 1. Values of C_0 and C_∞ from some works.

Authors	C_0	C_∞
Nicklin et al (1962)	1.2	0.542
Gregory e Scott (1969)	1.35	0
Bendiksen (1984)	$\begin{cases}1.05 + 0.15\sin^2\theta \\ 1.2\end{cases}$	$\begin{cases}0.54\cos\theta + 0.355\sin\theta \\ 0.35 sen\theta\end{cases}$
Woods & Hanratty (1996)	1.10	0.52

3. EXPERIMENTAL PROCEDURE

The experiments were carried out in the experimental facilities of the Research Group of Mechanical Egineering (GPEM – UniBrasil) were used. The facilities consist on a two-phase pipeline of 11m-length, 26mm-diameter, a centrifugal pump and rotameters in the liquid pipeline, and an alternate compressor, and rotameters in the gas pipeline. The scheme of experimental facilities are shown in Fig. 1 and 2.

The flow rates measured in this work is between 10-30 LPM for liquid, and 5-40LPM for gas, due to the capacity of facilities, giving 40 experimental combinations of flow rates of liquid and gas.

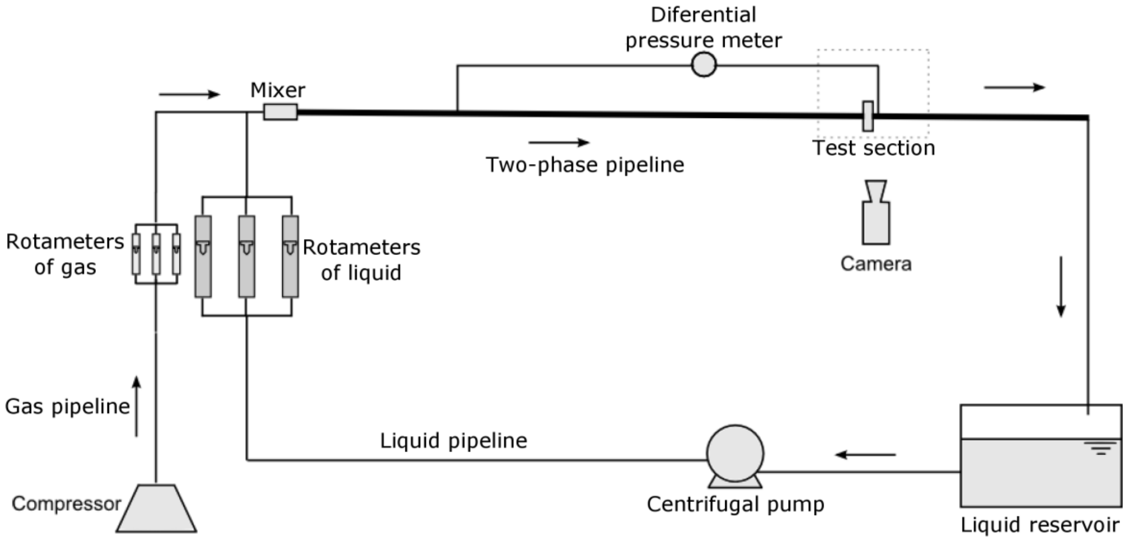

Figure 1. Experimental facilities to analyze the two-phase flow at the GPEM/UniBrasil.

Figure 2. Images of the experimental facilities for two-phase flow at GPEM-UniBrasil

The translational velocity of the elongated bubble was measured using a high speed video recorder. The recorder was used at a 120 fps. Those pictures have been taken in a section of 19.8 cm. Inside this section, a bubble is identified in the right benchmark. After this, the same bubble is identified in the left benchmark. The distance traveled by the bubble is given by the equation:

$$d_B = \frac{\begin{bmatrix}\text{Distance of reference} \\ \text{in the picture, in pixels}\end{bmatrix}}{\begin{bmatrix}\text{Distance covered} \\ \text{by the bubble in the picture, in pixels}\end{bmatrix}} \begin{bmatrix}\text{Distance of reference} \\ \text{in the picture, in meters}\end{bmatrix} \quad (4)$$

The time between one and other bubble is given in function of image frequency acquisition by a video recorder, thus the picture number between the left image bubble and right image bubble:

$$t_B = \frac{\begin{bmatrix}\text{Number of picturres between a bubble in right side} \\ \text{and the same bubble in the left side of the picture, in pixels}\end{bmatrix}}{[\text{Frequency of acquisition of the camera, in Hz}]} \quad (5)$$

Thus, the translational velocity of the elongated bubble can be calculated through the equation:

$$U_{TB} = \frac{d_B}{t_B} \quad (6)$$

4. RESULTS

In this work was analyzed the behavior of the bubble velocity for different superficial velocities of liquid and gas. For a same superficial velocity of gas, the velocity of the bubble does not remain constant, but increased as a liquid velocity of the liquid increases. Thus, all the experiments developed in this work, a linear correlation has been proposed

In Fig. 3 is shown the behavior of the velocity of translation of the elongated bubble as a function of the surface velocity of the liquid, for several superficial velocities of gas constant.

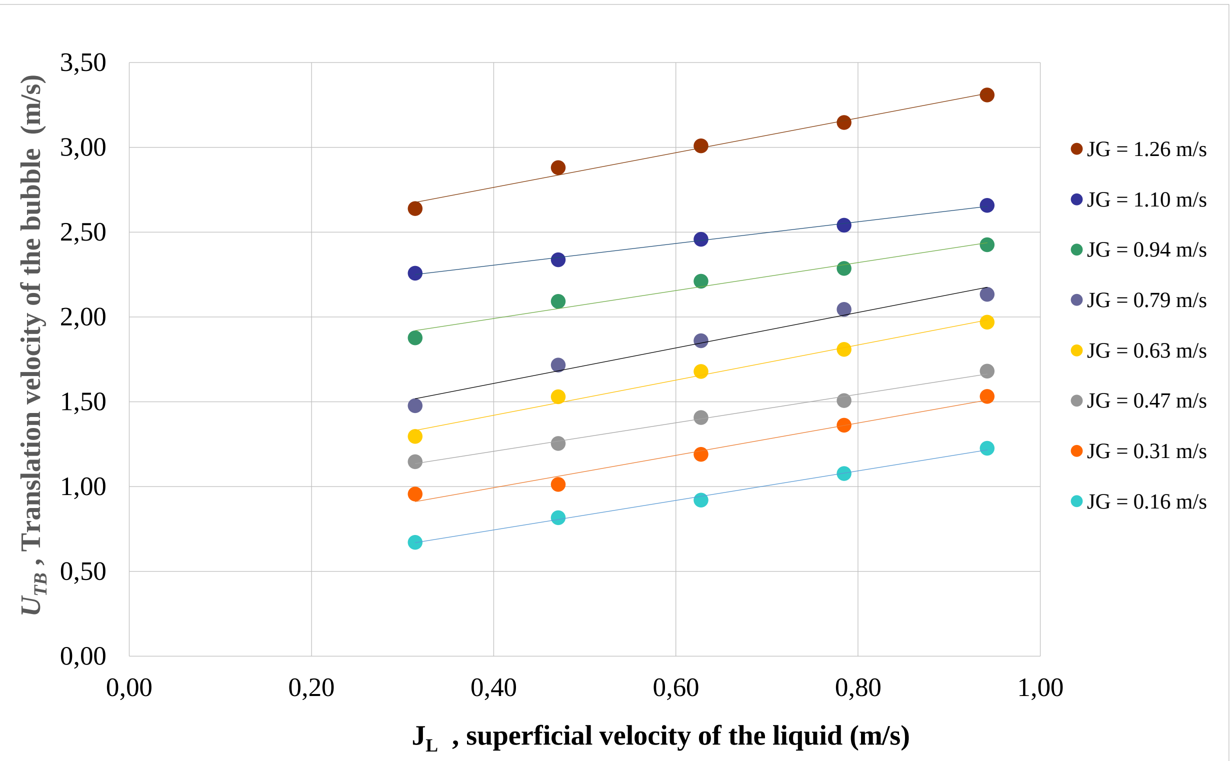

Figure 3. Bubble's translational speed along the function of the surface velocity of the liquid, for the constant surface velocities.

As seen in Fig. 3, for the same gas surface velocity, the velocity of the bubble does not remain constant, but increases as the surface velocity of the liquid increases, because the liquid piston that comes after the bubble acts as a piston which increases movement of the bubble. This is one of the reasons why authors such as Nicklin et al. (1962), Bendiksen (1984), and many others consider bubble velocity as a contribution of both liquid velocity and gas velocity, as well as velocity of slip.

To compare the data obtained in this experiment with others found in the literature, a correction was made Linear to bubble's translational speed along the function of the surface velocity of the mixture. An equation obtained from the experiments is given by:

$$U_{TB} = C_0 \times J = 1.39 \times J \tag{7}$$

This correlation is shown in Fig 4, where it was compared with the correlations mentioned in Table 1.

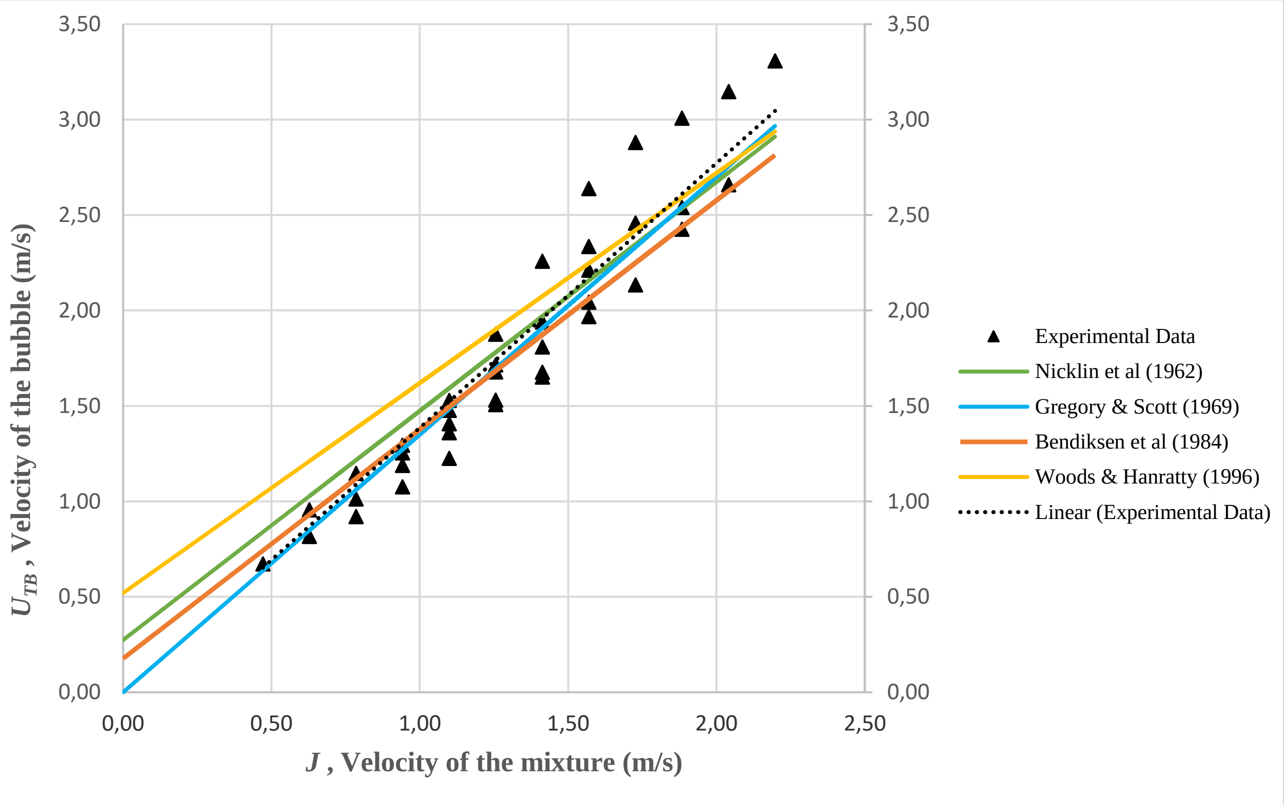

Figure 3. Bubble's translational speed as a function of the surface velocity of the mixture.

In Fig 4, can be observed the comparison between different correlations encountered in the literature, as Nicklin et al (1962), Gregory & Scott (1969), Bendiksen et al (1984) and Woods & Hanratty (1996). Some observations are indicated in Table 2. It should be noted that the correlation with best agreement with the experimental data is given by Gregory & Scott (1969).

Table 2. Observations of correlations of the literature compared with experimental data of this work.

Authors	***J* up to 1.5 m/s**	***J* above 1.5 m/s**
Nicklin et al (1962)	- Moderated agreement - Errors between 1.5% and 31.9%	- Moderated agreement - Errors between 0.3% and 18.6%
Gregory e Scott (1969)	- Good agreement - Errors between 0.4% and 21.0%	- Moderated agreement - Errors between 0.1% and 19.1%
Bendiksen (1984)	- Poor agreement - Errors between 1.3% and 54.4%	- Moderated agreement - Errors between 1.6% and 16.0%
Woods & Hanratty (1996)	- Poor agreement - Errors between 0.3% and 22.0%	- Moderated agreement - Errors between 0.4% and 22.0%

5. CONCLUSION

In this work an experimental study was developed to analyze the velocity of translation of the elongated bubble in the horizontal gas-liquid two-phase flow, in order to study its behavior and compare the measurements obtained in this work with other correlations founded in the literature.

The methodology was developed by using a high-speed camera of 120fps, in a two-phase,11m-length, 26mm-I.D., acrylic pipeline. The extraction of data was made manually, using a spreadsheet, by identification of a same bubble front in different images.

From the experiments, a correlation is proposed (see Eq. 8). It can be observed that the velocity obtained in this work also exhibits a linear behavior as a function of the surface velocity of liquid. The values of this correlations are similar to the other correlations.

It should be noted that when the Eq. 8 is compared with other correlations (Fig. 4), the results are similar. The more approximated correlation is the Gregory & Scott’s (1969) correlation.

Some divergences can be encountered by higher values of mixture velocity. This can occur due to complexity of measurement of the bubble velocity for higher flow rates, where a lot of instabilities due to turbulence exists. In this case, it is recommended to use more complex procedures to obtain this speed to minimize such errors.

Finally, this work can serve as database for other works of slug flow, by analyzing pressure drop, characteristics lengths and other parameters required for theoretical models

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Bendiksen, K.H., 1984. An experimental investigation of the motion of long bubbles in inclined tubes. *International journal of multiphase flow*, 10(4), pp.467-483.

Gregory, G.A. and Scott, D.S., 1969. Correlation of liquid slug velocity and frequency in horizontal cocurrent gas-liquid slug flow. *AIChE Journal*, 15(6), pp.933-935.

Nicklin, D. J. "Two-phase bubble flow." *Chemical Engineering Science* 17, no. 9 (1962): 693-702.

Vicencio, Fernando E. C., 2013. *Caracterização experimental do escoamento intermitente líquido-gás em tubulações horizontais*. Master Thesis. Federal University of Technology-Paraná.

Woods, B.D. and Hanratty, T.J., 1996. Relation of slug stability to shedding rate. *International journal of multiphase flow*, 22(5), pp.809-828.

8. RESPONSIBILITY NOTICE