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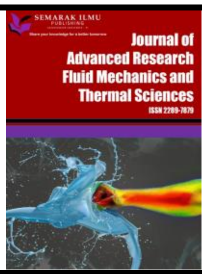

Void Fraction of Two-Phase Flow of Air – Emulsion of Water and Oil in Horizontal Mini Pipe

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ABSTRACT

Two-phase flow is the most straightforward flow of multi-phase flow. The void fraction is one of the significant parameters affecting the two-phase flow pattern on both small and mini channels. The flow pattern will be significantly sure, and fluctuations in pressure will change. If the pressure fluctuations are very high, it will affect the piping network system or channel and cause damage. Somebody can find the application of this case of damage to mini heat exchangers, mini boilers, and other small and mini equipment. This paper presents a significant correlation between void fractions and flow patterns. This study used a glass pipe with a length of 160 mm and a diameter of 1.6 mm with a horizontal position. The working fluids used are an emulsion of water and coconut oil with a concentration of 350 mg/dl and 500 mg/dl. The superficial velocity is gas (JG) = 0.08 m/s to 74.6 m/s, and the superficial velocity of the Liquid (JL)= 0.04 m/s to 4.15 m/s. Data measurements use a high-speed camera and are processed using MATLAB R2014a software. The research results showed that the difference in the concentration of the emulsion of water and coconut oil sufficiently affected the value of the void fraction significantly. The void fraction is because the increased concentration of such emulsions affects the increase in the viscosity value of the Liquid. The increase in the viscosity of the Liquid affects the speed of the Liquid tends to decrease. Under these conditions, the increasing superficial velocity of the gas affects the value of the growing void fraction.

1. Introduction

Two-phase flow is the most straightforward flow and part of a multi-phase flow [1,2]. A two-phase flow is the form of a substance flowing in one stream at the same time whose one of the phases can affect the characteristics of a gas-solid, liquid-solid, or gas-liquid flow [3]. Two-phase flows are often found in oil drilling, mining, and medical industries. In everyday life, the flow of two phases in the mini channel occurs naturally in the human circulatory system, where the bloodstream contains various mixtures that enter the body, such as protein, oxygen, fat, and triglyceride, which flow through human blood vessels. Two-phase flow applications in mini pipes include X-ray, MEMS,

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supercomputers, and aerospace systems. Cheng [4] group channels with different diameter ranges, one of which is a diameter with a 200 µm – 3 mm range in the mini channel. Chung and Kawaji [5] also investigated the properties of two-phase flow in mini channels, i.e., 250 - 530 m. Sharan and Popel [6] represented a two-phase flow in the human bloodstream. They assumed that the viscosity in the free layer of cells is from plasma due to the dissipation of additional energy near the wall caused by the movement of red blood cells near the cell layer.

Two-phase flow on mini pipes differs from pipes of larger diameter [7]. In mini tubes, the surface tension is found a lot, while in heat transfer, it is not found, and it can be said that no phase change occurs in mini pipes [8-10]. Dibek and Demir [11] say the void fraction is the ratio of the gas's cross-sectional area to the tubes. In determining the pressure drop value, heat transfer coefficient, and flow pattern in application to gas-liquid two-phase flow, pipeline systems, nuclear power systems, and chemical process systems are essential parameters in a void fraction [11-13].

The characteristics of the two-phase flow in mini pipes are closely related to surface tension, viscosity, shear stress, and the number of Reynolds [14]. Besides, the addition of surfactants affects all these factors where the smaller the diameter and the higher the concentration of surfactant addition reduces surface tension [15]. Besides that, the pipe's position influences the basic parameters studied, namely, flow patterns and void fractions. Triplett *et al.,* [16] doing an experiment to know the characteristics of void fractions and pressure drops in the two-phase gas and water flow on microchannels channels. The result is a decrease in pressure and void fraction in the annular flow pattern; at the transfer of fluid interface momentum, friction on the walls of the micro-channels differs significantly. Dai and Zhang [17] researched the two-phase flow of water and oil as a liquid fluid. The parameters measured include a pressure drop and a void fraction using a pipe that is 1.2 mm in diameter with a length of 400 mm.

Sukamta *et al.,* [18] studied the characteristics of the void fraction in a two-phase flow with an inclination angle of 45 degrees. This study used a mixed fluid of pure water and glycerin with concentrations such as 40%, 50%, 60%, and 70%. In addition, mini pipes are 1.6 mm in diameter and 130 mm in length. This study focuses on determining the characteristics of void fraction values in plugs, slug-annular, annular, bubbly, and churn, as well as the speed of the long pattern and frequency of the bubbly and plug patterns. This study used superficial gas (JG) = 0.025 – 66.3 m/s and fluid velocity (JL) = 0.033 – 4.935 m/s. This study found that the void fraction value in the bubbly flow showed a stable condition and a low value. At the same time, the void fraction value in the plug flow tends to be close to number 1 in a certain period. Sudarja *et al.,* [19] also researched the characteristics of the void fraction of the two-phase flow of air and water. The results show that the increase in JG influences the void fraction, except on very low JG. Experiments are conducted to measure the void fraction (the inner diameters of the pipes are 2.8mm, 3.9mm, 5.3mm, and 7.0mm, respectively). The experiment results demonstrate that using the C4D technique to measure the void fraction of a gas-liquid two-phase flow in a millimeter-scale conduit is possible. The suggested method for measuring the void fraction is efficient, and measurement performance is acceptable (the most significant absolute error of the void fraction measurement is less than 7%). The findings suggest that the C4D technique may have many possible applications in the two-phase flow research sector [20].

In horizontal, smooth tubes with an internal diameter of 4.8 mm, previous researchers evaluated the void fraction in an adiabatic two-phase flow of R1234yf. For the experimental testing, two saturation temperatures (15 and 25 °C) and two mass flow rates (180 and 280 kg.m2s1) are explored while the vapor quality varies from 0.1 to 1. The volumetric void fraction is calculated using the quick-closing valve(s) approach. The findings show that the void fraction of R1234yf is 5% smaller than that of R134a [21]. The void fraction in annular two-phase flow in macroscale and microscale channels is predicted using a novel approach. As it depends on the vapor quality and gas-liquid and more accurately reproduces the given data than existing prediction methods, the new prediction method is significantly more straightforward than most existing correlations. Importantly, this research demonstrates that there doesn't seem to be a macro-to-microscale transition in annular flows, at least down to diameters of roughly 1.0 mm [22].

Previous studies show that surface tension, viscosity, and superficial velocity significantly influence the two-phase flow pattern in mini pipes. The flow pattern will affect the pressure fluctuations along the mini-channel, and it will be perilous if the pressure suddenly increases significantly. Therefore, panting to find out the characteristics of flow patterns and void fractions of two-phase flows to predict the pressure that occurs and the danger that will happen, as well as being an initial reference in developing early warning system technology.

2. Methodology

Research materials are gaseous and liquids. The Liquid is a mixture of coconut oil and pure water (350 mg/dl and 500 mg/dl), which are flowed into the mixer with the aid of pressure vessels. The gaseous comes from a small air compressor with low humidity at room temperature conditions of 27° and pressure of 1 atmosphere. The physical characteristics of both fluids are shown in Table 1.

Table 1
Physical properties of the fluid

Properties	Mix Coconut Oil and Pure water (350 mg/dl)	A mixture of Coconut Oil and Pure water (500 mg/dl)
Density (g/m³)	0.985	0.998
Viscosity (Cp)	130	161.67
Surface tension (N/m)	0.038	0.036

The setup of the instruments used in this study is depicted in Figure 1. It includes a compressor, a container for a mixture of liquid fluid, water pumps, pressure vessels, water, and air flowmeters, a test section in the form of a 1.6 mm dwelling glass pipe and a length of 160 mm horizontal position, a camera, lighting lamp, air and liquid hose, gate valve, mixer, optical correction box, and flanges. The study was conducted under adiabatic conditions and was carried out at the superficial speed of the gas (J_G) = 0.08 – 74.6 m/s and the superficial speed of the Liquid (J_L) = 0.04 – 4.2 m/s.

Figure 1 explains the test scheme in this study. The liquid in coconut oil and pure water is accommodated in a container and then pumped into a pressure vessel, after which all the outer valves are closed until the vessel has a maximum pressure of 50 psi. After passing through the flowmeter, the flow of liquid and gas will then enter *the mixing chamber* and flow simultaneously on the test section pipe. The test section is equipped with *an optical correction box* that eliminates the convex effect on the surface of the pipe wall of the test section when retrieving flow pattern data. Flow pattern shooting is carried out using a Nikon J4-type high-speed camera. The flow pattern generated from the camera was then processed to obtain a void fraction using *digital image processing* assisted by the *MATLAB R2014a* application [23].

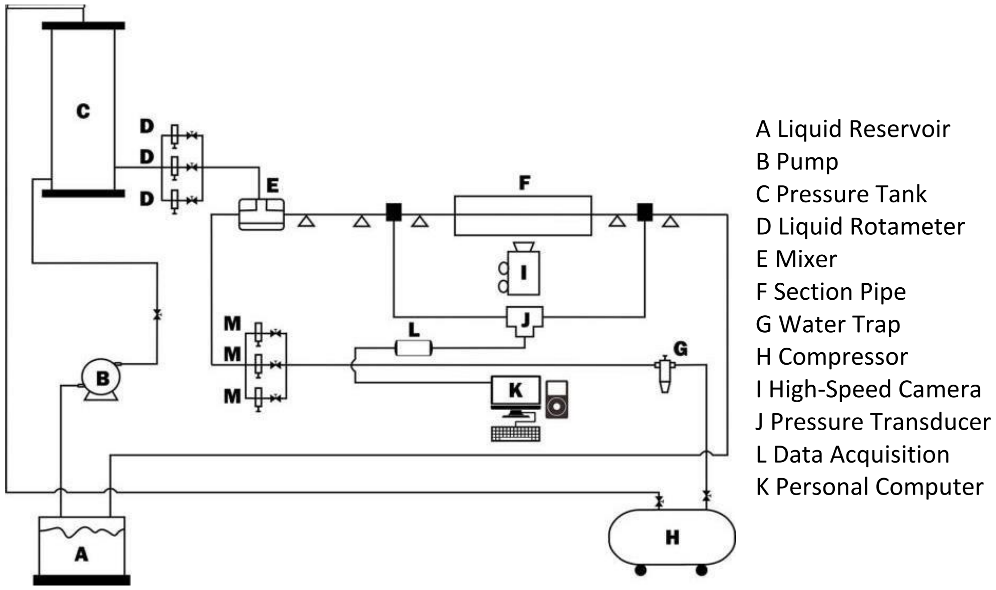

Fig. 1. Installation and scheme of the test equipment

3. Results

3.1 Void Fraction

3.1.1 Void fraction of plug

The plug flow pattern is characterized by air bubbles resembling bullets covering the entire pipe wall with varying flow pattern lengths. Plug flow occurs at low of both J_G and J_L, and at moderate J_G with low to moderate J_L. It is seen that superficial velocity of gas (J_G) strongly affects the plug length, here, the higher the J_G the longer the gas plug. This condition also stated previously by Fukano and Kariyasaki [24], Saisorn and Wongwises [25], and Sudarja *et al.,* [26]. Meanwhile, this study obtained a plug flow pattern with a pattern length of J_L = 0.4 m/s and J_G = 0.08 m/s.

Figure 2 shows that the plug flow pattern has the distance between one gas and the other gas being the same, and this factor occurs because the superficial speed of the liquid and gas in the pipeline is constant. Figure 3 reinforces the explanation of Figure 2 by displaying the binary image of the plug flow pattern, based on this figure it can be determined the magnitude of the void fraction that occurs.

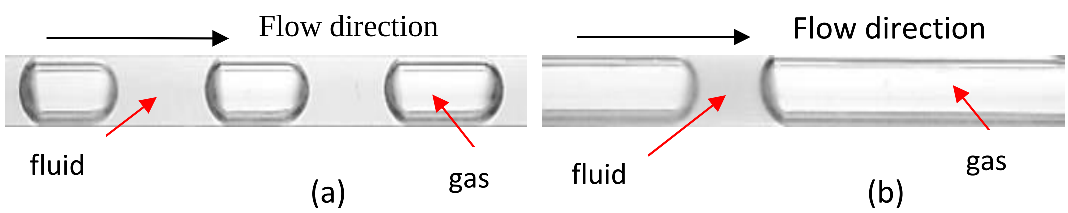

Fig. 2. Flow patterns plug on (a) oil 350 mg/dl, (b) oil 500 mg/dl

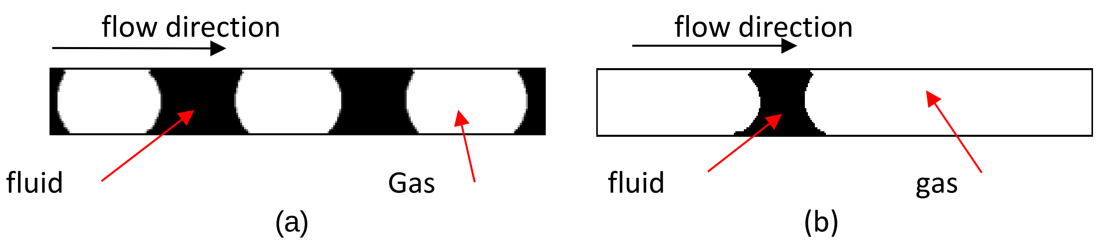

Fig. 3. Binary image of flow pattern plugs on (a) oil 350 mg/dl, (b) oil 500 mg/dl

Figure 4 shows the time average void fraction graph shows the data reaching the number 1, which explains that air at a certain time fills the pipe wall caused by the flow pattern of plugs flowing in the pipe. There is an equation found in graphs (a) and (b), with the shape of the graph being the length of the number 0 at a certain time which explains that the distance between plugs is almost the same.

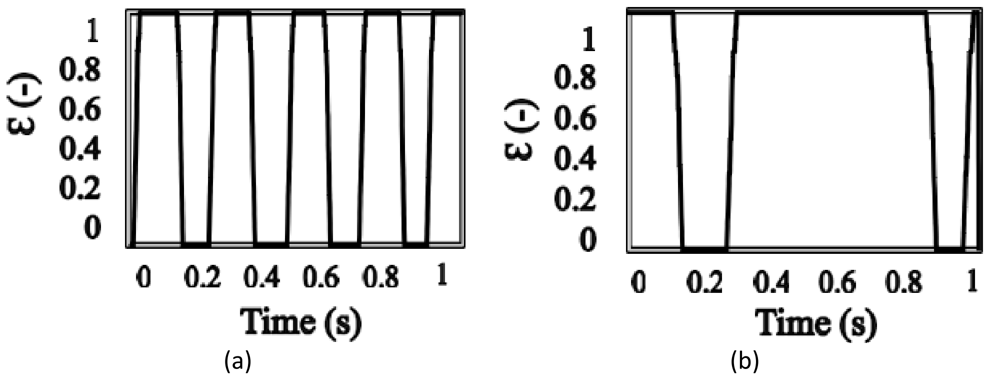

Fig. 4. Time average plug flow pattern void fraction on (a) oil 350 mg/dl (b) oil 500 mg/dl

Figure 5 shows the probability value at the most dominant concentration of 350 mg/dl, which is 0.46 with a void fraction value 1. At a 500 mg/dl concentration, the dominant probability value is 0.68 with a void fraction value 1.

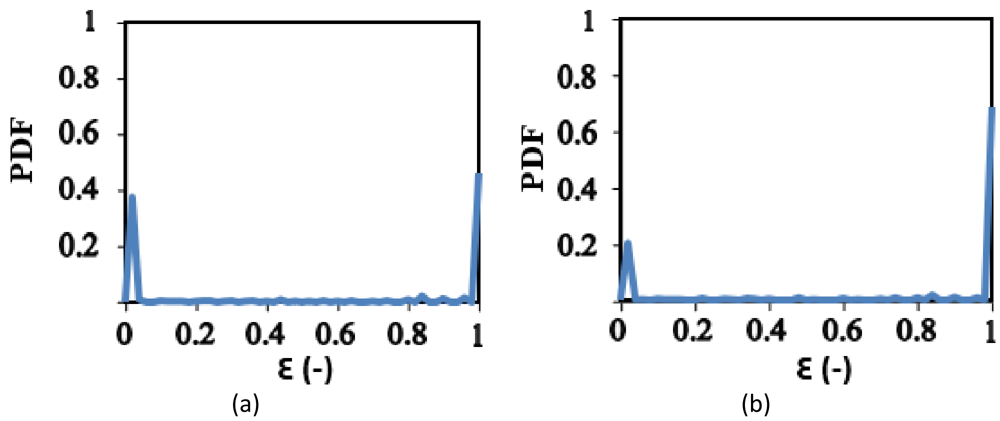

Fig. 5. PDF of the void fraction of *the flow plug* pattern on (a) oil 350 mg/dl (b) oil 500 mg/dl

3.1.2 The void fraction of the annular flow pattern

The annular flow pattern is a continuation of the *slug-annular* flow pattern form [27]. This case occurs because the increase in the gas's superficial speed is much more significant than the liquids, so the gas phase will pass through the liquid's middle side distributed on the pipe's walls. In this study, the annular flow pattern of 350 mg/dl was at J_L = 0.622 m/s with J_G = 74.604 m/s. In addition, the annular flow pattern was 500 mg/dl at J_L = 0.622 m/s and J_G = 74.604 m/s. Fluid viscosity factors caused differences in the formation of annular flow patterns at 350 mg/dl and 500 mg/dl.

Figure 6 shows an annular flow pattern that looks volatile but insignificant. There is a significant difference in shape in the annular flow pattern with both concentrations. Due to higher viscosity at 500 mg/dl. Figure 7 shows the results of the image processing from Figure 6 which illustrates the void fraction that occurs in these conditions which is dominated by gas.

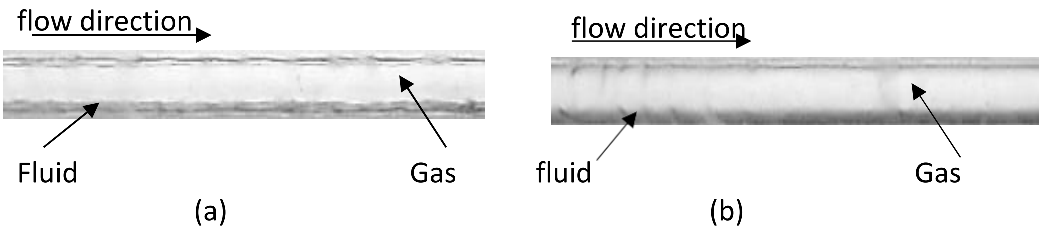

Fig. 6. Annular flow pattern on (a) oil 350 mg/dl, (b) oil 500 mg/dl

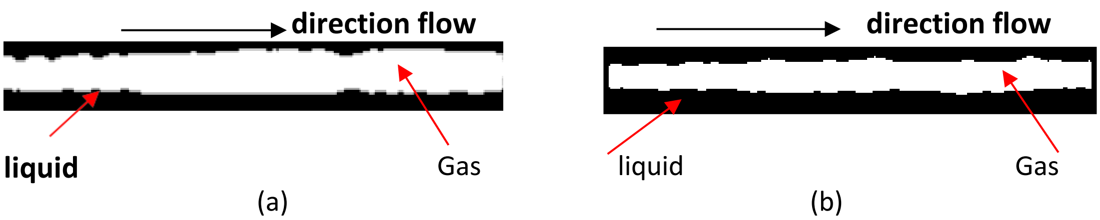

Fig. 7. Binary annular flow pattern on (a) oil 350 mg/dl, (b) oil 500 mg/dl

Figure 8 shows a fluctuating value of the vacuum fraction that is quite significant in a certain time span. The graphic form of the two concentrations is quite different, with a range distance of 0.1 void fractions.

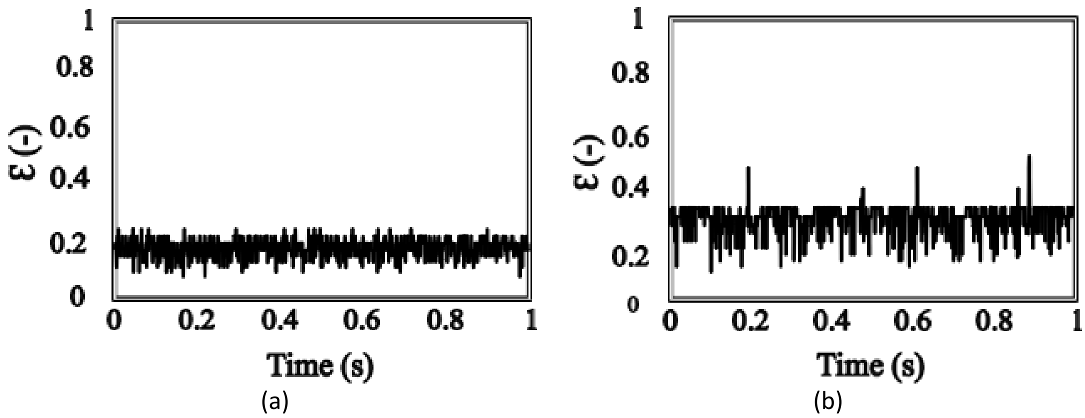

Fig. 8. Time average void fraction of annular flow patterns in (a) oil 350 mg/dl (b) oil 500 mg/d

Figure 9 states the most dominant probability value of 0.29 with a vacuum fraction value of 0.22 at a concentration of 350 mg/dl. In comparison, in oil of 500 mg/dl, there is a dominant probability value of 0.43 with a vacuum fraction value of 0.34.

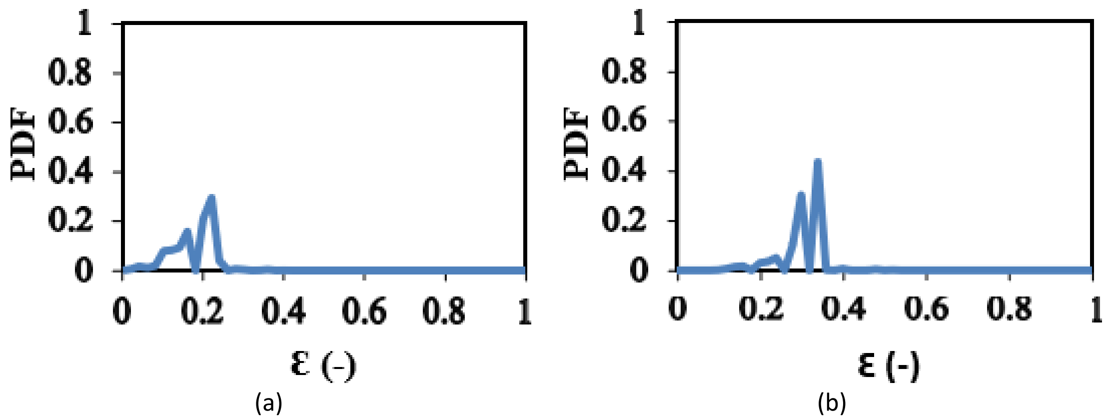

Fig. 9. PDF of the vacuum fraction of the *annular* flow pattern on (a) oil 350 mg/dl and (b) oil 500 mg/dl

3.1.3 Vacuum fraction in slug-annular flow pattern

The *slug-annular* flow pattern is formed from a plug flow pattern that is raised by the superficial speed of the gas. The *slug-annular* flow pattern has a structure where the liquid phase is symmetrically distributed on the pipe wall, but at some point, there is a thicker liquid film than at other points. This flow pattern resembles an *annular* flow pattern but has a *liquid neck*. This happens when the air's superficial speed experiences a significant increase. The air phase tries to penetrate the liquid bridge that separates the air in the plug flow pattern formed due to the presence of a thick film layer. The slug-annular flow pattern occurred at JG = 3.316 m/s with JL = 0.207 m/s at 350 mg/dl, while at 500 mg/dl, the slug-annular flow pattern occurred at JG = 3.316 m/s with JL = 0.207 m/s. Here's the *slug-annular* flow pattern.

Figure 10 shows that a *liquid neck* occurs in the *slug-annular* flow caused by air penetrating the thick liquid bridge. There was also a difference in *slug-annular* flow patterns concentrated at 500 mg/dl, where more than one point attempted to stab the fluid bridge. Figure 11 is the result of image processing of flow patterns as shown in Figure 10. Based on Figure 11, it can be explained that in the slug-annular flow pattern, the fluid begins to rise, and the gas begins to potentially clog the flow, and this is dangerous because it is able to raise the pressure to be higher.

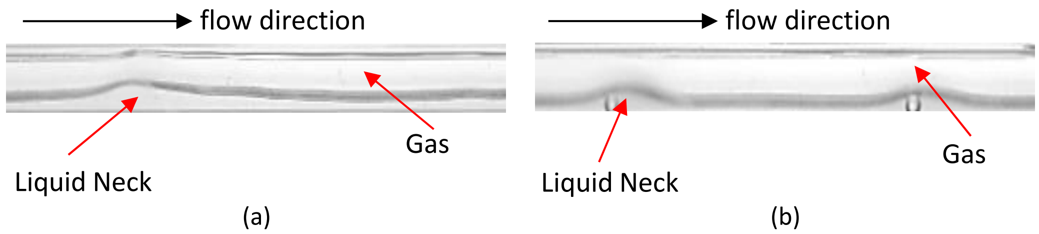

Fig. 10. *Slug-annular* flow pattern on (a) 350 mg/dl oil (b) 500 mg/dl oil

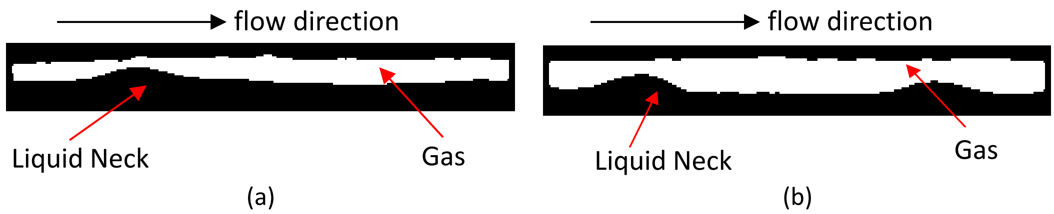

Fig. 11. Binary *slug-annular* flow pattern on (a) oil 350 mg/dl, (b) oil 500 mg/dl

Figure 12 shows the value of the void fraction that drops in a certain range randomly caused by the occurrence of a liquid neck. It can also be seen that the shape of the graph between the two concentrations has a significant difference.

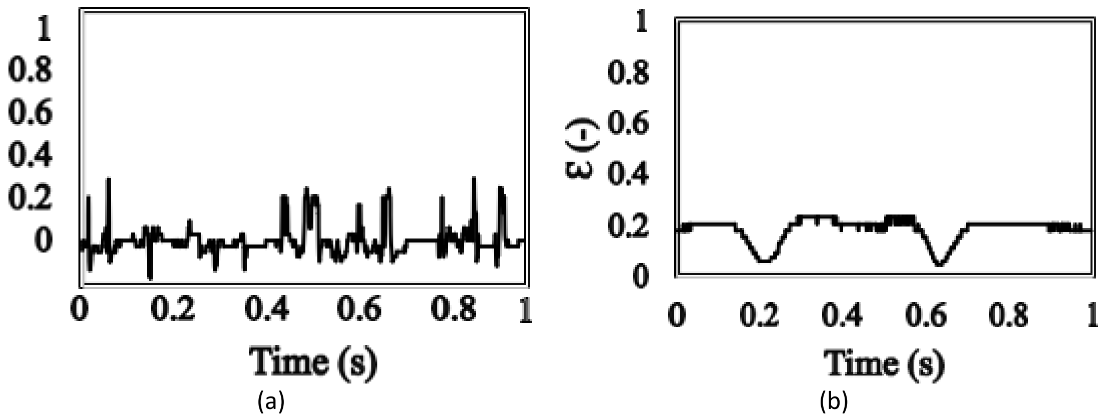

Fig. 12. Time average void fraction of the slug-annular flow pattern at (a) oil 350 mg/dl, (b) oil 500 mg/dl

4. Conclusions

The value of the void fraction at a concentration of 500 mg/dl does not have a bubbly flow pattern because the shear stress that occurs is quite large, and the resulting viscosity of 500 mg/dl oil increases (significantly), so the surface tension obtained is quite high. This is because the oil concentration at 500 mg/dl is much higher. When compared with the oil concentration of 350 mg/dl. The value of the void fraction studied in this study was at the superficial velocity of the liquid (JL) = 0.041 m/s to 4.145 m/s and the superficial velocity of the gas (JG) = 0.083 m/s to 74.604 m/s. Two-phase flow can be affected by the superficial velocity of the liquid and the superficial velocity of the gas, so that the value of the void fraction is affected when the superficial velocity of the gas is increased, and the value of the superficial velocity of the liquid is very small. It will increase the value of the void fraction. The difference in concentration between the distilled water and oil solutions of 350 mg/dl and 500 mg/dl in a pipe with a diameter of 1.6 mm sufficiently affects the shear stress, surface tension, and Reynolds number that occur so that the value of the void fraction can be said to be different from the concentration that occurs.

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