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BULLET FLOW VOID FRACTION IMAGING COMPARISON WITH CORRELATIONS

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Abstract: In this work, the study of the void fraction of experiments is carried out through image processing for a bullet-type flow pattern. The void fraction is a fundamental parameter used for the design of heat exchange equipment. The result of the void fraction obtained is compared with 8 correlations widely used for its determination at an industrial level. It is seen in the comparison that the image processing has a comparable level to the correlations and that, by optimizing the processing, it will be possible to use it to develop new, more efficient correlations.
Keywords: Void fraction, two phase flow, image processing

INTRODUCTION

TWO-PHASE FLOW, FLOW PATTERNS

Two-phase flow is when two fluids go through the same conduit, and for this study we will focus on the liquid vapor fluid.

Two-phase flow is present in many unit operations, in condensation and evaporation processes, separation of components, purification and nucleation, which is why its study has always been very important in the chemical, nuclear, and oil industries, among others, in Currently, its importance has extended to smaller conduits where the dominant physical properties can change, such as surface tension, the influence of the boundary layer, roughness, thus much of the research is aimed at increasingly intensive use. of compact heat exchangers, as in the case of cooling systems for mini and micro components such as computing processors, lasers, power supplies.

FLOW PATTERNS

The liquid-gas flow can occur in different geometric configurations, that is, the shapes that the phases acquire when flowing called patterns or flow regimes, each one with special characteristics that depend on the types of flow present such as physical properties, vapor quality, flow speed, in addition, the type of conduit through which they flow, the roughness, the diameter, as well as the direction and orientation of the flow, vertical, horizontal, inclined, ascending, descending.

Flow patterns are an important part of the design, since it has been seen that the pressure drop will depend on how each phase is distributed (Urbina-Salas, Vázquez-Ramírez, García-Sánchez, & Martínez-Rodríguez, 2021). Flow patterns can be identified, also with a void fraction value.

VOID FRACTION

The void fraction is one of the most used parameters in the study of two-phase liquid-gas flow, since it is fundamental for determining the pressure drop, heat transfer and the present flow pattern. The void fraction is represented by one of the following definitions:

- Volumetric void fraction: Indicates the volume fraction occupied by the gaseous phrase.
- Void fraction of cross-sectional area. Transverse area that is occupied by the gas phase. This is shown in figure 1.
- Local void fraction. It is the fraction of vapor at a specific point or in a small volume

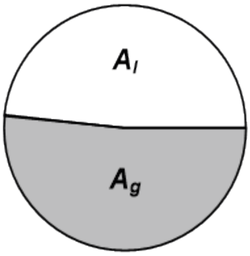

Figure 1. Sectional area void fraction. Cross section view of a tube

Due to the importance of the fluid fraction, there are many correlations according to (Pietrzak & Płaczek, 2019) they can be cataloged in 5 models

Homogeneous model, phase slip, Kαh parameter model, drift flux model and individual correlations.

- The homogeneous model considers that the flow is a uniform mixture that moves at the same speed

$$\alpha_h = \left[1 + \frac{\rho_g}{\rho_l}\left(\frac{1-x}{x}\right)\right]^{-1}$$

- The phase slip model considers that each phase moves at different speeds and uses a phase slip coefficient, S, such that the equations are of the form.

$$\alpha_{ps} = \left[1 + S\frac{\rho_g}{\rho_l}\left(\frac{1-x}{x}\right)\right]^{-1}$$

y

$$S = \frac{u_g}{u_l}$$

Where: u_g y u_l are the velocities of the gas and liquid phases respectively

- The parameter model: $k\alpha_h$ is based on a correction factor applied to the homogeneous model
- The slip or drift flux model takes into account the slip speed between the phases, u_{gm} y and the so-called distribution parameter C_o.

$$\alpha = \frac{u_g}{C_0 u_m + u_{gm}}$$

Several studies have been carried out where an attempt is made to develop a single global void fraction prediction equation, however, it has been shown that if the present flow pattern is not taken into account, there are large deviations from the theoretical values with the experimental. (Godbole, Tang, & Gha, 2011) this shows that the way the flows are distributed in the pipe is a parameter that must be taken into account.

JUSTIFICATION

It has not been possible to develop a single void fraction prediction equation. It has been shown that if the present flow pattern is not taken into account, there are large deviations of the theoretical values from the experimental ones. This shows that the way the flows are distributed in the pipe is a parameter that must be taken into account.

EXPERIMENT

Each of the flow regimes presents a specific behavior that affects the pressure drop, and therefore the work of the pumping system, and the heat transfer.

In this work, the comparison of void fraction correlations that are widely used is carried out with an analysis carried out on an experiment using image processing for a Bullet-type flow pattern.

This flow pattern was selected due to its importance in fluid transport processes and, furthermore, that it allows speed and shape variables to be measured in a very specific way.

An image processing system is used to calculate the size of the bullet and perform an analysis of the amount of air-water passing through a duct at a given time.

METHODOLOGY

1. Select an experiment that allows obtaining a stable bullet-type flow pattern.

2. Record the experiment on video and obtain images

3. Processing the images by applying the appropriate filters and extracting the information

4. Obtaining the area and 3D reconstruction for volume

5. Experimental measurement of volumetric void fraction

6. Perform void fraction calculations with experimental correlations

7. Compare the results of the correlations with those obtained from image processing

RESULTS

IMAGE PROCESSING OF EXPERIMENTAL DATA

Data are taken from experiments obtained from a prototype of an internal heat exchanger (Vazquez-Ramirez, Polley, Riesco-Avila, Rios-Orozco, & Aguilar-Moreno, 2012), which was videorecorded at 440 frames per second. It was verified that the experiment was stable and that the two-phase flow pattern was bullet type. In this flow pattern, the gas phase joins in the center forming a figure similar to a bullet, in such a way that the liquid phase surrounds said bullet and accompanies the movement. Figure 2 shows one of the frames taken from the video before any procedure. A flow pattern detection technique was used through neural networks to support the selection of the flow type (Urbina-Salas, Vázquez-Ramírez, García-Sánchez, & Martínez-Rodríguez, 2021).

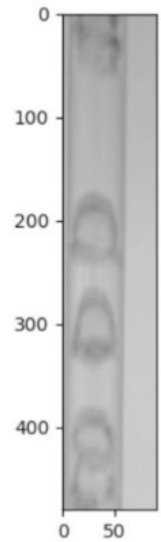

Figure 2. Adjusted test video image

Image processing allows us to calculate the areas of the image that correspond to each of the phases, although this is the area of an image and does not correspond to the volume of each of the phases, it serves us to carry out an initial analysis.

At the same time, the processing of the images allows us to take data on the bullets, their shape, height, diameter, and with this data it allows us to reconstruct their volume approximately.

Image processing is carried out using programming in Python, in such a way that the program detects:

- Border of the test area consisting of a glass tube,
- Tube thickness detection
- Detection of bubble edges in bullet shapes

4 shapes are detected that correspond to the formed bullets, shown in figure 3, with the detection of the edges and with figure 4, identification of areas.

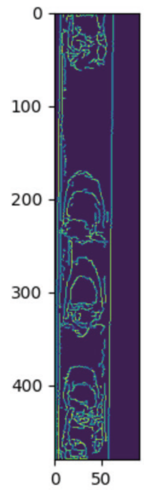

Figure 3. Image with edge detection processing

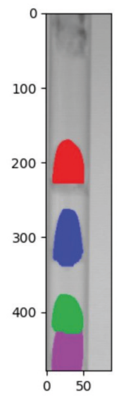

Figure 4. Identification of bullets by color for the case study.

The calculation of the areas of the image that correspond to:

- Area through which both flows flow, which correspond to the test flow
- Area occupied by the gas phase that corresponds to the bullets'
- Area occupied by the liquid phase

PHASE VOLUME

The volume is calculated through the images considering a reconstruction from the area, with measurements of heights, base widths and the bubbles are sectioned as cylindrical parts and spherical caps as appropriate.

Figure 5. Quick volume measurement. Volume decomposition

The bubbles are tracked across multiple images to confirm that the area and volume remain constant.

It is necessary that, once measuring the 4 bullets that remain constant in the video, it was calculated that the fraction of the area of the image that corresponds to the gas phase is 0.331 for the gas phase, and for the volume ratio, applying reconstruction it is calculates that the void fraction is 0.3538

VOID FRACTION CORRELATIONS

For the choice of correlations, it was taken into account that they belonged to some of the categories that exist to calculate the void fraction; those that are widely used or that have proven to be good when applied in channels with diameters equivalent to the study were used.

The correlations are:

1. Homogeneous flow correlation. In this case it is not considered that there is slip between the phases and they go at the same speed.

2. Parameter correction correlations,

- An empirical Chisolm correlation is used due to its broad and simple application (Chisolm, 1983), as well as the Armand correlation (Armand, 1946)

3. Phase slip correlations. Those that have analytical development are used

- A kinetic energy correlation is used (Zivi, 1964)

- A Fauske momentum flow correlation is used (Thome & Cioncolini, 2015)

4. A widely used analytical correlation called CISE (Premoli, Francesco, & Prina, 1971)

In addition, two correlations that were best adjusted for Bala-type flows were selected according to the studies carried out by (Godbole, Tang, & Gha, 2011), these are:

- Bonnecaze correlation (Bonnecaze, Erskine, & Greskovich, 1971)
- Nicklin correlation (Nicklin, Wilkes, & Davidson, 1962)

The correlations are shown in the following table:

Name	Co-relation
Homogeneous Flow	$\alpha_h = \left[1 + \frac{\rho_g}{\rho_l}\left(\frac{1-x}{x}\right)\right]^{-1}$
Chisolm	$\alpha_{Ch} = \left[1 + S_{Ch}\frac{\rho_g}{\rho_l}\left(\frac{1-x}{x}\right)\right]^{-1}$ $S_{Ch} = \left(1 + x * \left(\frac{\rho_l}{\rho_g} - 1\right)\right)^{1/2}$
Armand	$\alpha_{ar} = (0.833 + 0.167x)\left[1 + \frac{\rho_g}{\rho_l}\left(\frac{1-x}{x}\right)\right]^{-1}$
Zivi	$\alpha_{Zi} = \left[1 + S_{Zi}\frac{\rho_g}{\rho_l}\left(\frac{1-x}{x}\right)\right]^{-1}$ $S_{zi} = \left(\frac{\rho_l}{\rho_a}\right)^{1/3}$
Fauske	$\alpha_{Fa} = \left[1 + S_{Zi}\frac{\rho_g}{\rho_l}\left(\frac{1-x}{x}\right)\right]^{-1}$ $S_{Fa} = \left(\frac{\rho_l}{\rho_g}\right)^{1/2}$
CISE	$S_{CISE} = 1 + E_1\left[\left(\frac{y}{1+yE_2}\right) - yE_2\right]^{1/2}$ $E_1 = \frac{1.578}{Re^{0.19}}\left(\frac{\rho_L}{\rho_G}\right)^{0.22}$ $E_2 = 0.0273\frac{We}{Re^{0.51}}\left(\frac{\rho_G}{\rho_l}\right)^{0.08}$
Bonnecaze	$\alpha_B = \frac{u_g}{C_O u_m + u_{gm}}$ $u_{gm} = 0.35\sqrt{gD}\left(1 - \frac{\rho_G}{\rho_L}\right)$ $C_o = 1.2$
Nicklin	$\alpha_N = \frac{u_g}{C_O u_m + u_{gm}}$ $u_{gm} = 0.35\sqrt{gD}$ $C_o = 1.2$

Table 1. Void fraction correlations and formulas used

Correlations were applied for the experiment according to the following parameters

Datos			
	Liquid	Steam	
Density	997.061962	2.45280153	kg/m³
Viscosity	0.00089051	1.8766E-05	Pa-s

x=	0.00077259		
Diameter	0.009	m	
Mass flow =	0.03174778	kg/s	

Table 2. Parameters and properties of the experiment

Applying the correlations we then have the following void fraction values and their deviation to the results of the image processing part

Source	**Void fraction**	**Deviation**
Image processing	0.2474	-
Homogeneous	0.2694	-8.9%
Chisolm	0.2397	3.1%
Armand	0.2244	9.3%
Zivi	0.0474	80.8%
Fauske	0.0180	92.7%
CISE	0.1756	29.0%
Bonnecaze	0.2188	11.5%
Nicklin	0.2188	11.5%

Table 3. Void fraction and deviation values with respect to image processing

According to the results, we can observe in the values obtained that using image processing gives us values comparable to

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using void fraction correlations, there are distortion errors due to the curvature of the glass of the experimental installation, as well as the fluctuations present due to the movement of the flow and the compression of the gas phase. However, the values provided by image processing are more appropriate than using some of the correlations since they are developed for specific experiments or their application ranges are limited.

The correlation of homogeneous flow gives values very close to image processing, this is because in bullet flow, the velocity of the gas phase tends to equal that of the general flow and there is no recoil or slip phenomenon.

The Zivi and Fauske correlations are developed from simplified conservation equations and have been shown to be better for annular flow patterns, in this case they have a deviation from the results of more than 80%.

The Chisolm equation with a variation of 3.1%, the lowest in the comparison, and the Armand equation with 9.3% are very appropriate and confirm why they continue to be widely used despite the time they have been developed.

The Bonnecaze and Nicklin slip equations have a deviation of 11.5%, which are still very appropriate since they are within the parameters of the studies carried out previously.

CONCLUSIONS

Image processing was performed for bullet flow produced in an experimental facility. It was determined that the void fraction has a value of 0.2474 through volume reconstruction of the bullets formed by the gas phase.

The result is compared with homogeneous type void fraction, parameter correction, phase slip and analytical correlations. The Chisolm correlation turned out to give the most approximate values to that obtained by image processing, the Armand correlations, and homogeneous flow are applicable and recommended due to their simplicity. The Bonnecaze and Nicklin correlations provide values with relatively small deviations and can be considered for application when direct measurement of the void fraction is not possible.

It is expected to improve the volume reconstruction procedure, as well as be applied to other flow patterns.

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