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Computational Fluid Dynamics (CFD) and Experimental study of Two-Phase Flow Patterns Gas-Liquid with Low Viscosity in a Horizontal Capillary Pipe

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Sukamta Sukamta[1,*]

[1] Department of Mechanical Engineering, Universitas Muhammadiyah Yogyakarta, Yogyakarta, Indonesia

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ABSTRACT

This paper describes a new corresponding between computational and experimental data of two-phase flow in mini pipe with low viscosity of fluid. Computational Fluid Dynamics is needed to predict the phenomenon before conducting experimental study in order to get an expected appropriate result. The simulation was carried out on the two-dimensional horizontal capillary pipe with a diameter of 1.6 mm and a length of 100 mm. The simulation used air-water with glycerin of 0%, 10%, 20%, and 30%, and liquid superficial velocity (J_L) = 0.033 m/s – 4.935 m/s, gas superficial velocity (J_G) = 9.62 m/s as well. The experimental research used same parameter relatively with the simulation. The results showed the good corresponding between simulation and experimental data for a slug-annular, annular and churn flow patterns. The viscosity affects significantly the abundance of liquid that clings to the inner walls of the pipe. The higher liquid viscosity will increase wave and stuck in the inner pipe wall.

Keywords:
Churn; Glycerin; Phenomenon; Simulation; Slug-Annular

1. Introduction

Two-phase flow in mini pipe plays an important consideration in design and development of several industrial and medical applications, such as micro heat exchangers, micro cooling electronics, and bio-micro-electro-mechanical system. Type of flow patterns occurs in two-phases flow caused by a lot of factors. Therefore, proper calculations and simulation to avoid error are necessarily needed. Triplett *et al.,* [1] stated that it usually discovered the flow pattern of the bubble, slug-annular, churn, slug, plug and annular in the air-water two-phase flow in the horizontal pipe. One research methods of two-phase flow is the method of a computing system or Computational Fluid Dynamics (CFD). CFD is suitable for calculating and analysing the complicated and difficult system with manual calculation. CFD can also simulate the mass transfer rate, heat transfer rate, and chemical reaction with modelling on a computer. Furthermore, CFD will also provide the data, figures, and curves that show the prediction of the system simulation. By its advantages, CFD is usually used

* *Corresponding author.*
E-mail address: sukamta@umy.ac.id (Sukamta Sukamta)

to analyse a pattern of a system. On the other hand, the experimental study on the effect of multilayer microchannel arrangement to the thermal hydraulic performance of microchannel arrays was also conducted [2]. The main objective of the study is to design /develop array of micro channel with different layer arrangement and to experimentally investigate the effect of layer arrangement in microchannel arrays performance.

The previous study [3] investigated the simulating CFD of stratified air-water flow for the horizontal pipe. The use of water and air was proposed to know the change of stratified flow characteristics. In this study, acrylic pipe with a diameter of 19 mm and length of 1000 mm was used. Fukano *et al*., [4] researched the characteristic of air-water two-phase flow in a capillary pipe with a diameter of 1 mm, 2.4 mm, 4.9 mm and 9 mm, and direction of flow are vertical upward, horizontally and vertically downward. The research result that capillary force is important in the case of a pipe with a diameter of 5 mm – 9 mm and the flow pattern has no significant changes according to the flow direction. The case of pressure loss that was caused by long bubbles from sudden expansion in the flow field of liquid flow is becoming important issues. Meanwhile, a study on numeric modelling and experimental investigation of gas-liquid which forming slug on T-junction microchannel with a hydraulic diameter of 113µm and superficial water velocity of 0/.042 – 0.757 m/s and 0.018 – 0.791 m/s was conducted [5]. The used modelling was CFD with software Fluent. From the study, it can be observed two flow patterns; slug and annular flow pattern. The result of comparison between numeric and experimental modelling is that the slug flow was shorter 400µm. The differentiation might be caused by fluid oscillation resulting from the pressure change that was caught in the numeric model. CFD also is used to study the fluid flow through the cancellous structure. Result of the work show that geometries with the same porosity and overall volume can have different permeability due to the differences in bone surface area[6]. P. A. Baru et.al used CFD to study the fluid flow through the cancellous structure[7].

The investigation of two-phase flow, holding fluid and the decreasing pressure in the thick oil-gas flow were also studied [8]. The result was the flow pattern of stratified, stratified wavy, bubbly flow, plug flow, roll-wave, and slug flow. Meanwhile, the flow pattern and the decrease in the two-phase ionic fluid pressure of liquid-water in the microchannels were investigated too [9]. The results were the flow patterns of 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*., [10] conducted a research about the two-phase flow pattern on short horizontal rectangular microchannels. The result of this research was the flow patterns of bubble, annular, jet, stratified and churn regimes. The effect of liquid viscosity in the gas-liquid two-phase flow pattern in the horizontal pipe was researched [11]. The research was carried out in the transparent horizontal pipe with a diameter of 10 mm and a length of 19 m. Polysaccharide solution as the liquid phase and air phase as the gas phase. The lowest variation in viscosity was 100 mPa s, and the highest was 11.000 mPa s. The result of the research is that the wavy and stratified flow pattern was changed to be annular and intermittent flow pattern in order to increase the liquid velocity. When viscosity liquid is higher than 100 mPa, viscosity liquid is quite affected by the flow pattern, and the model of Taitel-Dukler was used for transition flow. Therefore, the other different approaches need to be developed to predict the flow pattern in the case of high viscosity.

The effect of gas-liquid two-phase flow on fluctuation force in the horizontal pipe-wall was found [12]. Fluid that was used in this research is water-air. The variation of water streamflow is 5, 10, 15, 20, 25, 30, and 35 litre/minute. The variation of the air flow is 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 litre/minute. The research result showed that the greatest force occurs when the bubble flow pattern is 0.143 N. This value is relatively stable. At the same time, the liquid plug flow pattern shows that the generated force is more fluctuating compared to other flow patterns. Santoso *et al*., [13] Studied the differential pressure fluctuation on water-air slug flow pattern in the two-phase flow of horizontal pipe with a diameter of 24 mm and length of 10 m. The speed of data collection is 400 Hz in 50 seconds and using a high-speed camera to visualize flow pattern. The result is that the characteristic of differential pressure fluctuation of slug air-water two-phase flow pattern is significantly affected by the superficial fluid velocity. The change of superficial air velocity and superficial water velocity can be distinguished by the statistical analysis, probably density function (PDF), autocorrelation and power spectral density (PSD). Wibowo *et al.,* [14] carried out an experiment on sub-sub stratified flow pattern in the two-phase flow based on differential pressure fluctuation in the horizontal pipe. The research was done by using transparent acrylic pipe with an inner diameter of 26 mm and a length of 10 m, the use of the high-speed camera in order to visualize the flow. The result showed that flow patterns that were successfully observed visually in this research were classified into sub-sub areas *i.e*., stratified smooth, two-dimensional wave, rolling wave, and atomization. The visualization of the sub-stratified flow patterns observed is still quite difficult to detect if only using differential pressure fluctuations. It because the differential pressure signal indirectly describes the morphology of flow pattern. Korawan *et al.,* [15] found the two-phase flow pattern (water + air) in the horizontal pipe with a diameter of 36 mm, and the variation of superficial water velocity is 0.4; 0.55; 0.7; 0.85; and 1.0 m/s and the volumetric ratio of 0.05 The research result showed that the observed flow pattern was bubble flow, slug flow, and stratified flow, and the greater U_{sl}, the more extended bubble region. When the amount of U_{sl} is increasingly more significant then shifting changes in flow patterns will be occurred. Furthermore, when U_{sl} is low, there will be a change of bubble flow becomes stratified flow and when U_{sl} is high, there will be a change of bubble flow becomes slug flow.

From the above description, it can be known that many of the researches which have been conducted still used the experimental method and still used water-air two-phase flow to know the flow pattern of the system. Only a few of those researches used the computational method especially for mini channel and low viscosity. This research gave a new data of two-phase flow air-water with low viscosity in the horizontal capillary pipe both from computational fluid dynamics and experimental. This result can be used to predict and control the experiment data. This result can be compared to previous study for same condition relatively. This study is hoped to contribute to the industrial application and biomedicine sector especially in analysing the circulatory system disorders.

2. Methodology

To illustrate the phenomenon of the two-phase flow pattern in the horizontal capillary pipe, a simulation was performed. The simulation was conducted in the two-dimension horizontal capillary pipe with the diameter of 1.6 mm and length of 100 mm and used quadrilateral structured mesh type. The work of the fluid used air-water with glycerin 0%, 10%, 20% and 30% and liquid superficial velocity (J_L) = 0.033 m / s – 4.935 m/s and gas superficial velocity (J_G) = 9.62 m/s. Solution set-up and method is shown in Table 1. To validate the result of the simulation was conducted the experimental study using same parameters and conditions relatively.

Table 1
Solution Set-Up and Solution Method

Solution Set-up	Solution Method
Fluent Launcher Option	Single Precision
Processing Option	Parallel (6 Processor)
Additional Models	Laminar Models
Layout	Titles
Autosave	Get Data File Every 20 Time Steps

3. Results and Discussion

3.1 Flow Pattern

The overall simulation result is summarized in Figure 1. The flow pattern obtained in this simulation were slug-annular, annular, annular-churn and churn.

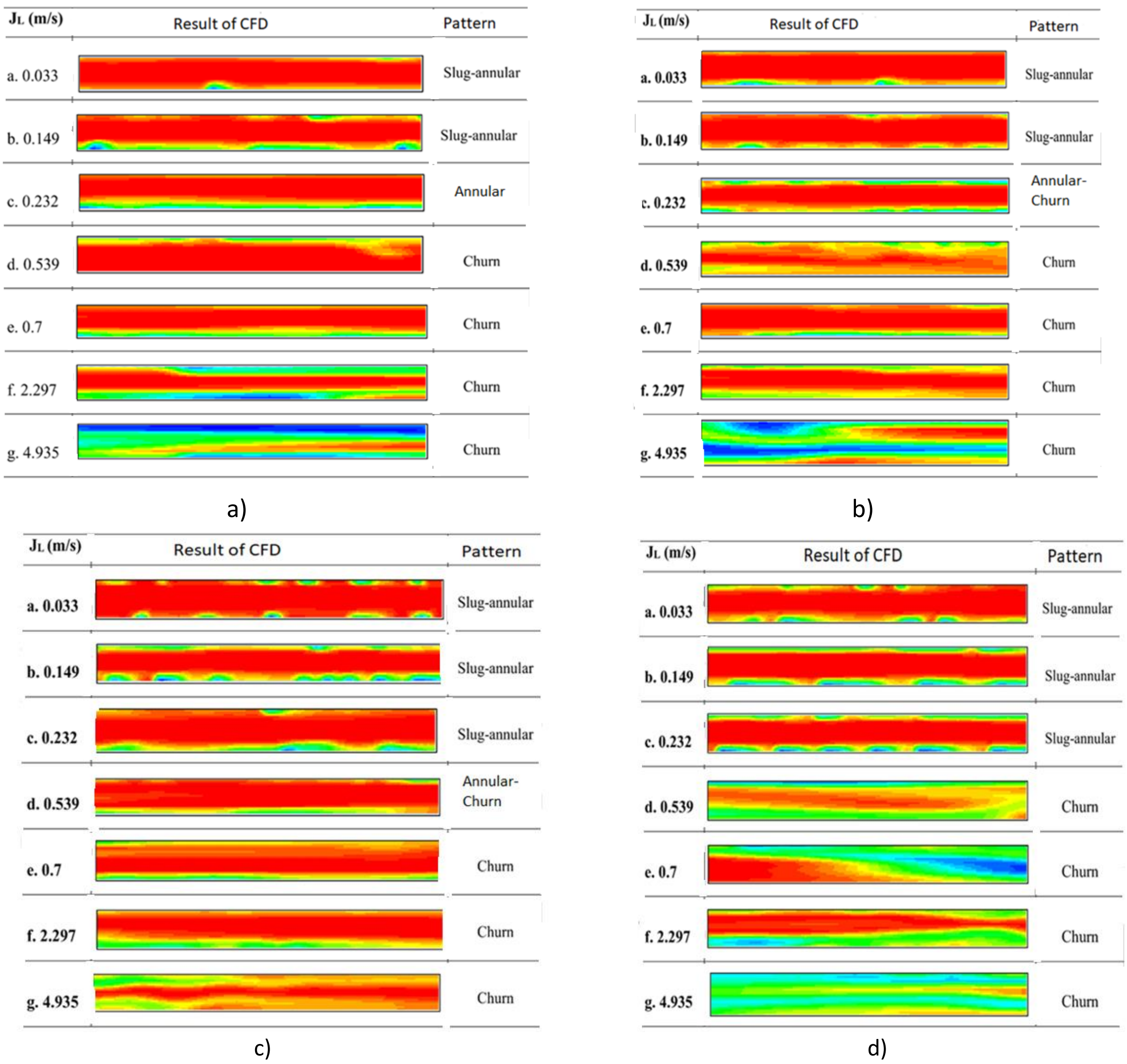

Fig. 1. The Flow Pattern with JG = 9.62 m/s and Various Variation of JL a) Air-Water with 0%Glycerine, b) Air-Water with 10% Glycerine, c) Air-Water with 20% Glycerine, and d) Air-Water with 30% Glycerine

The increase of J_L contributed to cause instability wave at inner wall of pipe. This instability wave can result slug-annular flow for lower of J_L, and annular, annular-churn and churn flow for higher of J_L. Beside that, the increase of concentration of fluid can effect significantly the flow pattern. For lower concentration of fluid, the flow pattern was slug-annular. On the other hand, churn Flow was formed for highest concentration of fluid.

Meawhile, annular and annular-churn were resulted by midle concentration of fluid. The previous research on CFD of annular two-phase flow was done [16]. This research is focused on the prediction of drying by modeling the annular flow. A unified computational fluid dynamics (CFD) model for annular flow was developed for drying applications. The integrated framework produced for annular flow has been applied to steam-water flow with conditions typical for Boiler Water Reactors. Simulation results for the flow of liquid films and the occurrence of drying show compatibility with available experimental data.

Experimental data of flow pattern were shown in Figure 2 to 4. The Instability wave started to occur for high of gas superficial velocity (J_G=7 m/s) and low concentration of fluid (20%). The increase of J_L cause increase number of instability wave happen (Figure 2). Meanwhile, the increase of J_G impacted impact the decrease number of instability or wáter wave for constant of J_L (Figure 3). For furthure, the increase of concentration of fluid can increase the number of wáter wave (Figure 4). The previous study was conducted [17] that the most studies identify the following two-phase flow regimes: bubble, slug and annular. The regimes found in some papers are described. Here they analyse the main factors affecting the structure of the two-phase flow, such as gas and liquid flow rates, parameters of the channel and input section, wettability of the inner surface of channels, liquid properties, and gravitational forces. It was shown that development of instability of the two-phase flow has a significant impact on formation, evolution, and change of the flow regimes.

If we compared the simulation result with the experimental data, we found a good agreement trend. Both of result showed that for high of J_G and low of J_L formed slug-annular, annular, annular churn and churn flow pattern.

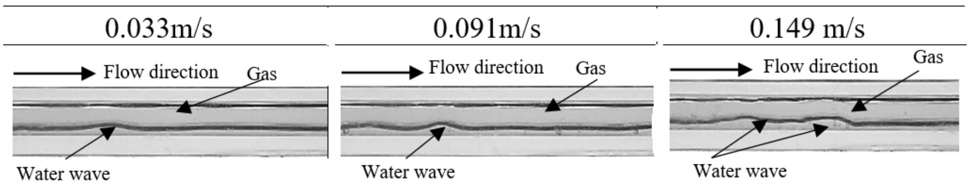

Fig. 2. Experimental data of Flow Pattern with J_G = 7.0 m/s and Various of J_L with concentration of 20% glycerin

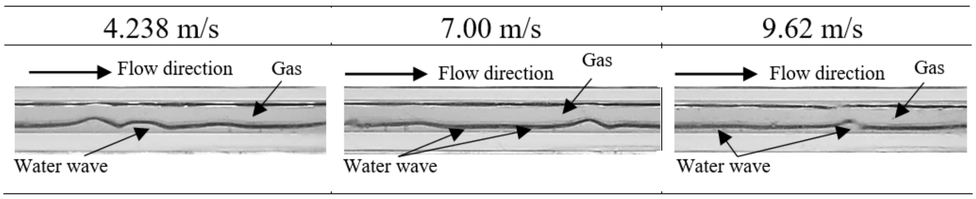

Fig. 3. Experimental data of Flow Pattern with J_L = 0.149 m/s and Various of J_G with concentration of 20% glycerine

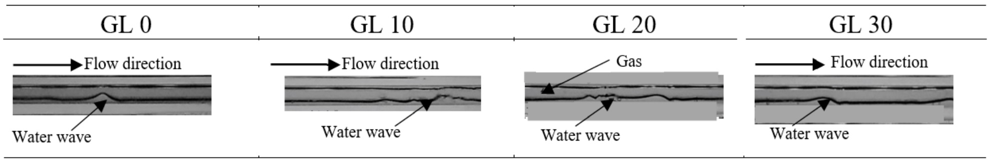

Fig. 4. Experimental data of Flow Pattern with J_G = 4.238 m / s and J_L = 0.091 m / s with various concentration of glycerin

3.2 Pressure Gradient

Results of pressure gradient data were shown in Figure 5 and Figure 6. The meaningful effect of liquid superficial velocity (J_L) to the pressure gradient was shown in Figure 5 which the increase of J_L contributed to increase the pressure gradient significantly. Meanwhile, the impact of viscosity of fluid to the pressure gradient was indicated in Figure 6 which the higher concentration of fluid will increase the pressure gradient prominently. The Pressure gradient can impact to the flow pattern.

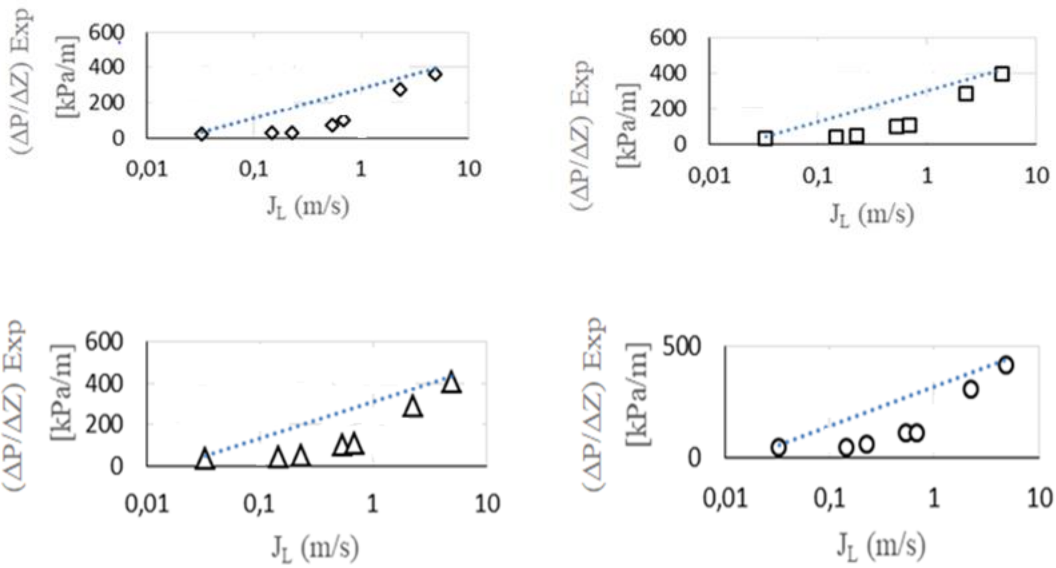

Fig. 5. The effect of J_L to the pressure gradient of two-phase flow

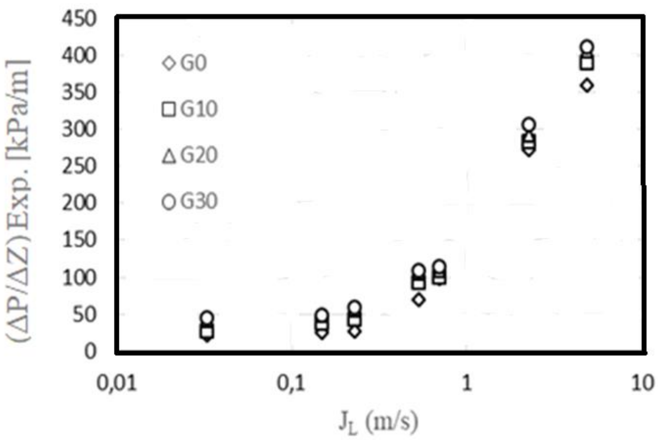

Fig. 6. The effect of concentration of fluid to the pressure gradient of two-phase flow

The concentration of fluid impacted to the Reynolds number. On the other hand, research focus on effect of increasing of flow rate to the Reynolds number was conducted [18]. The flow rate is increased linearly with time from an initial Reynolds number of 9308 (based on hydraulic diameter and bulk velocity) to a final Reynolds number of 29,650. The increase of Reynolds number was caused by the increase of flow rate and also by the increase of viscosity or concentration of fluid. So that why the higher flow rate and viscosity, the higher Reynolds number. For furthers, the increase of Reynolds number impacted to the flow instability. The number of flow instability effect to flow pattern. Meanwhile, the turbulent viscosity trend shows similar behavior. Such a reduction in the intermittency leads to further reduction in turbulent kinetic energy and shear stress in the wall region [16]. The superficial velocity can be expressed by flow rate parameter. The flow rates of the fluids are nonlinear functions of the pressure gradients. The conventional as well as the generalized relative permeabilities depend strongly not only on saturation but also on flow rate ratio, and viscosity ratio. Large viscosity ratio produces cooperative effects that cause increases of the relative permeability to both fluids at any given saturation value [19]. The increase of relative permeability will effect to type of flow.

4. Conclusion

This paper has clearly shown that there was good corresponding between simulation and experimental data for a slug-annular, annular and churn flow patterns. This research also clearly contributed a new data that the liquid and gas superficial velocity effected to pressure gradient significantly. Besides that, the viscosity of fluid also has meaningful impacted to the pressure gradient. For furthers, the pressure gradient impacted to the above flow pattern.

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