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IMAGE PROCESSING TO CALCULATE THE LIQUID FRACTION OF A TWO-PHASE KEROSENE-WATER FLOW

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Abstract. The study of the two-phase liquid-liquid flow is not ample explored compared to the two-phase gas-liquid flow, however, it is extremely important in several industrial applications, such as in the oil and chemical industry. Thus, the patterns and geometric arrangements must be studied, as well as the contributing factors for those variables, such as the fraction of each liquid present in the pipe, since this parameter can indicate instability, and then enable the identification of characteristics of flow patterns. Therefore, it is aimed through digital image processing, to obtain the fraction of each liquid present in an image of a liquid-liquid flow. The analysis is carried out with the "Matlab" software, which receives a two-dimensional image of a two-phase water-kerosene flow, and a pre-treatment is executed to provide a better distribution of colors and normalize the histogram of the input data. Then it is implemented the filling of voids and binarization, moreover, the image is transformed into a matrix with three dimensions and submitted to projections to obtain a format similar to the real cylinder of the flow. Finally, the calculation of the liquid fraction is done by counting white and black pixels in the resulting matrix, and for this, the fraction is obtained from the ratio of pixels associated with a liquid and the total number of pixels in the matrix, counting a given correction by the circular mask created, to preserve the calculation of the liquid fraction in the cylindrical section of interest. It is worth noting that images with different flow rates of liquids are analyzed, all, although, photographed in an acrylic tube with a diameter of 25 .4 mm. Thus, this study intends to develop a program capable of estimating the fraction of each liquid in a two-phase liquid-liquid flow without providing initial parameters such as pipe diameter and flow rates, so that the results are obtained only with the use of the image and an autonomous algorithm for application to data obtained under similar conditions of light exposure and viewing.

Keywords: two-phase flow, image processing, liquid fraction, phase fraction, oil-water flow, horizontal flow.

1. INTRODUCTION

Two-phase flow is found in several industrial applications, for example, the food, oil, and chemical areas. The studies of these types of flow contribute to the improvement of various processes and consequently favor these sectors. A special characteristic of two-phase flow is the flow patterns, which are the distribution of the phases along the channel. In two-phase flows, the patterns vary according to parameters such as velocities and volumetric fractions of each phase, diameter and orientation of the duct, and the physical properties of the fluids, like density and viscosity. In gas-liquid flow, the main patterns are the bubble, slug, churn and annular for vertical flow and stratified, intermittent, and annular for horizontal flow. For liquid-liquid, there is no consensus on the definition of the flow patterns. Jana et al. (2006) identified four patterns for vertical flow: dispersed bubbly, bubbly, churn turbulent, and core annular. For horizontal flow, Trallero et al. (1997) identified six patterns: stratified flow, stratified flow with mixing at the interface (ST & MI), the dispersion of oil in water (Do/w & w), oil-in-water emulsion (o/w), dispersion of water in oil and oil in water (Dw/o & Do/w) and water in oil emulsion (w/o), as shown in Fig. 1.
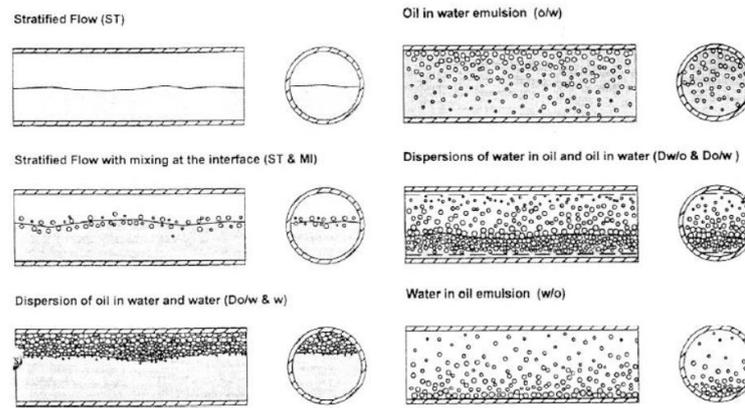
Figure 1. Patterns for horizontal oil-water flow.
Available from: TRALLERO, J. L.; SARICA, Cem; BRILL, J. P. A study of oil-water flow patterns in horizontal pipes. SPE Production & Facilities, v. 12, n. 03, p. 165-172, 1997.

However, those registered by Mazza and Suguimoto (2020) for vertical liquid-liquid flow (water -kerosene) are, Dispersed, Core Annular, Bubbly, Churn Turbulent, and Elongated Water Drop, and by Suguimoto (2016) for horizontal liquid-liquid flow (water-kerosene) are, Oil dispersed in water and water (Do/w&w), Stratified with surface mix (ST&MI), water emulsion in oil (w/o), oil emulsion in water (o/w), Water dispersed in oil and Oil dispersed in water. These patterns are usually exposed in graphical maps that depend on the superficial velocity of each phase, as shown in Fig. 2.
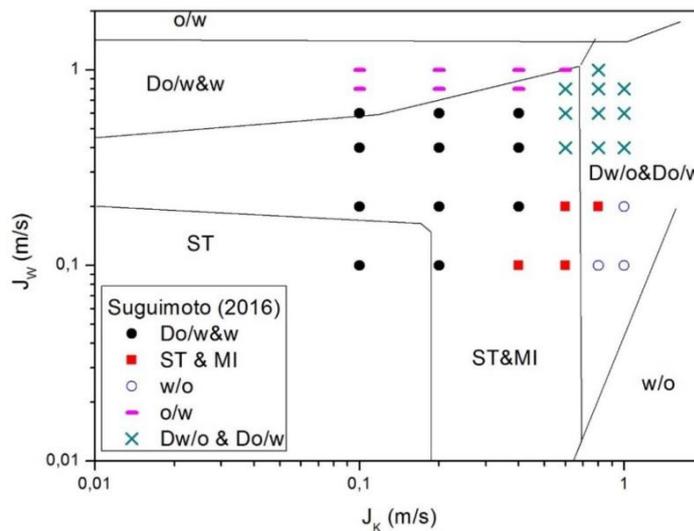

Figure 2. Comparison of the patterns obtained by Suguimoto (2016) represented by the points and the patterns obtained by Trallero (1997) represented by the lines.
Availiable from: SUGUIMOTO, Fabio. Experimental Analysis of Liquid-Liquid Flow. 2016. Doctoral dissertation (Doctorate in mechanical engineering in the field of thermal and fluids) - Campinas State University, [S. l.], 2016.

Knowing the flow pattern of a system, it is possible to obtain information on parameters including heat transfer, pressure drop, velocity, slip between phases and pressure gradient, and, consequently, its stability, once it is defined with parameters linked to the value of the volume fraction. As in Xu (2007) to identify instability with the phase inversion in oil-water flow identified as a point of significant pressure drop, PIP (Phase Inversion Point), characterized by the critical volume fraction of the dispersed phase, Fig. 3, while for gas-liquid flows, for example, it is related to the pressure drop generated due to friction.
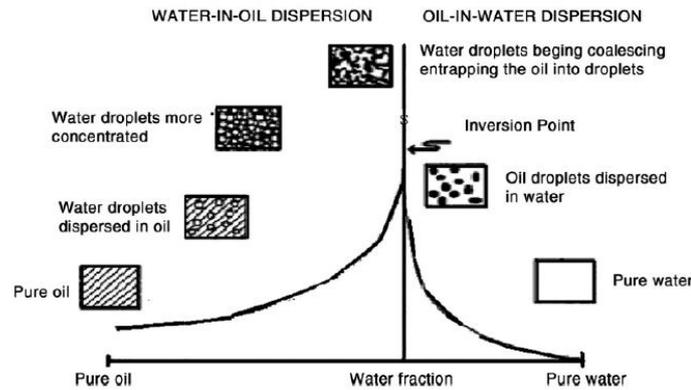
Figure 3. Graphical representation of the phase inversion in an oil-water flow.
Available from: ARIRACHAKARN, S.; OGLESBY, K.D.; BRILL, J.P. An analysis of oil/water flow phenomena in horizontal pipes, SPE 18836. 1989.

The calculation of the fraction of each component in closed systems of two-phase flows, that is, a mixture composed of two components in the same phase or in different phases, is given by the analysis of the volume occupied by each substance, however, for purposes of calculations it is done, the ratio of the volume of the component by the total volume of the region under analysis., the formula for the average volume fraction (α) in a region of the pipeline is Eq. (1):

$$\alpha_n = \frac{V_n}{AL} \qquad (1)$$

Where V_n is the volume of fluid/phase n, A is the flow section area, L is the total length of the pipe, and the subscript n is the identification of the phase or fluid.

For the two-phase gas-liquid flow, the amount of gas is called the void fraction, while for the liquid-liquid, it is called the liquid fraction of a given phase or component, being, in both cases, the average volumetric concentration of a phase. The liquid-liquid flow is less studied compared to gas-liquid. Recently, Mazza and Suguimoto (2020) studied the kerosene-water flow. They determined the flow behavior with the analysis of parameters such as pressure loss, phase inversion, and others. The experiment was carried out in a vertical tube of 26 mm in diameter, with phase speeds ranging from 0.1 to 1 m/s, in addition to quick-closing valves in a test section, allowing measure the volume fraction. Still, an impedance probe and high-speed video recording were used to determine the flow patterns, being identified as dispersed bubbly, annular core, bubbly, turbulent churn, and elongated water drop, the latter not been recorded in the literature yet. Furthermore, it was verified that the phase inversion occurs when the kerosene input fraction is β_k=0.35, in addition, the drift velocity is associated with the misalignment of the dispersed fraction, the mixing velocity profile, and the distribution constant. Other parameters, such as pressure, presented a good correlation with the Blasius theory, except for the bubbly and turbulent churn patterns, obtaining a deviation of 5 to 25%, contributing to a better projection of pipelines.

Xu (2007) presented the importance of studying the simultaneous flow of oil and water given its occurrence in the oil industry, as the studies of oil-water flow patterns carried out by important names in the area demonstrate that despite similarities with the patterns observed in gas-liquid flows, there are particularities that should not be ignored, such as transition criteria of the flow pattern. Additionally, it brings different analysis techniques, visual observation, high-frequency impedance probes, particle image velocimetry, and others. Continuously, the author presents the main difficulties in the analysis of this type of flow, such as the existence of different interfaces and discontinuities, which implies that the lack of a generalized flow map for oil-water, specific parameters for each must be considered in which situation, such as inversion phase, surface velocity, etc.

Currently, several technologies are used for collecting data from two-phase flow patterns, an example is photographic cameras, which allow the recording of the flow inside a pipe at a given time t, which is associated with image processing techniques, making it possible to obtain information about the photographed flow. Several authors have carried out studies of two-phase flow through image processing.

Chakraborty and Das (2018) used the temporal and spatial characteristics of the flow to analyze digital images where flow with different phases (gas-liquid) is presented. Thus, the methodology consists of filming the flow, which will allow the selection of a suitable study area for processing, enabling the visualization of the interface change with time, the average intensity time series can be treated similarly to the signals obtained from conventional conductivity, capacitance, or optical probe. The authors observed that concordant and perpendicular lines provide relevant information about the flow patterns, and thus, proposed a graph of the flow regimes along the diameter of the tube.

Song et al. (2009) presented the analysis of different methods of processing digital images (by mass and by concentration) and their results obtained in terms of flow parameters. For this, the camera exposure time was controlled, obtaining a clear image of the flow, from which the analysis was carried out by the mass flow method, after the wave motion equation and the Otsu method, it was possible to obtain data such as particle velocity and volumetric concentration,

these results were confirmed by the experiments carried out by the pneumatic transport equipment. Dibek and Demir (2017) presented a method for calculating the void fraction in pipes without providing any additional information about the flow, thus processing images by analyzing a two-phase flow with R600a fluid with the MATLAB Image processing Toolbox software, obtaining method validation with a maximum deviation of 7% from the literature.

Amaral et al. (2013), proposed an image processing technique for the analysis of horizontal tubes with a two-phase liquid-gas flow since most studies focus on vertical analysis. The biggest challenge of the horizontal study is the detection of the Taylor bubble. Thus, the method developed an algorithm where happen a definition of bubble characteristics through the analysis of a high-speed video, then submitting the images to techniques such as watershed segmentation, top hat filter, and others, allowing the detection of bubbles, the results showed good similarity with those obtained in the literature.

Pal et al. (2019) proposed the identification of the flow pattern using image processing with the help of MATLAB software and the SDF (Symbolic Dynamic Filtering) technique, an algorithm was developed with lighting optimization, binarization, and limitations to determine the diameter and distribution of the bubbles. Dinaryanto et al. (2015) presented the slug flow record and its processing in MATLAB, generating a binary image, to calculate slug parameters, such as slug frequency and gas velocity. Finally, this method proved to be effective for measuring slug characteristics compared with the data already provided for the experiment.

Shi (2013) demonstrated the experiment carried out, initiated by capturing the gas-liquid flow in a transparent horizontal tube, thus, obtaining information such as area, length, and central coordinates by image processing. Therefore, with the use of cosine similarity, it is possible to compare flow patterns already known in the literature, allowing an approximate reconstruction with the binarized image obtained. During the experiment, some difficulties were observed, being the precise determination of the gas-liquid flow models and the ideal definition of weights for the similarity of the cosines.

Most studies related to image processing in two-phase flows deal with gas-liquid flows, therefore, there is a need for further studies in liquid-liquid flows.

2. METHODOLOGY

The void fraction was evaluated based on the image analysis using the Matlab Image Processing and Treatment toolkit. The images used for the study were taken from Suguimoto (2016), they were obtained from horizontal water and kerosene flow, with 0.026 m diameter and 9.25 m length, photographs were taken with a high-speed camera and with a digital camera for different speeds of water and kerosene. The kerosene fraction was obtained with a local impedance probe adjusted along the radius of the channel, more information about the experiments may be obtained in Suguimoto (2016).

The developed algorithm presented 12 steps, including the image input, manual cutting, reading of initial parameters, such as dimensions and color channels, the application of the developed mask, filling of voids, creation of a 3D matrix from the image treated, creating of a circular mask, subtracting it from each layer of the 3D matrix, counting white and black pixels in each level of the 3D matrix, subtracting extra black pixels from the circular mask, calculating the void fraction of each layer of the 3D matrix and finally, calculating the average void fraction of the image.

2.1 Image reading and manual cutting

The "Matlab" program receives the selected image, in JPG format, and initially, it is necessary to manually cut the image to select only the pipe with the flow, as shown in Fig. 4.
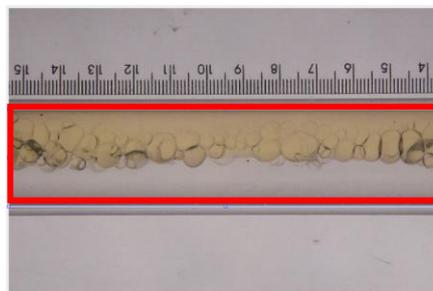

Figure 4. Cut in the image under analysis, to select only the flowing fluid.

2.2 Reading of initial parameters and image processing

Then, the image sizes are taken, such as a 2D matrix, rows, columns, and colors. After that, a mask developed with the "ColorThreshold" function is applied, the mask consists of converting the RGB image to HSV, then adjusting the image histogram, with the adjustment of maximum and minimum values for the three-color channels, thus, only the colors within this range remain in the image, finally allowing its binarization, as shown in Fig. 5.
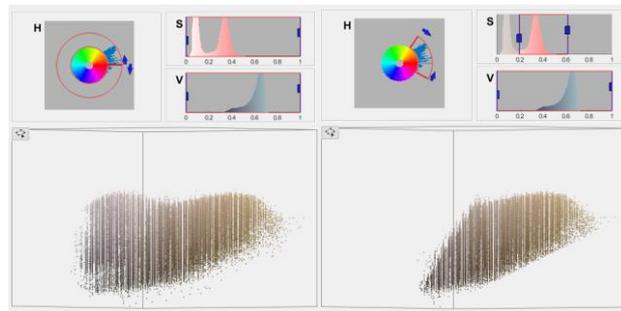
Figure 5. Image processing is based on the variation of the histogram range of each color channel.

With the completion of the mask application, possible discontinuities found are filled, as shown step by step in Fig. 6.
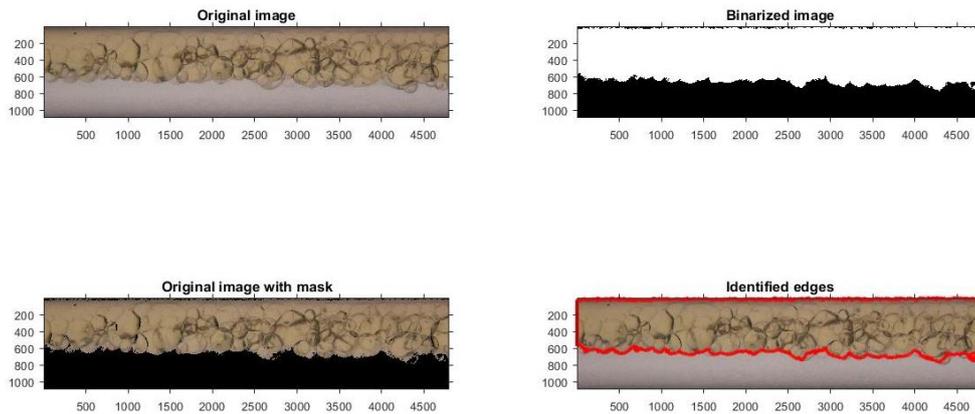

Figure 6. Original cropped image, image with the application of the mask developed with the ColorThrehold application, image binarization with filling of discontinuities, and highlighting of the identified final edges.

2.3 Creating a 3D matrix and circular mask

From this result, the image is read as a matrix and is repeated the number of times of its coordinated X (known as the diameter, in pixels), as shown in Fig. 7, thus forming a 3D matrix in parallelepiped format, from which will be later be analyzed layer by layer in the coordinates XZ. Then, a circular mask is made to subtract from each matrix XZ layer, a circle of diameter corresponding to the pipe used, Fig. 8, resulting in a 2D matrix in a square format with black edges in the regions outside the flow, Fig. 9.
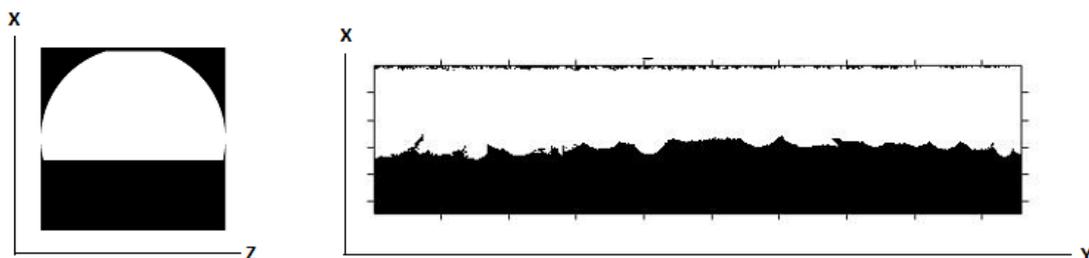
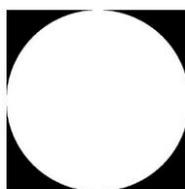

Figure 7. Coordinates adopted in the analysis

Figure 8. Circular mask to form the cylindrical analysis of the 3D matrix.
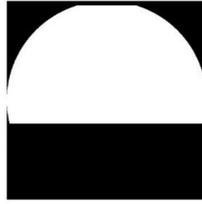
Figure 9. XZ image of layer 2 of the 3D matrix (1092X1092X4797) with the application of the circular mask over the flow

Then, layer by layer the 2D matrices (XZ) are submitted to the counting of black pixels, the inside the pipe diameter is characterized as water, and the outside of the pipe is due to the circular mask, so the number of black pixels outside the pipe must be subtracted later for not alteration of the results. Also, is realized the counting of the white pixels that are characterized as kerosene. The water (black pixels), must be the counting of black pixels of the image and the subtraction of the black pixels present in the initial circular mask in Eq. (3) because those were pixels that just filled the space outside the pipe. The kerosene fraction, must be the division of the kerosene (white pixels) for the total area, identified as the sum of white pixels and the black pixels Eq. (5), so with the 3D matrix will be calculated a considerable number of kerosene fractions since every layer will return a value, so for the analysis taken the average for the whole 3D matrix created.

$$N^{\underline{o}}\ black\ pixels = \ ImageXZ_{black} - Circular\ mask_{black} \tag{3}$$

$$N^{\underline{o}}\ white\ pixels = \ ImageXZ_{white} \tag{4}$$

$$Kerosene\ fraction = \frac{N^{\underline{o}}\ white\ pixels}{N^{\underline{o}}\ black\ pixels + N^{\underline{o}}\ white\ pixels} \tag{5}$$

3. RESULTS

By analyzing the digital images of the water-kerosene flow at different combinations of superficial velocity it is possible to obtain the kerosene fraction. Figure 10 show the kerosene fraction comparison between the experimental, obtained by Suguimoto (2016), and the image processing. Figure 10 (a) is for water superficial velocity of 0.1 m/s and kerosene superficial velocities varying from 0.1 to 1m/s. Figure 10 (b), (c), (d), (e) and (f) the water superficial velocities are 0.2, 0.4, 0.6, 0.8 and 1 m/s consequently.
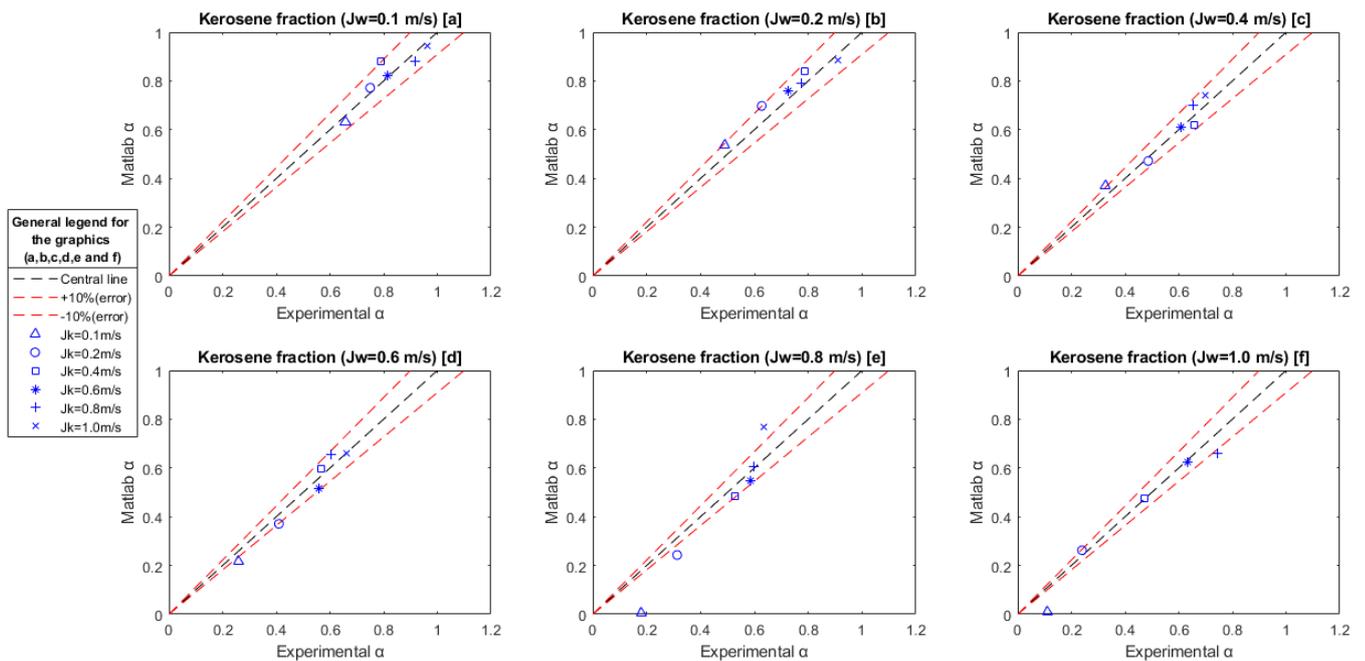

Figure 10. Comparison between the fractions of liquids for different speeds of water and kerosene

It can be noted with the error bar of 10% in the Fig. 10, that errors greater than 10% occurred at the water and kerosene velocities, respectively, 0.1-0.4 Fig. 10 (a), 0.2-0.2 Fig. 10 (b), 0.4-0.1 Fig. 10 (c), 0.6-0.1 Fig. 10 (d), 0.8-0.1 Fig. 10 (e), 0.8-0.2 Fig. 10 (e), 0.8-1 Fig. 10 (e), 1-0.1 Fig. 10 (f) and 1-0.8 Fig. 10 (f). It is observed that in general, the error can be attributed to the analyzed image, with the possibility that the algorithm has not recognized the flow correctly, or because it does not represent the real flow inside the pipe, since a projection is made with Matlab, an error that can be visually attributed mainly to cases with higher fluid velocity.

Figure 11 to 19 shows the original images and their respective binarizations of the cases with an error greater than 10%.

Figure 11. Flow Jw-Jk (0,1-0,4)

Figure 12. Flow Jw-Jk (0,2-0,2)

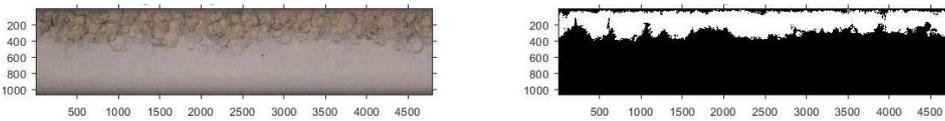Figure 13. Flow Jw-Jk (0,4-0,1)

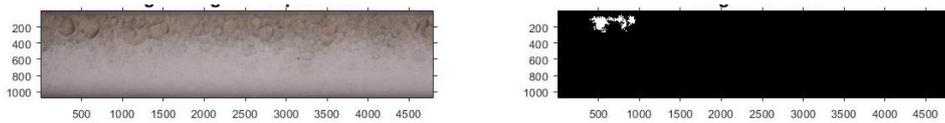Figure 14. Flow Jw-Jk (0,6-0,1)

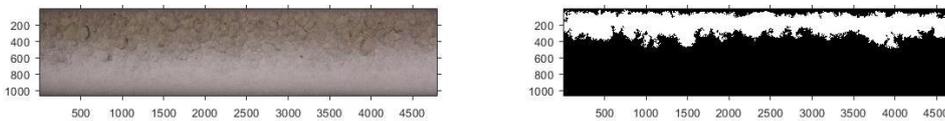Figure 15. Flow Jw-Jk (0,8-0,1)

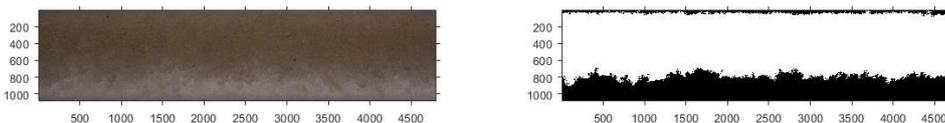
Figure 16. Flow Jw-Jk (0,8-0,2)
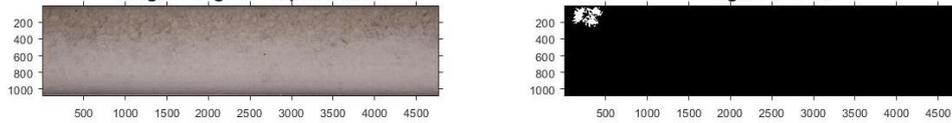

Figure 17. Flow Jw-Jk (0,8-1,0)
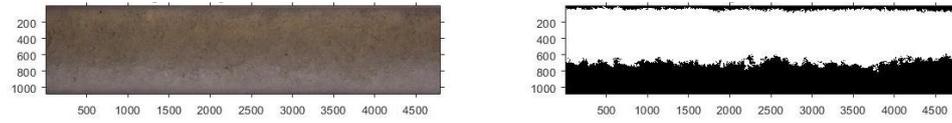
Figure 18. Flow Jw-Jk (1,0-0,1)

Figure 19. Flow Jw-Jk (1,0-0,8)

It can be seen in Fig. 11, 12, and 13 that the flow profile was well identified by the algorithm, thus, the error can be attributed to the non-uniformity of the same inside of the pipe or the error obtained in the experiments conducted by Suguimoto (2016). Figures 14,15,16,17,18, and 19 show a failure to read the algorithm, this can be attributed to the distribution of colors in the image, as they present little contrast between the fluids, a factor linked to higher flow velocities.

4. CONCLUSION

The developed algorithm presents good similarity with the experimental results when the water velocity is below 0.8 m/s exhibited in Tab. 1. For higher velocities, the analysis presents a higher concentration of errors, this occurs due to the greater dispersion of kerosene in the water, generating a drastic decrease in contrast and defined edges, this can be visibly identified in the images. However, for lower velocities, the algorithm presented an error for some cases where the 2D projection on the channel did not coincide with the distribution of the fluids in it, that is, the image does not correspond or it does not approach the arrangement of the fluids in the channel, however, the identification of edges and fluid separation proved to be efficient compared to the image used, a solution to this problem would be to implement the use of neural networks in the pipeline to guarantee the results in similar cases. This study about the liquid-liquid flow is not usually found in articles related to image processing, this way it shows its importance and relevance for the field, as it is possible to observe in Tab.2, where it is possible to relate the flow patterns in SUGUIMOTO (2016) with the average error in image processing, by using the liquid fraction.

Table 1. Error comparison based on water velocity

Water speed (m/s)	Error average
0,1	4%
0,2	6%
0,4	6%
0,6	8%
0,8	26%
1	23%

Table 2. Error comparison based on pattern flow

Pattern	Do/w&w	ST&MI	Dw/o&Do/w	w/o	o/w
Error average	5%	16%	7%	65%	4%
Quantity	11	4	10	3	7

Thus, the patterns were identified according to Fig. 2, and the "Quantity" refers to the number of images analyzed and identified within a certain pattern, it is observed that the Do/w&w, Dw/o&Do/w and o/w patterns obtained good results, while the ST&MI and w/o patterns present an error greater than 10%. These patterns are related to higher water or kerosene speeds, confirming what was identified in Tab.1.

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