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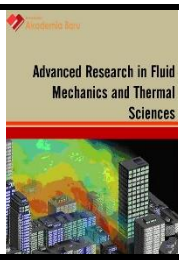

Pressure Gradient on Gas-Liquid Two-Phase Flow with High Viscosity in Capillary Pipe with the Slope of 5 Degrees of Horizontal Pipe

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ABSTRACT

The essential characteristics of two-phase flow are flow pattern, flow pattern maps, void fraction, and pressure gradient. This paper discussed the influence of the pressure gradient on the two-phase flow to know the fluid pressure difference in the pipe. The main problem is that superficial fluid velocity and viscosity affect the pressure gradient significantly. This research was carried out on a glass pipe whose diameter is 1.6 mm with a slope of 5°. The condition of the system is not affected by the environment (adiabatic) at room temperature of 27°C in a steady state. Materials used in this research are air and, water with a mixture of 40%, 50%, 60%, and 70% Glycerine. Pressure drop was measured with a pressure transducer and resulted in voltage data which are then converted into pressure. The new result was obtained that an increase of superficial velocity increased the pressure gradient, whereas the pressure gradient affected by viscosity was shown in the time-series graph. The pressure gradient on J_G = 0.116 m/s, J_L = 0.149 m/s and a viscosity of 40% yielded an average pressure gradient of 45.24 kPa/m. Meanwhile, the viscosity of 50%, 60%, and 70%, resulted in the average pressure gradients of 47.59; 47.61; and 47.75 kPa/m respectively. These results indicated that an increase of the viscosity increased the pressure gradient significantly.

Keywords:
Fluid; Pressure Drop; Superficial; Velocity; Multiphase

1. Introduction

Two-phase flow is part of the multiphase flow that consists of several phases, i.e., gas-liquid, liquid-solid, and solid-gas. The position of the channel for two-phase flow is varied, i.e., upright, horizontal, and tilted position. Several pipe sizes are used in the two-phase flow, among others are; large channel, conventional channel, mini-channel, microchannel, and the smallest pipe size is nanochannel. Two-phase flow can be encountered in daily life, for example, in the industrial field, and biomedical field, etc. The instance of two-phase flow in the biomedical area is found in the human circulatory system.

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The study of pressure gradients in a two-phase flow of water-air in a horizontal direction is carried out using predictive rough surfaces and double circle models [1]. Research on experimental studies of pressure drop in two-phase flow in mini channels has also been carried out with three diameters, namely 3 mm, 1 mm, and 800 µm. Experimental pressure drop data were compared with homogeneous models, and the results were in agreement [2]. Research on the characteristics of water-air flow has also been carried out among others regarding the two-phase flow pattern, void fraction, and pressure in a circular pipe with an inner diameter of 0.53 mm [3]. Research on the two-phase dry plug pressure drop (drywall conditions in some parts of the gas) in the mini-channel has also been carried out. The air-water mixture is channelled through round mini channels made of polyurethane and Teflon, respectively, with an inner diameter ranging from 1.62 to 2.16 mm. In the dry plug flow regime, the pressure drops measured becomes higher both by increasing the shallow liquid velocity [4]. Studies on the reduction of two-phase flow pressure using gas and liquid oil have also been carried out [5]. Furthermore, studies on flow patterns and water pressure drop with oil mixes that have low viscosity in horizontal pipes have also been found [6]. The pressure gradient increases with increasing viscosity of the mixture in this phenomenon. Pressure drop and liquid build up occur when the flow rate differs from the two-oil-water flow.

On the other hand, there is previous study that focus on experimental studies on the effect of multilayer microchannel on the thermal-hydraulic performance of microchannel arrays. The main objective of this study is to investigate experimentally the effect of layer arrangement on the performance of microchannel arrays [7]. Previous research also found that the amplitude of annular flow also became thicker because the depth of thick penetration became thinner with increasing frequency [8]. The previous paper also provided a comprehensive evaluation of 3947 experimental data points that were used to produce gas-liquid flow maps in vertical pipes. The critical review also created a critical analysis of measurement techniques used to identify bubbles, slugs, churns, and annular [9]. Based on the analysis of previous investigations, it was shown that changes in horizontal channel heights had a large effect on the boundaries between regime flow patterns. The churn regime region increases with decreasing channel thickness.

An air-water-oil three-phase flow pattern experiment has been investigated. The superficial velocity used is in the range of 0.25-3 m/s, 0.25-2.3 m/s, and 0.08-13 m/s for water, oil with low viscosity and air. Two main parameters have been considered to illustrate flow patterns in three-phase flow, namely interactions between gas and liquid mixtures, and water and oil phase interactions. Flow patterns for various pipe angles are discussed. The results show that by increasing the oil slice to different tilt angles, the bubble area is elongated, and the puncture region becomes smaller [10]. Correlation of void fractions on pressure gradients of water-air flow in vertical rectangular channels has been investigated experimentally. Superficial gas and liquid velocity range from 0.58 to 32 m/s and from 0.16 to 3.8 m/s. The results showed that the void fraction had a significant influence on the gravity gradient of churn flow and annular flow, but it did not have effect on bubble flow [11].

Based on the previous description, it can be seen that the pressure gradient has a very important role in the application of two-phase flow in minichannels. The main problem is how much influence the superficial velocity, viscosity, and slope of the channel has on the magnitude of the pressure gradient. As far as we know, few studies have focussed on this case. So that why, this study discussed the pressure gradient on two-phase flow air-water and glycerine with high concentration ranging from 40 to 70 % (high viscosity) with the slope of 5 degrees of horizontal pipe.

2. Methodology

The experimental set up used in this study is shown in Figure 1. The components in the tool are the test section, mixer, air compressor, pump, gas flowmeter, fluid flowmeter, pressure sensor, high-speed camera, and computer. The glass pipe with a diameter of 1.6 mm was set in the slope of 5° against the horizontal position. A pressure transducer was used to measure the pressure drop on the system under the Validyne brand which was connected to the inlet and outlet of the test section. The data generated by the pressure transducer was analogue data which were then changed to be digital data by using the data of acquisition of Advantech. The calibration was conducted before using the pressure transducer by a vertical manometer (water column manometer) under static conditions.

The used material in this study was gas and liquid fluid. The gas fluid was pressurized dry air resulted from the compressor. For liquid fluid, the mixture of water and 40 %, 50 %, 60 %, and 70 % glycerine were used (Table 1). This study was carried out at the superficial gas velocity (J_G) = 0 - 66.3 m/s, and the superficial liquid velocity (J_L) = 0.033 - 4.935 m/s.

Table 1
The physical characteristic of the liquid fluid

Fluid	Specific Gravity	Kinematic Viscosity [mm^2/s]	Surface tension [*N/ cm^2*]	Index
Air+40 % glycerin	1.1114	3.32	58.6	G40
Air+50 % glycerin	1.1421	5.505	57.5	G50
Air+60 % glycerin	1.1671	9.393	56.4	G60
Air+70 % glycerin	1.1896	16.98	53.9	G70

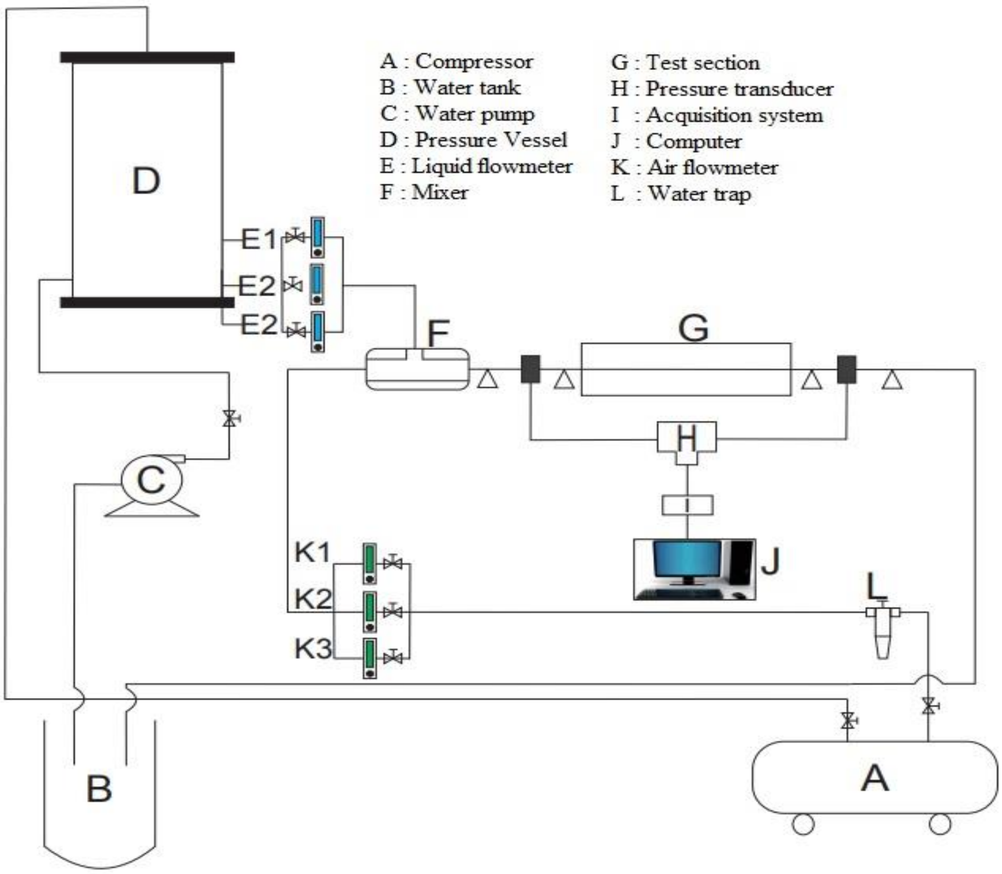
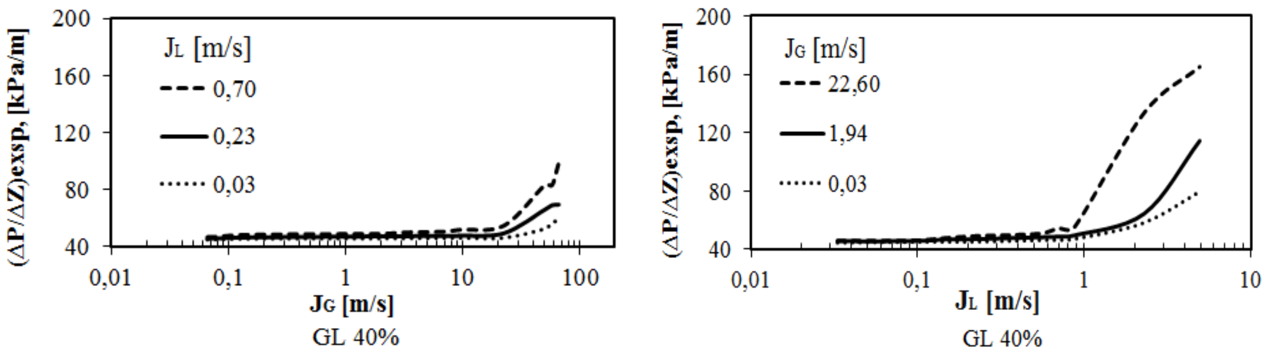


Fig. 1. Experimental set up

3. Results

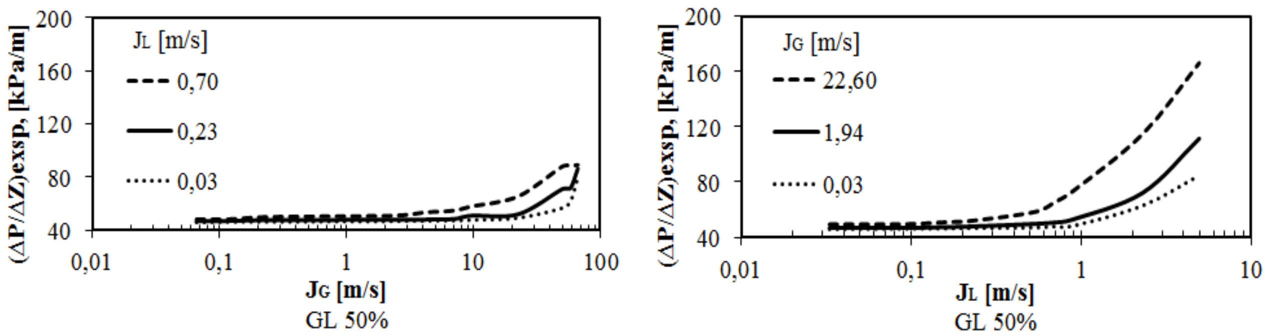
The way to show the effect of superficial gas velocity and superficial liquid velocity against the pressure gradient is by implementing the variation of J_G and J_L. Figure 2(a), 3(a), 4(a), and 5(a) show the increased pressure gradient at constant J_L and various J_G. The tool used to measure the superficial gas and superficial liquid velocity is rotameter with the range of 3 J_L (0.03; 0.23; and 0.70 m/s) and varies J_G (0-66.3 m/s) on every J_L. The pressure gradient with constant superficial gas velocity (J_G) and superficial liquid velocity (J_L) is presented in Figure 2(b), 3(b), 4(b), and 5(b). The mechanism of measurement was similar to the constant with the use of rotameter at the range of 3 J_G (0.03; 1.94; dan 22.60 m/s) dan various J_L (0.033-4.935 m/s). From those figures, it can be seen that the superficial velocity affects the pressure gradient. The higher the velocity of superficial gas or liquid yields the greater the pressure gradient. The increase of pressure gradient which affected by the superficial gas velocity and superficial liquid velocity leads to an increase of the total volumetric flux. On the other hand, the increase of steam mass flow rate (m_{st}) resulted in larger instability and started to generate a wavy slug flow pattern [12].

The previous study on pressure drop on the two-phase flow by using microchannel showed that the increased pressure gradient was caused by the increase of superficial velocity [13]. Research on a more substantial amount of viscosity was resulting in significant pressure different if compared to the fluid which had a low viscosity. This phenomenon can be proved by the pressure drop which is getting more significant due to the higher viscosity. The study on the characteristic of the pressure gradient in a two-phase flow of air-mixture of water and 20 % glycerin in a horizontal glass pipe 1.6 mm in diameter to know the effect of superficial velocity of gases and liquids on pressure gradients was conducted [14].



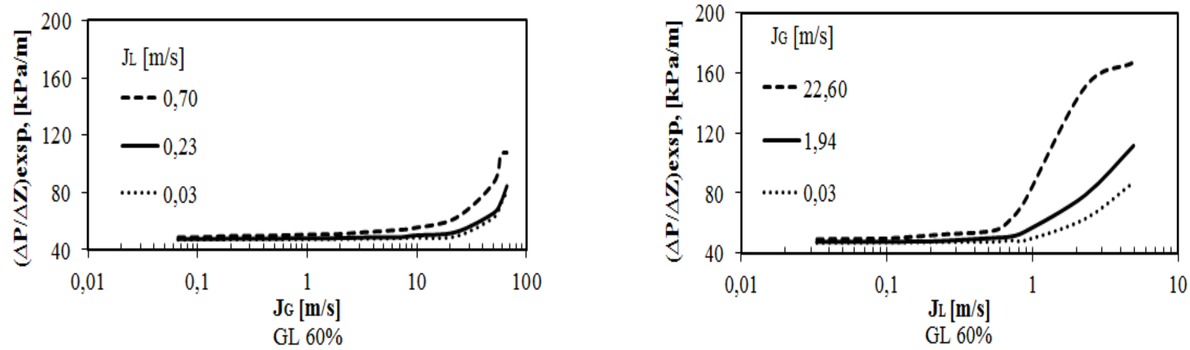
(a) (b)

Fig. 2. Pressure gradient at (a) J_G = 0-66.3 [m/s] with the range of J_L (0.70; 0.23; dan 0.03 [m/s]), (b) J_L = 0.033-4.935 [m/s] with the range of J_G (22.60; 1.94; dan 22.60 [m/s]), the mix of 40% glycerin



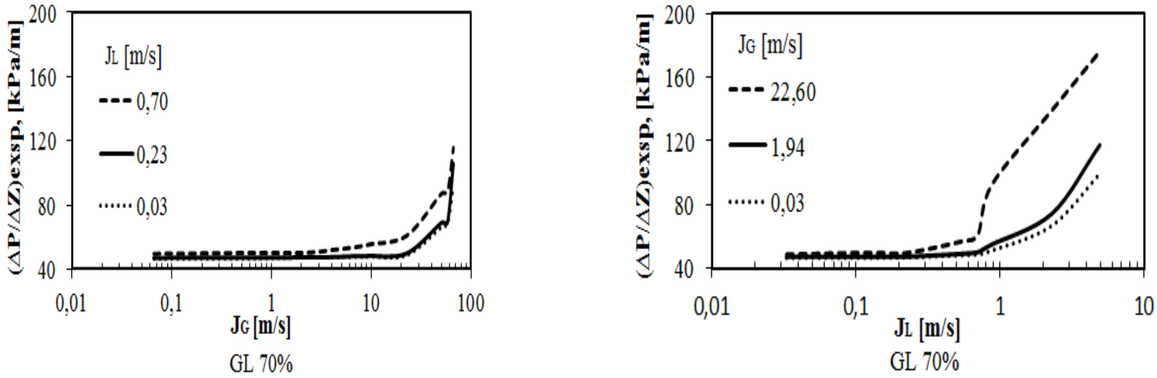
(a) (b)

Fig. 3. Pressure gradient at (a) J_G = 0-66.3 [m/s] with the range of J_L (0.70; 0.23; dan 0.03 [m/s]), (b) J_L = 0.033-4.935 [m/s] with the range of J_G (22.60; 1.94; and 22.60 [m/s]), the mix of 50% glycerin



(a) (b)

Fig. 4. Pressure gradient at (a) J_G = 0-66.3 [m/s] with the range of J_L (0.70; 0.23; dan 0.03 [m/s]), (b) J_L = 0.033-4.935 [m/s] with the range of J_G (22.60; 1.94; and 22.60 [m/s]), the mixture of 60% glycerin



(a) (b)

Fig. 5. Pressure gradient at (a) J_G = 0-66.3 [m/s] with the range of J_L (0.70; 0.23; and 0.03 [m/s]), (b) J_L = 0.033-4.935 [m/s] with the range of J_G (22.60; 1.94; and 22.60 [m/s]), the mixture of 70% glycerin

Figure 6(a) and 6(b) show the effect of viscosity on the pressure gradient at constant J_L and vary J_G, and at constant J_G and vary J_L, respectively. An increase in viscosity significantly increases the pressure gradient. Based on the equation of the Reynold number and friction factor, the Reynolds number has an inverse comparison with the friction factor. From these inverse comparisons, it can be known that the higher viscosity, the Reynold number will be smaller. If the Reynold number decreases, the friction will increase, causing a pressure gradient to rise. Comparing to the study of which uses the slope of 0°, the effect of geometry was not significant enough [15]. This phenomenon caused by the effect of gravity force in two-phase flow is very small.

The figure of time-series showed the relationship between the viscosity and the pressure gradient which can be recognized from the increase of pressure gradient average at a higher concentration of glycerin. The pressure gradient average at the percentage of glycerin of 40 %, 50 %, 60 % and 70 % are 45.24; 47.59; 47.61; and 47.75 kPa/m respectively. These pressure gradients were obtained at J_G = 0.116 m/s and J_L = 0.149 m/s and time of 0.5 seconds. Furthermore, the data of the time-series pressure gradient is presented in Figure 7. The time-series pressure gradient was used to prove that the obtained data are valid.

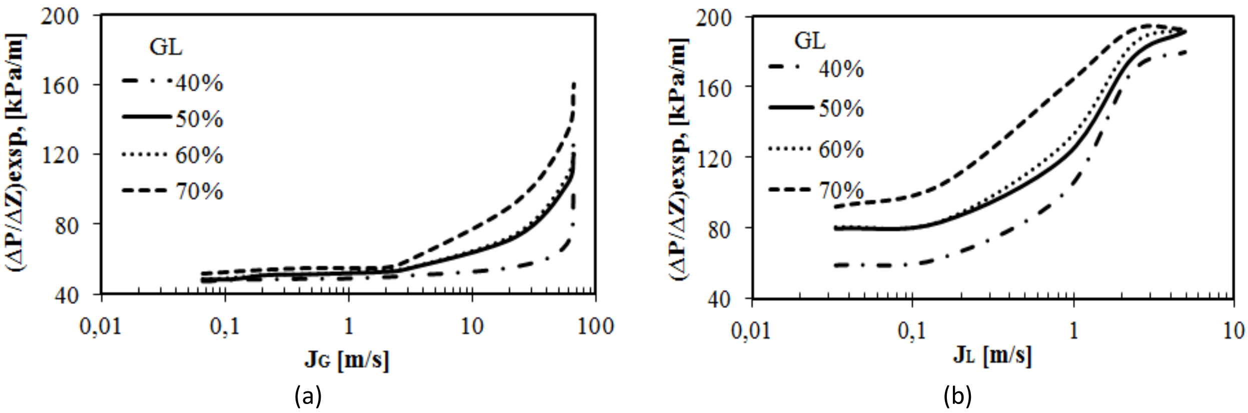


Fig. 6. The effect of viscosity against the pressure gradient at (a) J_L = 0.879 m/s and varies J_G, (b) J_G = 66.3 m/s and varies J_L

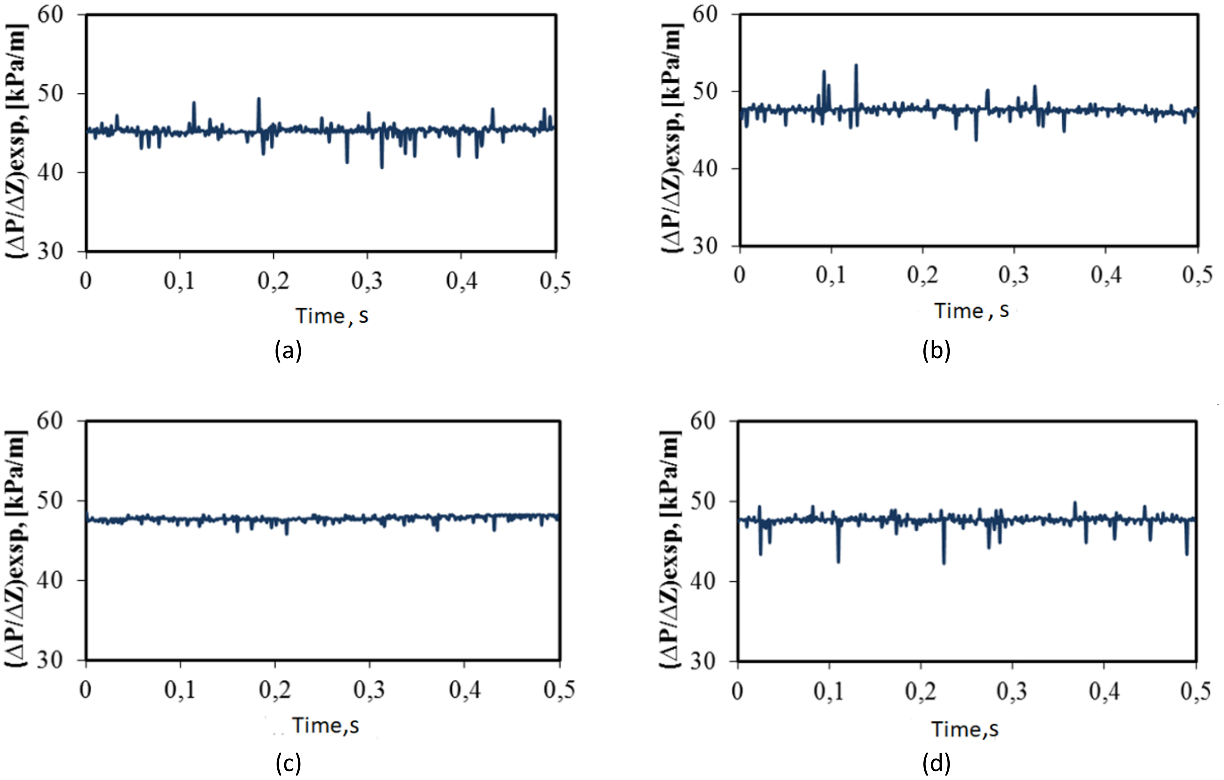


Fig. 7. Time-series pressure gradient at J_G = 0.116 m/s and J_L = 0.149 m/s (a) GL 40, (b) GL 50 (c) GL 60, dan (d) GL 70

The previous 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 [14]. Previous studies also analyzed two-phase flow patterns in capillary channels. The impact produced by the capillary effect is analyzed and compared with the influence of other factors. The characteristics of two-phase flow in noncircular cross-section channels have also been considered. This shows that the thermocapillary effect is significant under conditions of two-phase non-heat flow in microchannels and weak gravitational forces [16]. The experimental results show that the low pressure and friction gradients in the microchannel are higher than those provided by conventional laminar flow theory. The higher-pressure gradients and the lower friction measured were caused by the effect of the surface roughness of the microchannel [17]. Meanwhile, previous studies also presented numerical simulations of flow in microchannel heat sinks with dimensions less than 1.0 mm and greater than 100.0 µm (for the velocity of 0.1 and 0.5 m/s). The software used to predict the flow regime is ANSYS CFX 2015. The results showed that the pressure drop on rectangular microchannel with width 0.75 mm is higher by 58.12 %, and 0.02 % closer to rectangle microchannel with height 0.75 mm. These results are compared and validated by published data, and there is a match [18].

4. Conclusions

The pressure gradient at J_G = 0 - 66.3 m/s with the range of J_L (0.70; 0.23; and 0.03 m/s) was increasing because the bigger J_G, the bigger pressure gradient will be produced. A similar result occurred at J_L = 0.033 - 4.935 m/s with the range of J_G (22.60; 1.94; and 0.03 m/s). The pressure gradient average at J_G = 0.116 m/s J_L = 0.149 m/s and the viscosity of 40 %, 50 %, 60 %, and 70 % consecutively were 45.24; 47.59, 47.61, and 47.75 kPa/m. This phenomenon shows that the more significant viscosity, the more significant pressure gradient will be produced as well f18].

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References
[1] Badie, S., C. P. Hale, C. J. Lawrence, and G. F. Hewitt. "Pressure gradient and holdup in horizontal two-phase gas–liquid flows with low liquid loading." *International Journal of Multiphase Flow* 26, no. 9 (2000): 1525-1543.

[2] Pehlivan, K., I. Hassan, and M. Vaillancourt. "Experimental study on two-phase flow and pressure drop in millimeter-size channels." *Applied Thermal Engineering* 26, no. 14-15 (2006): 1506-1514.

[3] Sira Saisorn, and Somchai Wongwises. "Flow pattern, void fraction and pressure drop of two-phase air–water flow in a horizontal circular micro-channel. "*Experimental Thermal and Fluid Science* 32, no. 3 (2008): 748-760.

[4] Chi Young Lee, and Sang Yong Lee. "Pressure drop of two-phase dry-plug flow in round mini-channels: Effect of moving contact line." *Experimental Thermal and Fluid Science* 34, no. 1 (2010): 1-9.

[5] Hatef A. Khaledi, Ivar Eskerud Smith, Tor Erling Unander, and Jan Nossen. "Investigation of two-phase flow pattern, liquid holdup and pressure drop in viscous oil–gas flow." *International Journal of Multiphase Flow* 67 (2014): 37-51.

[6] Darvind Nadaraja, Natrah Kamaruzaman, Ummikalsom Abidin, and M. Mohd Sies. "Experimental study on the effect of multilayer microchannel arrangement to the thermal hydraulic performance of microchannel arrays." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 57,* no. 1 (2019): 23-31.

[7] Fatimah Al Zahrah Mohd Saat, Siti Hajar Adni Mustaffa, and Fadhilah Shikh Anuar. "Numerical and Experimental Investigations of the Oscillatory Flow Inside Standing Wave Thermoacoustic System at Two Different Flow Frequencies." *CFD Letters* 11, no. 8 (2019): 1-15.

[8] Benjamin Wu, Mahshid Firouzi, Travis Mitchell, Thomas E. Rufford, Christopher Leonardi, and Brian Towler. "A critical review of flow maps for gas-liquid flows in vertical pipes and annuli." *Chemical Engineering Journal* 326 (2017): 350-377.

[9] Evgeny Anatol'evich Chinnov, Fedor Valer'evich Ron'shin, Vladimir Vladimirovich Guzanov, Dmitriy Markovich Markovich, and Oleg Alexandrovich Kabov. "Two-phase flow in a horizontal rectangular microchannel." *High Temperature* 52, no. 5 (2014): 681-687.

[10] Pedram Hanafizadeh, Amirhossein Shahani, Ashkan Ghanavati, and M. A. Akhavan-Behabadi. "Experimental investigation of air-water-oil three-phase flow patterns in inclined pipes." *Experimental Thermal and Fluid Science* 84 (2017): 286-298.

[11] Dianchuan Xing, Changqi Yan, Xinguang Ma, and Licheng Sun. "Effects of void fraction correlations on pressure gradient separation of air–water two-phase flow in vertical mini rectangular ducts." *Progress in Nuclear Energy* 70 (2014): 84-90.

[12] Sukamta and Sudarja. "Temperature Profiles on Multi-Location of Steam Flow Condensation Cooled Using Parallel Flowing Water in the Outside of a Horizontal Pipe." *J. Mech. Eng. Res. Dev.* 42, no. 4 (2019): 97–101.

[13] Kawahara, A., PM-Y. Chung, and M. Kawaji. "Investigation of two-phase flow pattern, void fraction and pressure drop in a microchannel. "*International journal of multiphase flow* 28, no. 9 (2002): 1411-1435.

[14] Sukamta Sukamta. "Computational Fluid Dynamics (CFD) and Experimental study of Two-Phase Flow Patterns Gas-Liquid with Low Viscosity in a Horizontal Capillary Pipe." *CFD Letters* 11, no. 8 (2019): 16–23.

[15] Sudarja, Jayadi, F., Indarto, & Deendarlianto. "Karakteristik Gradien Tekanan pada Aliran Dua-Fase Udara-Campuran Air dan 20% Gliserin Dalam Pipa Horizontal Berukuran Mini." *Proceeding National Symposium on Thermofluids* 8 (2016): 264–269.

[16] Chinnov, Evgeny Anatol'evich, and Oleg Alexandrovich Kabov. "Two-phase flows in pipes and capillary channels." *High Temperature* 44, no. 5 (2006): 773-791.

[17] Qu Weilin, Gh Mohiuddin Mala, and Li Dongqing. "Pressure-driven water flows in trapezoidal silicon microchannels." *International Journal of Heat and Mass Transfer* 43 (2000):353-364.

[18] Azlizul Aizat Razali, and Azmahani Sadikin. "A CFD Simulation Study on Pressure Drop and Velocity across Single Flow Microchannel Heat Sink." *Journal of Advanced Research Design* 8, no. 1 (2015): 12-21.