Mekanika: Majalah Ilmiah Mekanika

Pressure Drop and Void Fraction of Two-Phase Flow (Air-Water) in Grooved Vertical Pipes.

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Abstract

In an industrial environment, Two-phase flows has many weaknesses, including pressure drop and void fraction. One strategy to reduce losses that arise is to use passive methods. The passive method used is to utilize the shape of the grooves in the channel. In this study, the flow is used to determine its effect on the pressure drop and void fraction that appears in two-phase flow. The experimental method was used for this study. The test pipe is equipped with 16 grooves, while the smooth pipe (without grooves) is used as a comparison. The test pipe is made of acrylic material. The water fluid is circulated using a centrifugal water pump with a superficial speed of 0.33-0.42 m/s. Air fluid is supplied using a compressor with superficial speeds of 0.049, 0.066, and 0.082 m/s. Measurement of pressure drop was carried out using a pressure transmitter with an Arduino data logger. The void fraction is calculated by determining the ratio of the volume fraction of water and air in the test tube. The results of the study revealed that the use of 16 grooves in the pipe can reduce the pressure drop and cavity fraction that appears when compared to smooth pipes.

1 Introduction

Several studies have been conducted to investigate two-phase flow, including flow patterns, mechanisms, and fluid flow instability. Flow in vertical channels can be broadly classified into several flow patterns, such as bubbly flow, slug flow, churn flow, and annular flow [1,2]. Many efforts have been made to find efficient ways to reduce energy losses in channels. One method that can be employed is by modifying the channel's geometry, which is a concept associated with controlling vortex formation. Natural geometry forms are frequently used as inspiration for designing better channels. One example is adding grooves to the channel's geometry. Research on shark skin surface itself has been conducted and shown that the shape of shark skin surface is capable of reducing friction when moving through water. With the design of such skin surfaces, sharks can move through the water using minimal energy. The impact of grooves on laminar and turbulent flow in reducing drag has been successfully identified through numerical analysis and visualization [3,4]. In the context of turbulent fluid flow, the addition of grooves affects the boundary layer conditions and the viscous region near the pipe walls. This behavior significantly influences the reduction of pressure and viscous resistance that occurs during fluid flow. A comparative study between pipes without grooves and pipes with grooves has also been conducted.

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Under turbulent conditions, flow along the grooves successfully reduces friction and Reynolds number, indicating a reduction in fluid flow resistance [5-7]. Two-phase flow in corrugated pipe with a vertical position has been identified and compared with smooth pipe [8]. The droplet size of bubbles in grooved pipes indicates larger liquid fragments compared to smooth pipes. The friction factor is influenced differently by varying numbers of grooves with parallel flow patterns along the pipe. In a study of single-phase horizontal flow, it was discovered that pipes with 2, 8, and 32 grooves experienced reduced friction due to the larger size of vorticity formed compared to the groove width. As a result, the flow patterns became straighter with a smaller velocity gradient. In pipes with 4 or 16 grooves, vortices formed with sizes smaller than the groove width. This formation caused an increase in the friction factor, resulting in a more circular vortex movement with a higher velocity gradient. Choosing the correct number of grooves can minimize energy loss due to friction. Flow-through grooves can achieve better drag reduction compared to smooth pipes because they reduce shear stress and impede vortex flow translation [3,5-8]. After conducting research, it has been determined that grooves can be utilized for commercial purposes to decrease drag. Previous studies have explored flow patterns and structures passing through grooves on flat plates, external flows, and grooved pipes using numerical and experimental methods [9-11]. When pipes are in a vertical position, the pressure drop effect is more significant compared to pipes in a horizontal position. The gravity factor mainly causes this. Additionally, the air pressure in the pipe, which is inversely proportional to the nature of the water, can move up against gravity, resulting in a higher void fraction. As a result, water falls because it is attracted by gravity [2,12,13].

Studying the flow of two-phase fluids through fluted pipes is fascinating because the grooves in the channel can reduce losses in industrial-scale applications [8,9,14]. Additionally, the presence of grooves affects the resulting flow pattern. In this study, we observed pipes with varying numbers of grooves compared to smooth pipes (without grooves) using two-phase fluids like air and water. We modified the pipe's geometry by adding grooves along the pipe, which has yet to be researched with parallel grooves in pipes with a vertical position. However, pipe installation is carried out in various positions, both for daily and industrial use. This research aims to determine the effect of the number of grooves on the pressure drop and the fraction of void space that passes through the pipe in a vertical position.

2 Experimental Methods

This research used an experimental method to study pressure drops and void fraction characteristics. In this study, the test section was vertically directed with air and water as the fluids. The test section was an acrylic pipe with grooves inside and a diameter of 2.54 cm. The acrylic pipe was 100 cm long and had 16 grooves. In order to compare the outcomes, a smooth acrylic pipe was utilized. The research involved measuring the pressure drop and void fraction.

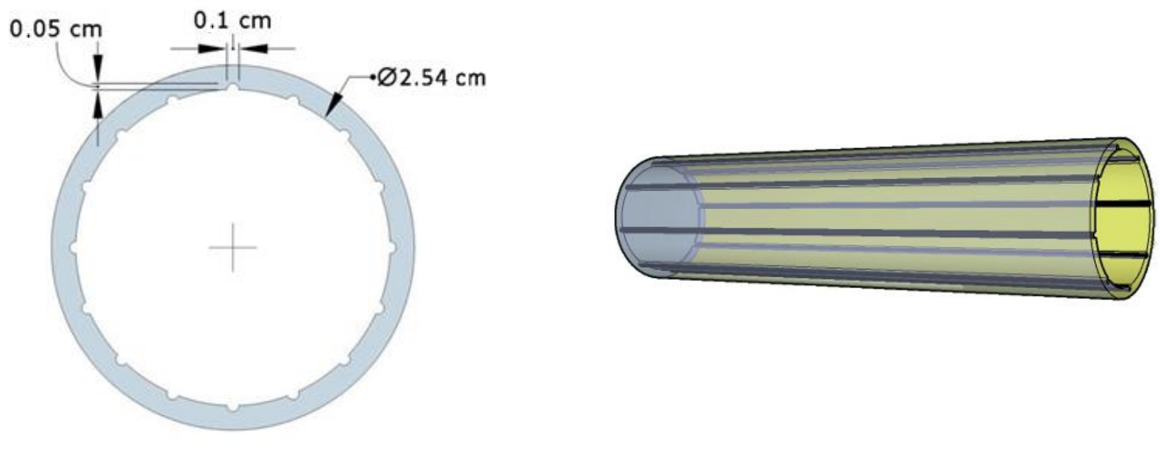
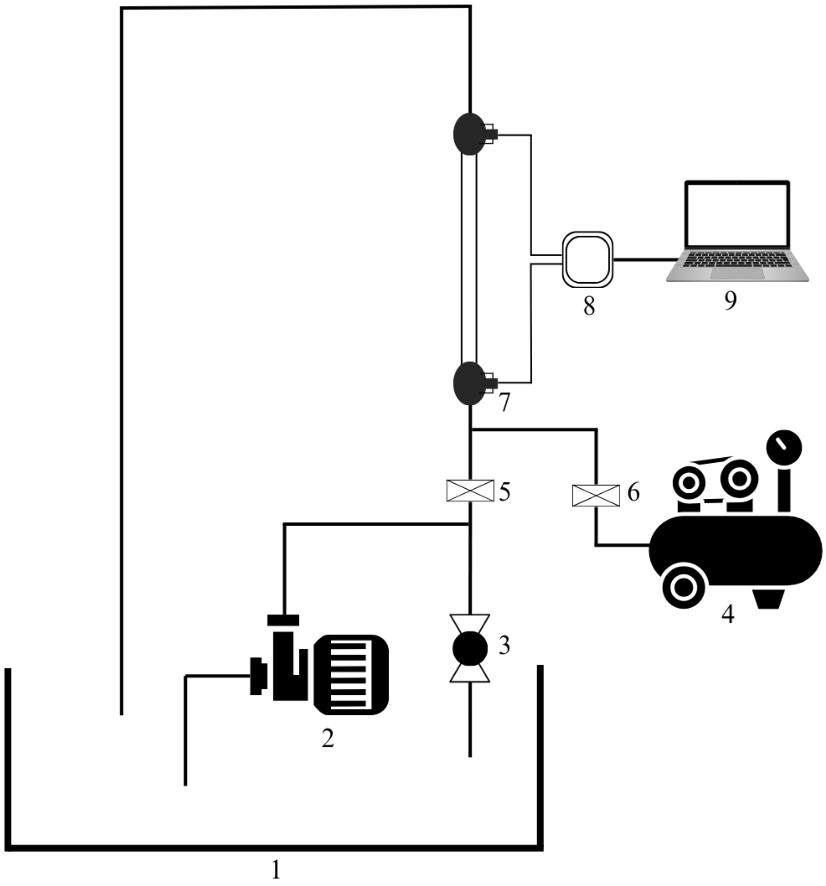


Figure 1. Cross section of the pipe design



Experimental Setup:

1. Water Tank
2. Water Pump
3. Valve
4. Compressor
5. Digital Flowmeter
6. Rotameter
7. Pressure Sensor
8. Arduino Data Logger
9. Laptop

Figure 2. Schematic diagram of research setup

The research setup, as shown in Figure 2, was used for the testing. After the availability of grooved pipes, they were installed vertically in the research setup. Pressure sensors were fixed at both ends of the grooved pipes and were directly connected to an Arduino data logger. Pressure measurement was carried out using a type Pressure Transmitter type 0-500 psi DC 5V Arduino pressure transmitter that has been calibrated with FESTO SDE1. Each pipe was subjected to alternating variations in air and water superficial velocities throughout the testing process. The air's superficial velocity ranged from 0.049 to 0.082 m/s, while that of water was between 0.066 and 0.23 m/s. The theoretical calculations listed below are needed to facilitate the research process [2,14-17]. The calculation of the superficial velocities of air and water can be determined using Equations 1 and 2, while for the mixed Reynolds number calculation, the Equation 3 can be used for the current calculation.

$$j_G = \frac{Q_G}{A} \tag{1}$$

$$j_L = \frac{Q_L}{A} \tag{2}$$

j_G = superficial velocity of gas (m/s)

Q_G = gas flow rate (lpm)

j_L = superficial velocity of liquid (m/s)

Q_L = liquid flow rate (lpm)

A = surface area (m^2)

$$Re_m = \frac{\rho_m V_m D}{\mu_h} \tag{3}$$

ρ_m = mixture density (kg/m^3)

V_m = actual velocity of the mixture (m/s)

D = pipe diameter (m)

μ_h = homogeneous viscosity (Pa/s)

α is the gas fraction in the channel, while $(1-\alpha)$ is the liquid fraction in the channel (see Equation 4)

$$\alpha_G = 1 - \alpha_L \tag{4}$$

From the gas quality and liquid quality equations, the value of mixture density can be determined using Equation 5, and the value of mixture viscosity can be determined using Equation 6. Furthermore, the value of the actual velocity for each phase can be determined using the Equations 7 and 8.

$$\rho_h = \alpha_G \rho_G + \alpha_L \rho_L \tag{5}$$

$$\frac{1}{\mu_h} = \frac{x}{\mu_G} + \frac{1-x}{\mu_L} \tag{6}$$

$$V_G = \frac{j_G}{\alpha_G} \tag{7}$$

$$V_L = \frac{j_L}{\alpha_L} \tag{8}$$

Table 1. Fluid properties at average temperature of 30 °C

Fluids	Density	Viscosity
Water	997 (kg/m^3)	10^{-3} Pa/s
Air	1.2 (kg/m^3)	1.81 x 10^{-5} Pa/s

Once all variations have been adjusted, the fluid flow is allowed to circulate until a stable two-phase flow condition is achieved. Once stabilized, the pressure drop is measured for a predetermined duration. The pressure sensor is set to display data every minute, and the Arduino data logger is always connected to the laptop when collecting pressure data. It ensures that every reading of the pressure sensor is directly stored in the laptop. The collected pressure data is processed and presented in graphical form based on the measurement results [2,9,14,18]. In determining the void fraction, the quick and simultaneous closing valve method is utilized. The test pipe's inlet and outlet sides are connected to a solenoid valve that can be controlled simultaneously, ensuring both valves open and close at the same time. Once pressure data collection is complete, the valve is closed, trapping air and water in the pipe. The trapped air and water gather according to their respective fractions, and Equation 4 is used to calculate the ratio of water volume to air volume in the pipe. For easier water volume calculation, a measuring cup on the mL scale is used. The above equation provides the volume of air, which is the void fraction [11,15,16,19].

3 Results and Discussion

3.1 Pressure drop

In the process of research results and data analysis, the pressure drop for each test pipe is graphically analyzed. Figure 3 clearly shows that as pressure drop values increase, both test pipes tend to have lower V_G/V_L ratios. Conversely, when pressure drop values decrease, V_G/V_L ratios tend rise. The pipe with 16 grooves has significantly lower pressure drop values than the smooth pipe, proving that the grooves effectively reduce pressure drop [9,18].

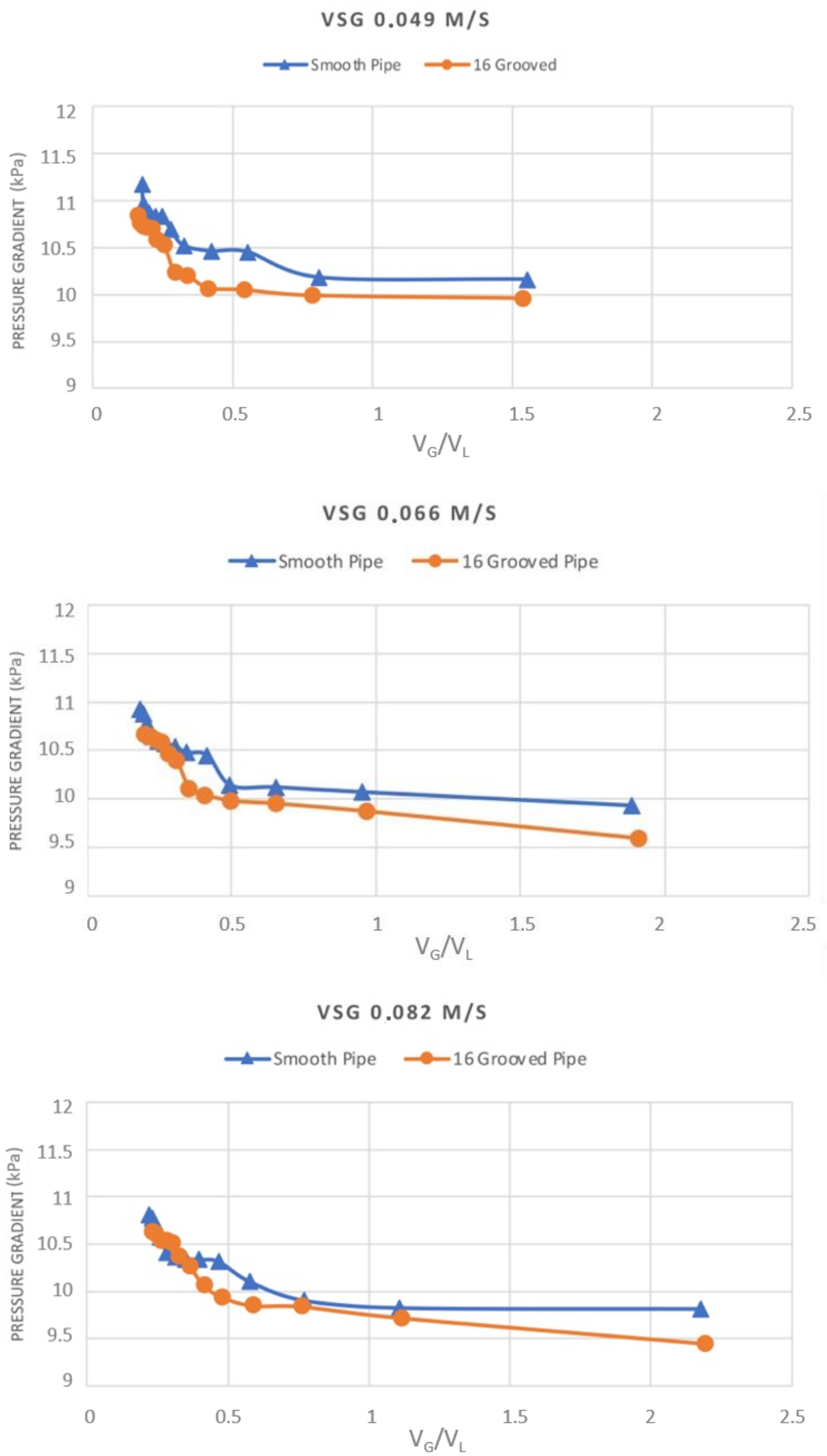


Figure 3. Pressure drop values against V_G/V_L at different superficial gas velocities

3.2 Void fraction

By analyzing the void fraction data, we can accurately determine the quantities of water and air within the pipe. It is important to note that void fraction directly influences the density of the two-phase mixture, which ultimately impacts the pressure drop of one component, specifically the hydrostatic pressure caused by gravitational force [14,16]. An analysis is conducted using graphical methods to examine the influence of void fraction on the grooved pipe by comparing the void fraction to the gas volume to liquid volume ratio (V_G/V_L). In all tested pipes, the change in void fraction with respect to V_G/V_L shows similar patterns. The void fraction is proportional to V_G/V_L, and when the void fraction is low, so is V_G/V_L. As the superficial gas velocity increases, there is a slight difference in the void fraction values when V_G/V_L is low. The changes in void fraction also affect the mixture density, which in turn affects the hydrostatic pressure as a part of the total pressure drop. However, in this study, the changes in the void fraction are minor and do not have a significant impact on the overall total pressure drop value.

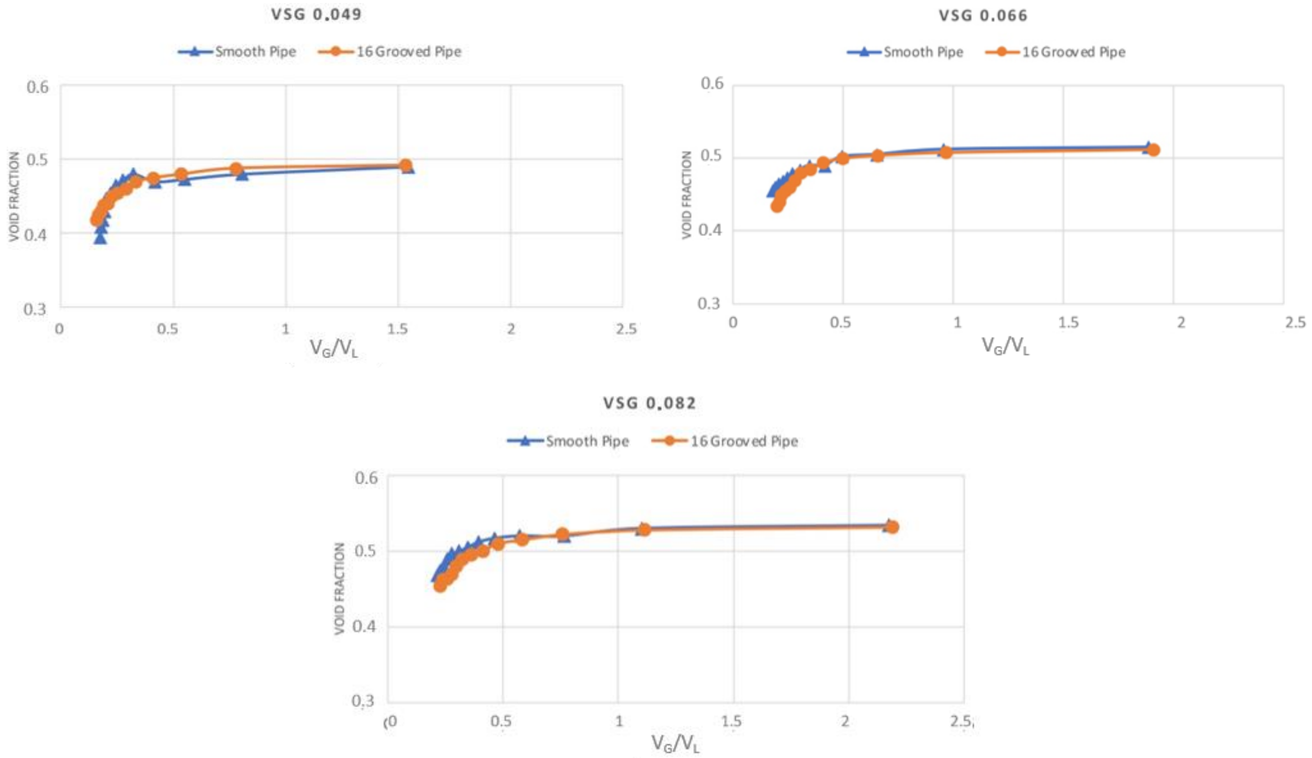


Figure 4. The void fraction values against V_G/V_L at different superficial gas velocities

4 Conclusions

The different pressure drop results are obtained between the two-phase flows that pass through smooth pipes and grooved pipes. In grooved pipes, the value of the pressure drop tends to be smaller than that of plain pipes. The addition of the superficial velocity of the gas also results in a smaller pressure drop in the grooved pipe. It is also influenced by the gravity factor, where air has the natural property of moving away from gravity so that it can push the movement of the fluid as a whole. Meanwhile, the data obtained for measuring the void fraction in grooved pipes shows a decrease. The results of measuring the void fraction at each increase in the superficial velocity of the gas also result in a change in the void fraction. However, the decrease is minimal, and the change is not very significant. Overall, the grooves used as a passive method to reduce pressure drop have been successful. The addition of grooves in the pipe turns out to affect changes in the value of the void fraction, which is relatively small when compared to plain pipes. For the development of knowledge in the future, the use of paths with more numbers can be used as a reference. So that the most efficient number of grooves can be obtained to reduce pressure drop and especially the void fraction because, in this study, changes in the value of the void fraction occur on a relatively small scale.

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