

Simulation of High Viscosity Gas-Liquid Two-Phase Flow in a Horizontal Mini Pipe

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ABSTRACT

Two-phase flow is used in many industries such as nuclear reactors, boilers, condensers, liquefactions of natural gas, etc. Two-phase flow is a flow in a pipe which has two states of fluid such as solid-liquid, liquid-gas, gas-solid. In a two-phase flow, there are three channels, namely vertical, horizontal and inclined channels. In the horizontal channel, the most widely found flow is the flow patterns of stratified flow, bubble flow, plug flow, stratified wavy flow, annular flow, and slug flow. Refer to the previous research above, the flow patterns were mostly obtained by using an experimental study. The advantage of using the simulation is the ability to predict the flow pattern and pressure gradient before doing the experimental study so it can be known earlier if it will have an insecure flow pattern, i.e. slug flow. This research was conducted to find the flow pattern and pressure gradient by using a Computational Fluid Dynamics (CFD) software, the Ansys Fluent 19.0 Student. The model which was used is the Volume of Fluid (VOF) with the fluid of air-water and glycerin (40%-70%). The length of the pipe was 200 mm, the inner diameter was 1.6 mm, and the length of the test section was 100 mm. Liquid superficial speeds (J_L) of 0.033 m/s; 0.149 m/s; 0.232 m/s; 0.539 m/s; 0.7 m/s; 2.297 m/s and 4.935 m/s were used, while the air superficial speed (J_G) was 9.62 m/s. The result of the simulation showed slug annular and churn flow patterns. Slug annular was formed at $J_L = 0.033$ m/s; 0.149 m/s and 0.232 m/s with the glycerin content of 40% and 50%. Slug annular pattern was formed when the glycerin content was 60% and 70% with $J_L = 0.539$ m/s. Viscosity affects the flow pattern, the higher the glycerin content, the higher the viscosity and the more fluid than air. The higher the J_L and glycerin content, the higher the pressure gradient.

Keywords: Glycerine, gas-liquid, pressure gradient, simulation, two-phase flow.

INTRODUCTION

Two-phase flow is used in many industries such as a nuclear reactors, boilers, condensers, liquefactions of natural gas, etc. In the phenomenon of fluid flow, there are two kinds of flow, namely one-phase flow and two-phase flow. One-phase flow is a flow in a pipe that has one state of fluid (gas or liquid). Two-phase flow is a flow in a pipe which has two states of fluid such as solid-liquid, liquid-gas, and gas-solid. The simulation to analyze this flow is CFD (*Computational Fluid Dynamics*) that analyzes and calculates the fluid flow process. The data will be more accurate and save time to calculate the result of the fluid analysis by using CFD. CFD not only produces the data but also moving flow images, graph calculation results and types of simulations such as velocity, pressure, mass flow, etc. CFD has many choices that can be used as needed such

as Solid, Fluent, etc. The fluid flow simulation could use the Fluent because it is specialized to analyze a flow and can simulate it.

Researches about the flow pattern in the capillary pipe have already been studied (Sudarja, Indarto, Deendarlianto, & Haq, 2016). They studied the flow pattern of two-phase flow of gas-liquid in a mini pipe and horizontal flow where the inner pipe diameter was 1.6 mm. Its result showed *bubbly*, *slug*, *churn*, *slug-annular*, *wavy annular* and *annular* flow patterns. The study used experimental method while this study used the CFD simulation method which had never been used before. They also conducted research about the characteristics of the pressure gradient in the two-phase flow of air-liquid mixture and 20% glycerin in a mini horizontal pipe. The result showed that the higher the superficial gas velocity and the superficial water velocity, the greater the pressure gradient. Previous research (Sukamta, 2019) studied the CFD simulation of

a liquid-air annular flow in the direction of a horizontal pipe with the inner pipe diameter of 1.9 mm. This research revealed that the flow pattern is not constant, depending on J_G and J_L , and the time of the data collection. The longer the time, the more perfect the annular flow which was produced. The increase of the J_G will cause a higher wave and less liquid flew at the upper part of the pipe.

Meanwhile, Korawan (2015) studied a two-phase flow (liquid-air) in a horizontal pipe with the variation of the liquid superficial velocity. The result of the research was the flow pattern being *bubble* and *Stratified*. Wibowo et al. (2015) researched the experimental study about the subs of the stratified flow pattern of two phases flowing in the same direction based on the fluctuations of the pressure difference in a horizontal pipe. A *stratified* flow pattern was observed. It was done by a direct visual observation, and the area was divided into subs, namely *stratified smooth*, *two-dimensional wave*, *roll wave* and *atomization*. Gunawan et al. (2015) conducted an experimental study about pressure fluctuation and interface shear stress of a liquid-air *stratified* flow in a horizontal pipe. The flow pattern was found being *stratified smooth* and the *Pressure gradient* will be larger if J_G and J_L are also larger. Khaledi et al. (2014) studied the a two-phase flow, holding fluid and the decreasing pressure in a thick oil-gas flow. The result showed *stratified*, *stratified wavy*, *bubbly flow*, *plug flow*, *roll-wave*, and *slug flow* flow patterns.

Tsaoulidis et al. (2013) studied the flow pattern and the decrease of two-phase ionic fluid pressure of liquid-water in a microchannel. The result showed that the flow pattern are *plug flow*, *disturbed plug*, *plug & drop train flow*, *intermittent flow*, *dispersed flow*, *quasi annular flow*, *throat annular flow*, *rivulet annular flow*, *drop flow* and *irregular flow*. Chinnov et al. (2016) conducted research about a two-phase flow pattern on *short horizontal rectangular microchannels*. The result of this research was the flow patterns being *bubble*, *annular*, *jet*, *stratified* and *churn regimes*. Saisorn and Wongwises (2008) studied the flow pattern, hollow fraction, and the two-phase pressure decrease of air-water in a horizontal circular microchannel. The result of this research was the flow patterns being *slug flow*, *throat-annular flow*, *churn flow*, and *annular-rivulet flow*.

Based on the previous researches above, the flow patterns were mostly obtained by using experimental study, and the flow patterns mostly are stratified, plug, slug, annular and bubble. The research which is studied has the same variables with the previous study but different method and concentration of glycerin. This research studied the flow pattern of air-water and glycerin (40%-70%) in a horizontal capillary pipe using a CFD simulation method of the *Volume of Fluid* (VOF). The CFD simulation of this research used Ansys Fluent 19 *Student* with a pipe diameter of 1,6 mm and the of $J_G = 9.62$ m/s and the variation of $J_L = 0.033 - 4.935$ m/s which have never been studied before.

RESEARCH METHOD

There are three processes in the CFD simulation, namely *pre-processing*, *processing* and *post-processing*. *Pre-processing* is the first stage in the research analysis with CFD simulation. In this stage, the generation of geometry or computational domain in the using Computer-Aided Design (CAD) in a 2D or 3D form was conducted. The generation of geometry can be done in the CFD software or by using Special CAD drawing software such as Inventor or Solidworks for complex geometry formation. *The processing* stage is the calculation phase of a simulation. In this stage, the parameter given in the *pre-processing* stage will be calculated repeatedly or called by iteration. For the horizontal two-phase flow of air-liquid in a pipe, the two-phase multiplier was determined based on the formula used by Xu, et.al (1998) as follows :

$$\Phi_1^2 = \frac{\Delta P_{TP}^F}{\Delta P_L^F} = \frac{\rho_1 \Delta P_{TP}^F}{2f_1 [G(1-x)]^2 N} \quad (1)$$

The calculation will finish if the calculation results have reached a predetermined level of accuracy or have reached the limit of the number of predetermined iterations. *Post-processing* is the last stage of the simulation. In this stage, retrieval, and processing of data in the form of magnitudes for certain variables, graphics, and visualization in the form of contours and animations. Similarly, at the mesh generating stage, the post-processing stage can be done on the CFD software or using other special post-processing software.

Geometry and mesh. Geometry drawing in 2D or 3D for the sims of CFD can be assisted by the use of some software, such as Fluent, Inventor, AutoCAD, Solid work, etc. After creating the geometry, the file is imported into the same format as Ansys Fluent. The geometry that is used in this research was a 2D drawing with the inner pipe diameter of 1.6 mm, pipe length of 200 mm, and a test section length of 100 mm and total obtained data in 0.2 seconds. The geometry of pipe model can be seen in Figure 1.

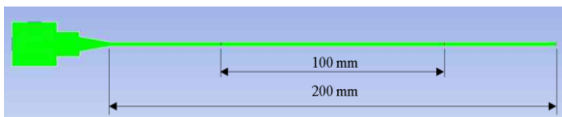


FIGURE 1. Geometry of pipe model

After making the geometry, it is necessary to do the meshing process, then it can be analyzed in a CFD program. It should be noted that the mesh size contained in an object will affect the accuracy and computational power of the analysis. The smaller or finer the mesh, the more accurate the results will be obtained. However, it requires greater computing power. After the meshing process is complete, then a mesh quality check is carried out with a report quality. The result of mesh can be seen in Figure 2.

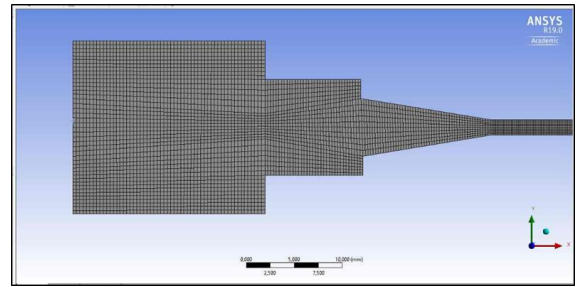


FIGURE 2. Result of mesh

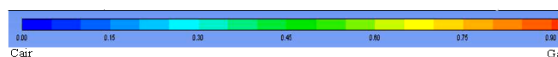
RESULT AND DISCUSSION

1. Liquid flow pattern + 40% glycerin with superficial air velocity (J_G) 9.62 m/s and various superficial liquid velocities (J_L).

Table 1 in the variation of $J_L=0.033$ m/s shows the annular slug flow pattern which is characterized by the presence of fluid that attached to the bottom of the pipe. This phenomenon occurs because of the superficial small water velocity so, the liquid is less than the air. Also, the liquid is attached to the bottom of the pipe because of the influence of the gravity and density of the liquid which is more substantial than the air. Therefore, the liquid is at the bottom of the pipe.

TABLE 1. Liquid flow pattern + 40% glycerine with $J_G = 9.62$ m/s and $J_L=0.033$ m/s; 0.149 m/s; 0.232 m/s; 0.539 m/s; 0.7 m/s; 2.297 m/s and 4.935 m/s.

J_L (m/s)	Figure	Flow Pattern
0.033		Slug Annular
0.149		Slug Annular
0.232		Slug Annular
0.539		Churn
0.7		Churn
2.297		Churn
4.935		Churn



2. Liquid-air flow pattern + 50% glycerin with superficial air velocity (J_G) 9.62 m/s and the superficial liquid velocity (J_L) that varies.

Table 2 shows the annular slug flow pattern on $J_L = 0.033$ m/s; 0.149 m/s and 0.232 m/s. In table 4.2 with $J_L = 0.033$ m/s, it is seen that the annular slug flow pattern formed is less than $J_L = 0.149$ m/s and 0.232 m/s. This happens because the superficial liquid velocity (J_L) is slower then, the annular slug flow pattern that is formed is less. For $J_L = 0.539$ m/s; 0.7 m/s; 2.297 m/s and 4.935 m/s show the churn flow pattern because there is a disturbance in the flow in the form of air then, the flow pattern is formed randomly. At $J_L = 4.935$ m/s, it can be seen that the pattern of the churn flow is more dominated by blue and green.

3. Liquid-air flow pattern + 60% glycerin with superficial air velocity (J_G) 9.62 m/s and superficial velocity of water (J_L) that varies.


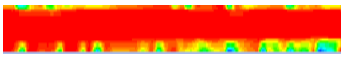
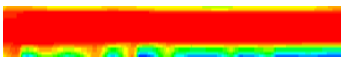
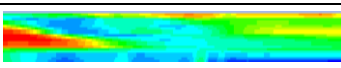
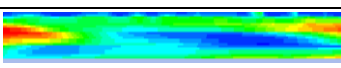
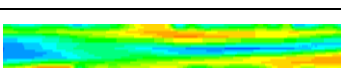
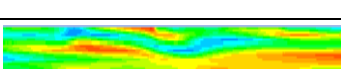
From table 3, slug annular flow pattern occurs in $J_L = 0.033$ m/s; 0.149 m/s; 0.232 m/s and 0.539 m/s. Slug annular flow pattern

still occurs in $J_L = 0.539$ m/s. This thing occurs because the percentage of glycerin was different. The percentage of glycerin affects the viscosity and superficial liquid velocity (J_L). The higher the percentage of glycerin causes the viscosity of the fluid increases so, the superficial air velocity (J_G) is difficult to penetrate the fluid. It causes the flow pattern that occurs is more dominated by fluid flow.

4. Liquid flow pattern + 70% glycerin with superficial air velocity (J_G) 9.62 m/s and superficial liquid velocity (J_L) that varies.

Based on table 4, many annular slug flow patterns more occur in the percentage of 70% glycerin than 60% glycerin. This is caused by the effect of viscosity on 70% glycerin is greater than 60%. As a consequence, the liquid is thicker and more difficult to be passed by air, and the mass-period on 70% glycerin is greater than 60% glycerin. Therefore, the annular slug flow pattern occurs more.

TABLE 2. Liquid flow pattern + 50% glycerin with $J_G = 9.62$ m/s and $J_L = 0.033$ m/s; 0.149 m/s; 0.232 m/s; 0.539 m/s; 0.7 m/s; 2.297 m/s and 4.935 m/s. (Please rearrange this table such that it will not be separated by column or page)

J_L (m/s)	Figure	Flow Pattern
0.033		Slug Annular
0.149		Slug Annular
0.232		Slug Annular
0.539		Churn
0.7		Churn
2.297		Churn
4.935		Churn

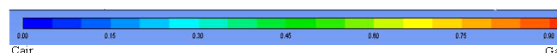



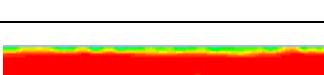
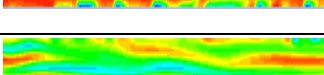
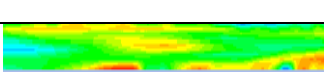
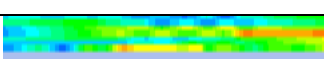
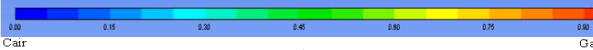


TABLE 3. liquid flow patterns + 60% glycerin with $J_G = 9.62$ m/s and $J_L = 0.033$ m/s; 0.149 m/s; 0.232 m/s; 0.539 m/s; 0.7 m/s; 2.297 m/s and 4.935 m/s.


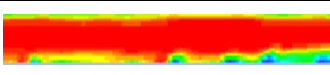
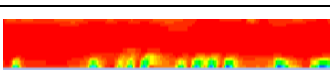

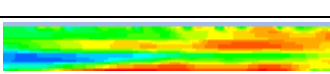
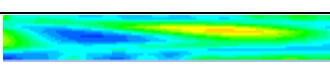
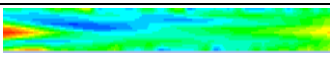
J_L (m/s)	Figure	Flow Pattern
0.033		Slug Annular
0.149		Slug Annular
0.232		Slug Annular
0.539		Slug Annular
0.7		Churn
2.297		Churn
4.935		Churn




0.00 0.15 0.30 0.45 0.60 0.75 0.90

Cair Gas

TABLE 4. Liquid flow patterns + 70% glycerin with $J_G = 9.62$ m/s and $J_L = 0.033$ m/s; 0.149 m/s; 0.232 m/s; 0.539 m/s; 0.7 m/s; 2,297 m/s and 4.935 m/s.

J_L (m/s)	Figure	Flow Pattern
0.033		Slug Annular
0.149		Slug Annular
0.232		Slug Annular
0.539		Slug Annular
0.7		Churn
2.297		Churn
4.935		Churn



0.00 0.15 0.30 0.45 0.60 0.75 0.90

Cair Gas

5. The relationship between superficial liquid velocity (J_L) varies with the pressure gradient of $J_G = 9.62$ m/s and the glycerin percentage of 40%, 50%, 60%, and 70% as seen in figure 3.
6. The relationship between superficial liquid velocity (J_L) varies with the pressure gradient of $J_G = 9.62$ m/s and the glycerin percentage of 40%, 50%, 60%, and 70%.

Figure 4 shows the increase in every glycerin percentage. This phenomenon occurs because the percentage of glycerin is increasing then, it affects the fluid viscosity and the pressure gradient. The rise of fluid viscosity makes the pressure gradient increases then, the graphics increase in every glycerin percentage. In figure 5, it can be seen that the more J_L , the more the pressure gradient.

Previous studies (Sukamta et.al, 2016) have also investigated air-water flow simulations for horizontal pipes. The use of water and air is used to determine changes in flow characteristics. In this study, acrylic pipes with

a diameter of 19 mm and a length of 1000 mm were used. Fukano et al., (Fukano et.al, 1993) have also examined the characteristics of two-phase flow of water in capillary pipes with diameters of 1 mm, 2.4 mm, 4.9 mm and 9 mm, and the direction of vertical upward, horizontal and vertical flow. down. The results of the study show that capillary force is important in the case of pipes with a diameter of 5 mm - 9 mm and the flow pattern does not have a significant change according to the direction of flow. Meanwhile, studies on numerical modeling and experimental investigations of gas-liquid forming slugs at T-junction microchannel with a hydraulic diameter of $113\mu\text{m}$ and superficial water velocities $0 / .042 - 0.757$ m / s and $0.018 - 0.791$ m / s were carried out (Santos et.al, 2010). The modeling used was CFD with Fluent software. From the research, two flow patterns can be observed; slug and annular flow patterns. The result of the comparison between numerical and experimental modeling is that the slug flow is $400\mu\text{m}$ shorter. Differentiation may be caused by fluid oscillations resulting from changes in pressure captured in the numerical model.

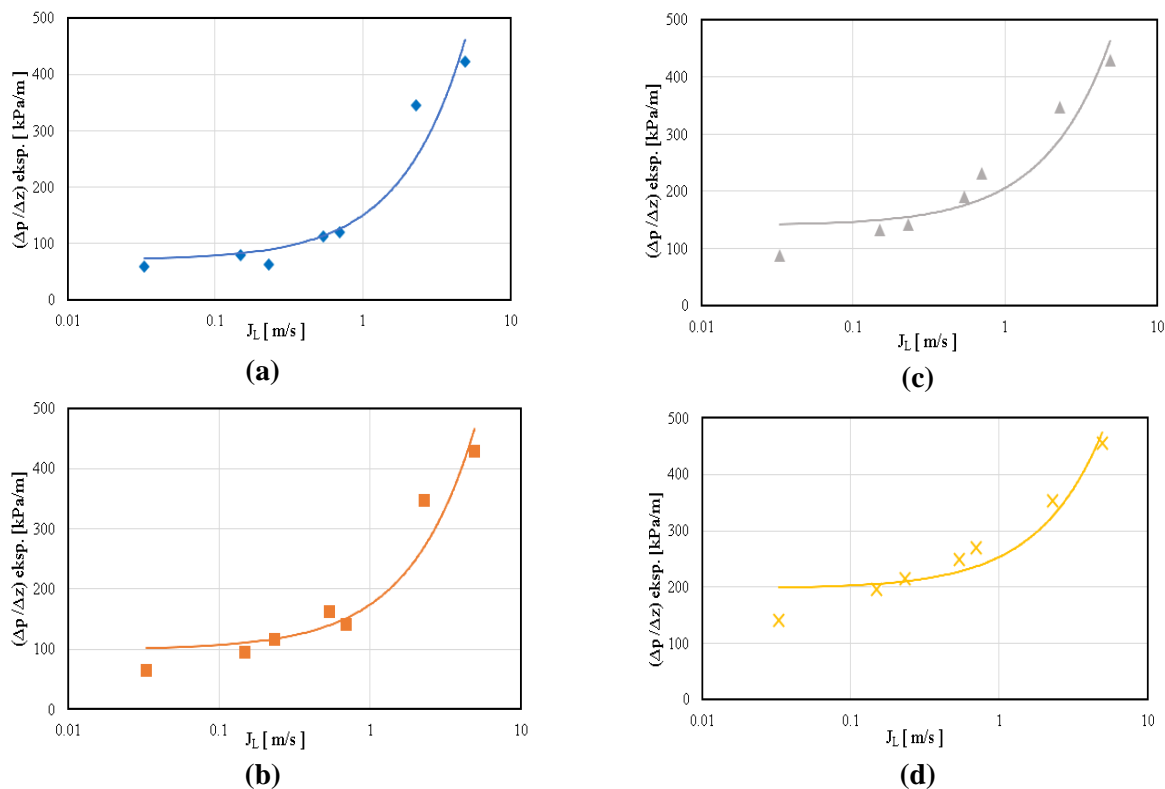


FIGURE 3. The graphic on the relationship between superficial liquid velocity (J_L) varies with the pressure gradient of $J_G = 9.62$ m/s and the glycerin percentage (a) 40%, (b) 50%, (c) 60% and (d) 70%.

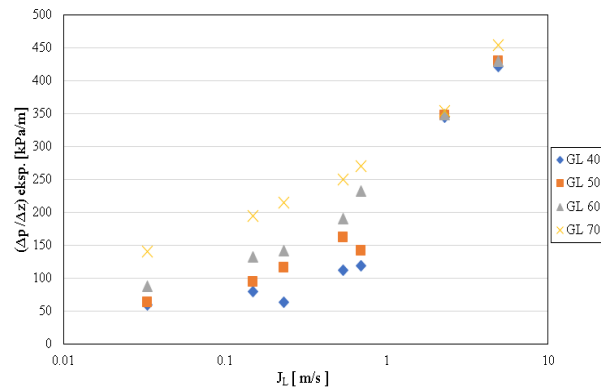


FIGURE 4. Graphic on the relationship between superficial liquid velocity (J_L) varies with the pressure gradient of $J_G = 9.62$ m/s and the glycerin percentage of 40%, 50%, 60% and 70%

CONCLUSION

We summarize the main contributions of the research that the flow pattern is the slug annular and churns. The Slug annular is formed at $J_L = 0.033$ m/s; 0.149 m/s and 0.232 m/s and the glycerin percentage of 40% and 50%. However, at the glycerin percentage of 60% and 70% with $J_L = 0.539$ m/s still can be seen in the presence of a slug annular flow pattern. It is caused by the greater influence of viscosity on glycerin. It also makes the air difficult to pass the fluids because of the high level of viscosity. Viscosity affects the flow pattern; the more glycerin percentage, the more viscosity level occurs. Therefore, the pressure gradient will be increasing. The increase of pressure gradient affects the percentage of liquid on the fluid pattern. The greater the J_L and the glycerin percentage, the greater the pressure gradient can be obtained.

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