Void Fraction Features Using Image Processing on a Clear Capillary Pipe with a 45° Slope to The Horizontal Line of Two-Phase Air-Liquid Flow with High Viscosity

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ABSTRACT

In supercomputer equipment, X-rays, satellite cryogenic cooling systems, and others, the two-phase flow phenomenon in mini channels are also used. A significant issue for them is the void fraction function induced by superficial velocity, fluid viscosity, and slope. This analysis's objective was to determine the characteristics of void fraction values on the bubble, plug, slug-annular, annular, churn in horizontal capillary pipes. The research was carried out on a mini-pipe with a diameter of 1.6 mm and a length of 130 mm, mounted at a horizontal angle of 45 degrees. A mixture of 40, 50, 60, and 70 percent air-pure water and glycerin concentrations is the fluid used. The flow pattern video was shot using a Nikon J4 camera with a speed of 1200 fps, gas speed (J_G) at 2.5×10^{-2}-66.3 m/s intervals, and fluid velocity (J_L) at 3.3×10^{-2} - 4.935 m/s intervals. A digital image processing technique is used to calculate the value of a void fraction with the MATLAB R2014a and Microsoft Excel application software. This paper's new finding is that the value of the void fraction for bubbly flow indicates conditions that are not so stable and have a low value. The void fraction for plug flow tends to be close to 1 over a certain period; this is induced by the air cavity that almost fills the vessel, as shown by the effects of the image processing and the graphs the time series of voids. The void fraction has a value that fluctuates to a moderate value in the churn flow pattern.

1. Introduction

Liquid-gas, liquid-solid, or gas-solid, is part of a multiphase flow where two phases flow in one channel. The two-phase flow is divided into current and countercurrent flow in either horizontal or vertical directions, depending on the flow and channel geometry path. It is divided into several categories based on the channel's dimensions, namely, wide channel, microchannel, nanochannel, mini channel, and regular channel [1]. Due to its wide use in science and advanced technologies such as medical design, air-conditioning cooling systems, radiators, cryogenic cooling systems on satellites,

the two-phase flow in mini and microchannels is very large in its application and continues to be developed.

Matsubara and Naito [2] suggested that the two-phase flow in mini and micro-sized fluid channels has very peculiar properties, where the formation of flow patterns is affected by the liquid fluid viscosity, the gas fluid surface velocity value, and the liquid fluid liquid surface velocity values. Research on the flow of two-phase gas-water in microchannels of 1.1 mm and 1.45 mm diameter was conducted by Triplett *et al.,* [3]. Sur and Liu [4], who studied the two-phase flow of water gas in microchannels with hydraulic diameters ranging from 100-500 mm, were also involved in the study. Using high-speed imaging techniques and producing Bubble, Slug, Churn, Slug-Annular, and Annular flow models, two-phase flow patterns have been visualized. Based on the above findings, it can be concluded that microchannel hydrodynamics in two-phase channels are distinct from larger channel hydrodynamics. A two-phase vacuum fraction was tested by Sudarja *et al.,* [5] using a 1.6 mm diameter pipe using air and pure water with working glycerin fluids. The void fraction values are obtained using a 1200 fps Nikon J4 camera by processing video files. This work was carried out with a surface gas velocity of 0.83-65.4 m/s and a surface liquid velocity of 0.02 to 4.14 m/s in an adiabatic setting. The result showed that the flow pattern plays a vital role in the estimation of the void fraction. Whereas the two-phase airflow void fraction and glycerin mixture with unique viscosities were recorded by Sukamta *et al.,* [6] in capillary channels inclined to the horizontal by 5°. The results are analyzed using image processing. The results showed that the liquid's viscosity is very significant for bubbly and plug flow patterns. The increased value of the gas's superficial velocity decreases the value of the vacuum component, and vice versa, respectively. Homogeneous flow values (β) are also produced to affect the bubbly and plug flow patterns' length.

Research on the effects of 0°, 30°, and 60° angle variations on two-phase flow was conducted by Wongwises and Pipathattakul [7]. This analysis was performed on annular tubes with internal diameters of 8 mm, 10 mm, and 11 mm and external diameters of 12,5 mm. Flow patterns obtained differ, namely plug flow, slug flow, slug-annular flow, annular flow, bubbly flow, churn flow, and bubbly flow dispersed—differences in angle variations influence flow change, based on this analysis. In pipes with 4 mm, 6 mm, and 8 mm diameters and 400 mm channel width, Autee *et al.,* [8] conducted a two-phase pressure drop test using angular variations of 30°, 60°, and 90° down. The research uses a mixture of air and water as working fluids. The analysis was performed to obtain the pressure drop value and compare the findings with established Crisholm correlations on parameter C. In order to predict a two-phase pressure drop to a satisfactory level, the proposed correlation was found.

Serizawa *et al.,* [9] also, measure void fractions using video analysis. For all bubbly flow patterns and slug flow, the result is $\varepsilon = 0.833 \beta$, showing a linear correlation between ε and β. The void proportion was measured by Chung and Kawaji [10]. Various image processing techniques are used to distinguish the distance and average of the vacuum fractions from the video images of gas and liquid interfaces. At 530 and 250 μm, the void fraction data was reduced to 300 video images per time the experiment was performed. By comparing the gas limit to the symmetrical volume and by calculating the gas volume fraction, a void fraction is obtained. This study provided a new model of slug flow to predict physical insights into microchannels' flow characteristics. This model is capable of predicting two-phase friction pressure gradients with diameters of 100 and 50μm. A one-phase and two-phase flow analysis with a working stream, namely ionized nitrogen water with a 100 μm diameter fused silica tube, was performed by Kawahara *et al.,* [11]. The parameters used are air surface velocity of 0.1–60 m/s and air-surface velocity of 0.002–4 m/s. Fuel flow patterns alone (oil slug), gas core flow with fine-thin liquid films, gas core flow with thick-fine liquid films, gas core flow with ring-shaped liquid films, and gas core flow deformed interface was the flow patterns found in

this study. A very narrow channel causes the number of Reynolds to shrink and increase the surface tension so that it is not possible to observe the bubbly and churn flow in this analysis. Jagan and Satheesh [12] conducted a study of the flow patterns of the water-air mixture in two-phase flow in different directions. The research used 8 mm diameter pipe and 2 m long pipe with angles of 0°, 30°, 45°, 60°, and 90°. Superficial gas and water velocities range from 0.06 to 1 m/s and 0.06 to 15 m/s. Flow patterns are obtained using high-speed recording and analyzed using an image processing technique. The results show that multilevel flow is seen in the pipe's horizontal position and not in the pipe's oblique position. Simultaneously, the effect of turbulence dominates when the angle of the pipe increases when it is the opposite of gravity and leads to churn flow.

In circular tubes with a diameter of 1.2 mm, Barreto *et al.,* [13] investigated the two-phase flow of water and air fluids. The gas velocity used in this analysis ranges from J_G = 0.1-34 m/s to J_L superficial liquid velocity = 0.1 to 3.5 m/s. In the annular pattern with superficial gas velocities of more than 18.6 m/s, the correlation of small tubes with air-water shows the strongest pressure drop. The void fraction in this analysis was used to improve the estimation of pressure drops. Jia *et al.,* [14] conducted measurements at various pressures on the void fraction of the two-phase flow. To get a void fraction, the pressure difference in the bubble and slug flow is replaced. The effects of surface tension are also explored in this study. It was found that the loss of friction cannot be ignored, especially when the fraction of the vacuum gas is less than 0.2. The characteristics of the vacuum fraction in the two-phase water gas flow in a small diameter pipe were studied by Gomyo and Asano [15]. This research was carried out to determine the void fraction in the 4 mm, 2 mm, 1.1 mm, and 0.5 mm diameter tubing. Using a high-speed camera, the void fraction is determined by the capacitance method and flow pattern. The study found that because the pipe diameter narrowed to 1.1 mm, the number of annular flow waves grew. The effect of surface tension increases, and the frequency of the waves decreases in the case of pipes with a diameter of 0.5 mm.

Based on the above definition, it can be inferred that there has been quite a lot of research relating to the void fraction, but no one has concentrated on high viscosity and significant slope capillary pipes. The findings of a two-phase void fraction of air-water mixed with Glycerin (40-70%) in a capillary tube with a 45° slope to the horizontal location are therefore presented in this paper. For this reason, the aim of this study is to determine the characteristics of the void fraction in the above-mentioned conditions in several two-phase flow patterns. A pressure drop can be measured by understanding the features of the void fraction, which is useful in the design of early warning system equipment in both industry and medical equipment.

2. Methodology

Study content in the form of air collected from a compressor fitted with a water trap has low humidity, whereas a mixture of water and Glycerin is 40 percent, 50 percent, 60 percent, and 70 percent for liquid fluid used. This study was carried out at the superficial gas's velocity (J_G) = 0.025 - 66.3 m/s, and the velocity of the superficial fluid (J_L) = 0.033 - 4.935 m/s. The research on the construction of test equipment was carried out, as shown in Figure 1. The water tank's key components, water pump, air compressor, pressure vessel, mixer, and test section are included in the installation of this equipment. In addition, supporting equipment such as cameras, personal computers, acquisition devices, and video processing systems are used. Instruments used for data collection, pressure transducers, airflow meters, water flow meters were measured. The analysis uses digital image processing, MatLab, and the Microsoft Excel program to obtain the value of the void fraction.

A = Water Tank	E = Flowmeter for fluid	I = Camera
B = Pump	F = Mixer	J = watertrap
C = Valve	G = Flange	K = Flowmeter for gas
D = pressure vessels	H = Test Section	L = Compressor
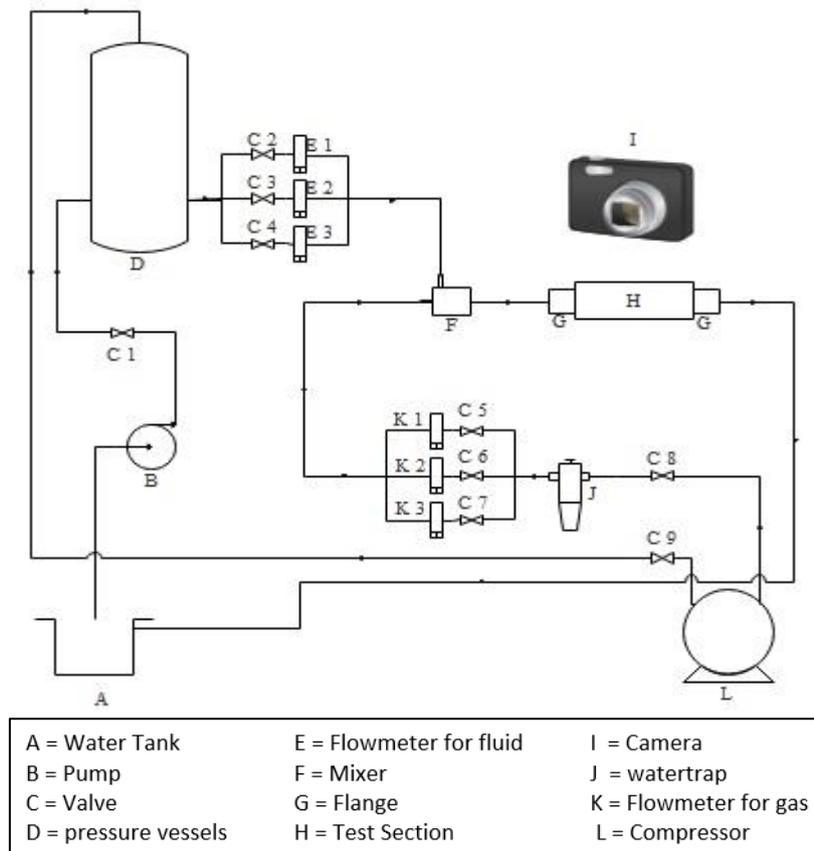
Fig. 1. Scheme of Research Installation

3. Results

3.1 The Void Fraction of The Bubble Flow Pattern

Small air bubbles that usually mimic a ball define the bubbly flow pattern. This pattern is created when the superficial gas velocity (J_G) position is low and the superficial fluid velocity (J_L) position is high. Figure 2 showed the outcome of the bubble flow pattern's image processing, and Figure 3 showed the void fraction time sequence.

Figure 2 and Figure 3 show that the void fraction in the bubble flow pattern has a relatively small and unstable number due to the frequency of non-steady bubbles appearing. Besides that, it can also be explained that increasing glycerine concentration will increase the size of the bubble, almost like a plug flow pattern, and reduce the frequency of appearance.
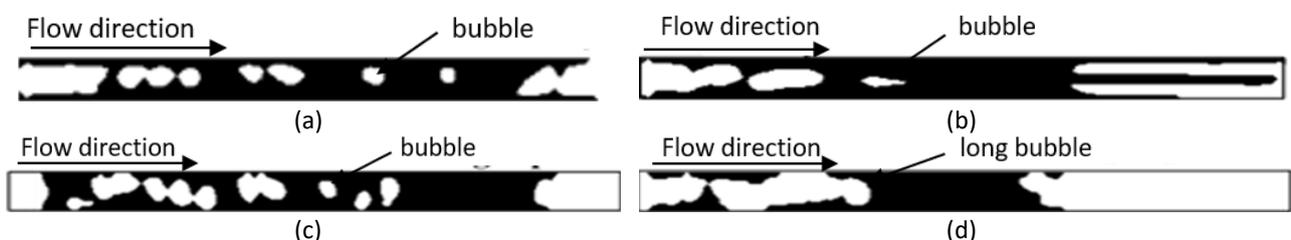
Fig. 2. The product of the bubble flow pattern image processing on J_L = 2.297 m/s, and J_G = 0.423 m/s; (a) Glycerin 40% and pure water 60%, (b) Glycerin 50% and pure water 50%, (c) Glycerin 60% and pure water 40%, (d) Glycerin 70% and pure water 30%
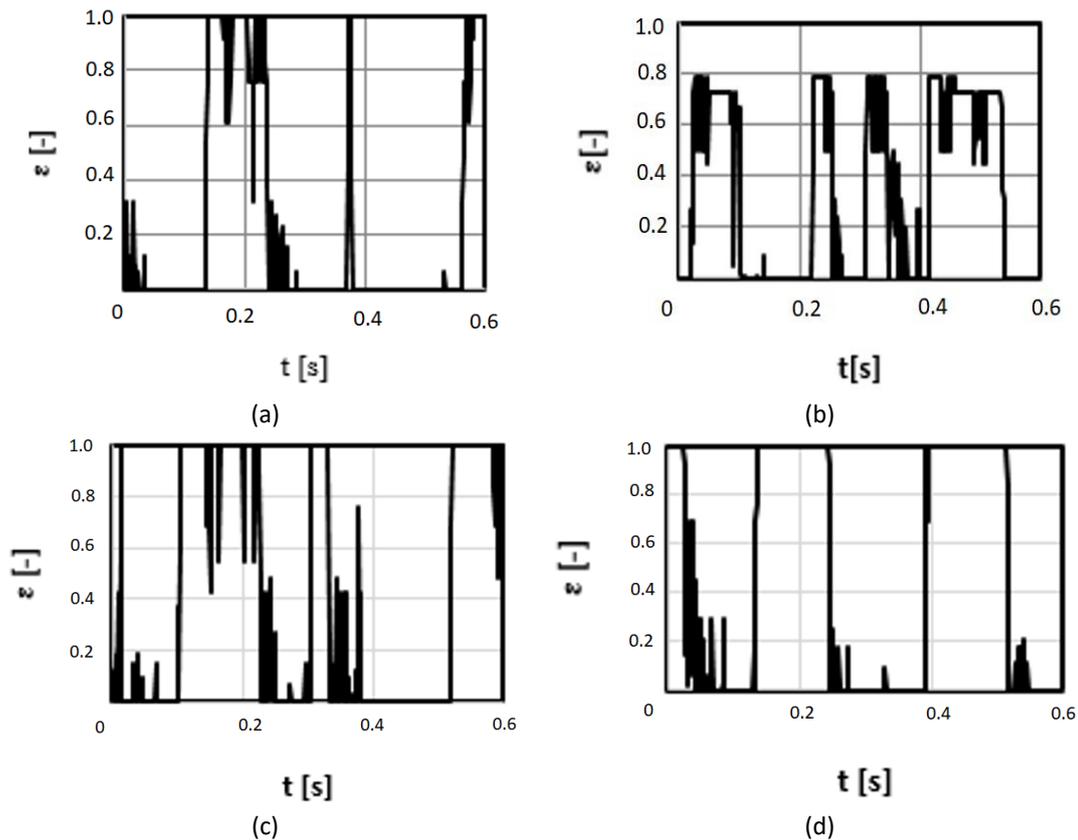
Fig. 3. Void Fraction time series on J_L = 2.297 m/s, and J_G = 0.423 m/s; (a) Glycerin 40% and pure water 60%, (b) Glycerin 50% and pure water 50%, (c) Glycerin 60% and pure water 40%, (d) Glycerin 70% and pure water 30%

3.2 The Void Fraction of the Plug Flow Pattern

The plug's flow pattern has a shape similar to an elongated bubbly whose flow pattern is like a bullet that covers the entire wall of the pipe with different length patterns. This flow pattern usually occurs when the superficial velocity of gases and liquids is low. The image processing and void fraction time series of the plug flow pattern can be seen in Figure 4 and Figure 5.

From Figure 4 and Figure 5, it can be interpreted that the void fraction in the plug flow tends to have a value close to 1. This means that the majority of the fluid is in the form of gas. This phenomenon can be seen in image processing results that show binary images in black and white, where black represents liquid and white represents gas. Figure 4 that gas dominates the mini pipeline, which is reinforced by the void fraction time series results in Figure 5.
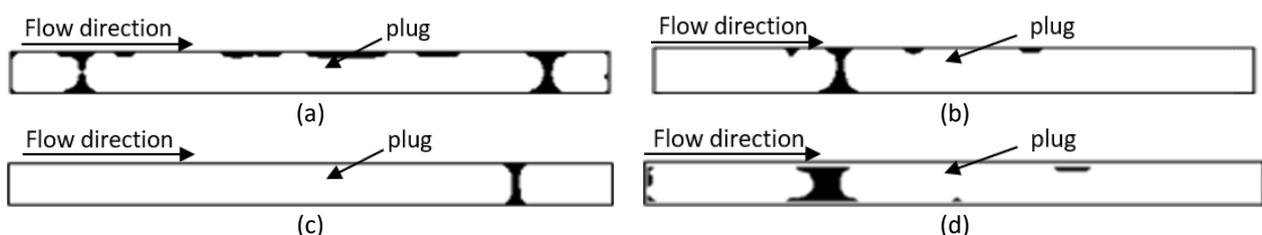
Fig. 4. The product of the plug flow pattern image processing on J_G = 0.066 m/s, and J_L = 0.7 m/s; (a) Glycerin 40% and pure water 60%, (b) Glycerin 50% and pure water 50%, (c) Glycerin 60% and pure water 40%, (d) Glycerin 70% and pure water 30%
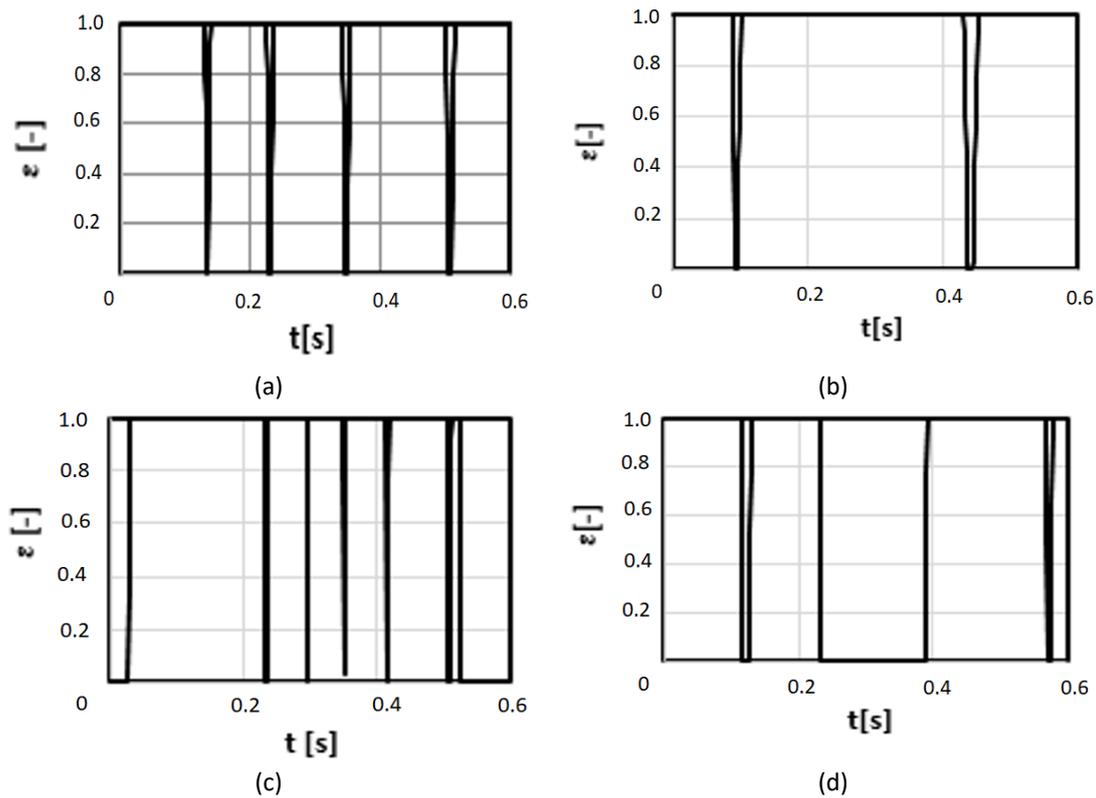
Fig. 5. Void Fraction time series on J_G = 0.066 m/s, and J_L = 0.7 m/s; (a) Glycerin 40% and pure water 60%, (b) Glycerin 50% and pure water 50%, (c) Glycerin 60% and pure water 40%, (d) Glycerin 70% and pure water 30%

3.3 The Void Fraction of the Churn Flow Pattern

Results of image processing and void fraction time series of the churn flow pattern can be seen in Figure 6 and Figure 7.
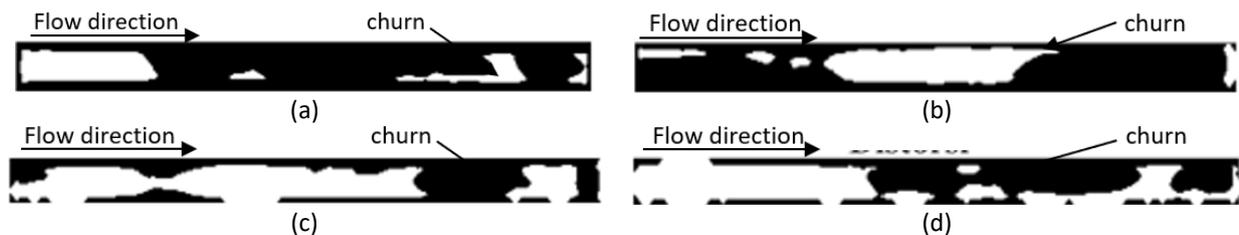
Fig. 6. The product of the churn flow pattern image processing on J_G = 66.3 m/s and J_L = 4.935 m/s; (a) Glycerin 40% and pure water 60%, (b) Glycerin 50% and pure water 50%, (c) Glycerin 60% and pure water 40%, (d) Glycerin 70% and pure water 30%
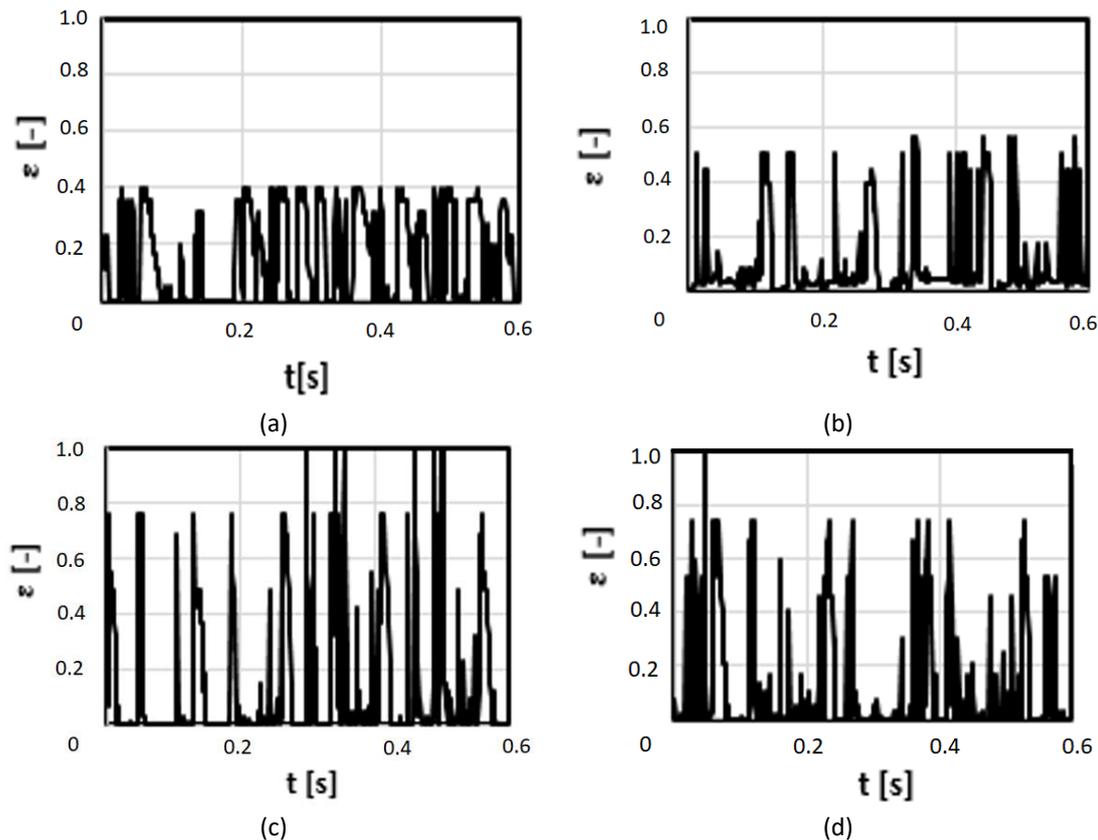
Fig. 7. Void fraction time series on J_G = 66.3 m/s, and J_L = 4.935 m/s; (a) Glycerin 40% and pure water 60%, (b) Glycerin 50% and pure water 50%, (c) Glycerin 60% and pure water 40%, (d) Glycerin 70% and pure water 30%

It can be explained from Figure 6 and Figure 7 that when both the superficial velocity of gases and superficial fluids are high and have a vast difference. The Churn flow patterns are created, in which this condition occurs in the flow of gas and liquid flow that flows randomly and experiences instability so that there is a distortion. The authors also previously examined various flow patterns experimentally using an inner glass pipe diameter of 1.6 mm and a length of 130 mm, a slope of 5 degrees to the horizontal position. The visualization method uses a high-speed camera, the working fluid used is air and water mixed with Glycerin with concentrations of 40%, 50%, 60%, and 70% for each mixture, and varies the speed of gas and water in the range of J_G = 0.207 m/s to 66.3 m/s and J_L = 0.149 m/s to 4.238 m/s. This research produces a mini bubble flow pattern, long plug, slug, slug-annular, and churn. The study also found new findings that the slug flow pattern influences the pressure difference significantly [16].

For mini channels based on different flow models and drift flux models, an alternative connection of the two-phase friction pressure reduction and the void fraction is examined. The dominant parameters for the correlation of two-phase friction multipliers and void fractions are selected via the application of an artificial neural network. It was noticed that the non-dimensional Laplace constant was the principal parameter for correlating the parameters of Chisholm as well as the distribution parameters in the mini-channel [17]. Experimental investigations have been carried out on boiling flow in mini channels based on local void fractions analysis. This research has been carried out at constant heat flux supplied to the mini channel with the inlet liquid's mass velocity ranging between 30 and 248 kg s^{-1} m^{-2}. The influence of hypergravity (1.8g gravity level) and microgravity (gravity level ± 0.05g) on the determination of the experimental void fraction used image processing. Pressure drop for two-phase flow in microgravity was found to be significantly higher than for single-

phase flow under the same conditions [18]. The previous research describes the process by which mini-channels test two-phase flow structures. High-speed visualization techniques obtained the images, and the stereological analysis used was based on linear methods. It has been found that the combination of stereological parameters can be used to monitor operating conditions during changes in flow structure. Therefore, knowledge of the character of changes occurring in inflow structures may be used for constant process adjustments for various two-gas or gas-solid gas-liquid systems [19]. Experimental data were collected and analyzed for the void fraction and the reduction of the two-phase friction pressure from multiple sources. Experimental data show that friction pressure reduction is very sensitive to these two parameters as superficial gas velocity and void fraction increase to higher values. The void fraction's correct characterization is essential when the two-phase pressure drop is prone to variations in the void fraction [20]. Xing *et al.,* [21] stated that the correlation effect of the void fraction on the separation of pressure gradients in rectangular vertical channels from the two-phase flow of water. The superficial gas and liquid velocities range between 0.58 and 32 m/s and between 0.16 and 3.8 m/s. The findings showed that while the association of the void fraction greatly impacted the gradient of the gravity pressure of slug flow, churn flow, and annular flow, it had almost no effect on bubbles' flow. The analysis was conducted to find data related to the characteristics of low viscosity air-water two-phase flow patterns [22]. At concentrations of 0 percent, 10 percent, 20 percent, 30 percent for each mixture, and varying the surface water and gas velocity in the range of J_L = 0.033 to 4.935 m/s and J_G = 0.025 to 66.3 m/s, the working fluid being used was gas (air) and water mixed with glycerine. The study found five new types of flow pattern characteristics with respect to bubbly, plug, annular, annular and churn slug. It was also found that in this research, the plug flow pattern dominates the outcome, viscosity changes impact to be seen on the bubbly and plug flows as well as on the pattern of transition flow.

4. Conclusions

The novelty value obtained from this paper's discussion is that the value of the void fraction for bubbly flow shows conditions that are not so stable and with a low value and is often followed by a plug's appearance. Meanwhile, the value of the void fraction for plug flow tends to be close to 1 in a certain period; this is caused by the air cavity almost filling part of the pipe, as shown from the results of image processing and void time-series graphs. However, the void fraction showed a value of 0 caused only by passing through water, and there was no emergence of air. The void fraction in the churn flow pattern has a value that is fluctuating with moderate value. This result shows that the composition of the liquid and gas tends to be balanced. This conclusion has been compared with previous studies and has a good fit of results.

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