ANALYSIS OF PRESSURE TRANSIENT IN HYDRAULIC SYSTEM (UTeM)

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled “Analysis of Pressure Transient in Hydraulic System” is the result of my own work except as cited in the references

Signature : ....

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Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion, this report is sufficient in terms of scope and quality for the award of the Bachelor degree of Mechanical Engneering (Thermal-Fluid).

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Date	:	....

DEDICATION

To my beloved mother and father

ABSTRACT

Water Hammer/ Hydraulic Transient in a problem that happened to all type of pipe that have the fluid flow on it. It caused due to the pressure difference in the pipe which happened when the velocity of the fluid flow is suddenly stopped when the valve is closed. This effect will caused the damage to the pipes when the pressure exceeding the maximum pressure that can withstand for the pipe. The analysis of the hydraulic transient/water hammer is done to overcome this problem from happen in the pipeline especially in hydraulic system and it needs to create a simulation circuit of the hydraulic system. The designing of the system included system layout, the components of the hydraulic parts and the various type of sensors. The design phase can be categories into 3 sections which is by using MATLAB software simulation to create the circuit and requirement components. Secondly is to modify the hydraulic system according to the variables needed. Finally, putting few pressure sensors and flow rate sensor to get the data needed. Besides, the hydraulic transient/water hammer effect value can get from each variables used and need to compare which is the most factor that can create the higher hydraulic transient/water hammer in the system.

ABSTRAK

Water Hammer / Hydraulic Transient dalam masalah yang berlaku kepada semua jenis paip yang mempunyai aliran bendalir di dalamnya. Ia disebabkan oleh perbezaan tekanan di dalam paip yang berlaku apabila halaju aliran bendalir tiba-tiba berhenti apabila injap ditutup. Kesan ini akan menyebabkan kerosakan kepada paip apabila tekanan melebihi tekanan maksimum yang boleh ditahan untuk paip. Analisis *Water Hammer / Hydraulic Transient* dilakukan untuk mengatasi masalah ini berlaku terutamanya dalam sistem hidraulik dengan cara menghasilkan litar simulasi sistem hidraulik. Ia perlu untuk mereka bentuk satu sistem termasuk susun atur sistem, komponen bahagian hidraulik dan meletakkan pelbagai jenis sensor. Fasa reka bentuk boleh menjadi kategori kepada 3 bahagian iaitu dengan menggunakan simulasi perisian MATLAB untuk mewujudkan litar dan keperluan komponen. Kedua adalah untuk mengubah suai sistem hidraulik mengikut pemboleh ubah yang diperlukan. Akhirnya, meletakkan beberapa sensor tekanan dan sensor kadar aliran untuk mendapatkan data yang diperlukan. Selain itu, nilai *Water Hammer / Hydraulic Transient* kesan boleh didapati bagi setiap pemboleh ubah yang digunakan dan perlu membandingkannya bagi mengetahui faktor terbesar yang menyebabkan *Water Hammer / Hydraulic Transient* itu lebih tinggi di dalam sistem.

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I would like to thanks to my beloved family who always give me non-stop support and motivation during completing my project. I’m appreciated their understanding so much. Not forget to all my course mates for their commitment and always with me by giving the inspiration and motivation for me to completing this project. Finally, thank you to the people who are around me who give me support which is direct or indirect for the contribution in this work.

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LIST OF SYMBOLS

P	=	Pressure
Q	=	Flow rate
ρ	=	Fluid Density
e	=	Thickness of pipeline
D	=	Diameter of pipe
E	=	Modulus of Elasticity
K	=	Bulk Modulus
c	=	Speed of sound for Fluid

CHAPTER 1

INTRODUCTION

1.1 Background

Hydraulic Hybrid Vehicle (HHV) technology is brand new technology that compete to the more conventional Hybrid Electric Vehicle (HEV) technology as already found nowadays. (RohanHatti, 2015). Additional storage for HHV consists of pressurize oil or water. The pressurized water will be store in the accumulator in term of potential energy by using pump. After the accumulator full, directional control valve (DCV) is utilized to channel the pressurized water to drive hydraulic motor. Regenerative brakes that has been used in certain hybrid, the energy lost normally occurred due to braking using the vehicle's inertia. (S.J. Clegg, 1996).

The flow rate of the system is controlled using electrical circuit by changing the speed of the motor. The performances of the system are measured and analyzed based on pressure, flow rate, torque of hydraulic motor, power output and power input of the system.

Transient weights are most essential when the flow rate is changed rapidly, such as resulting of fast or rapid valve terminations(closed) or pump stoppages. Such the disturbance happened, whether brought on by design or accident, may make voyaging or traveling pressure and very large magnitude of waves of the velocity. These transient of the pressure are superimposed on the enduring(steady)-state conditions present in the line when the time of the transient pressures happens. (Karl Kolmetz, 2014)

1.2 Problem Statement

Hybrid vehicles is considered as hybrid when it is using two or more power sources to operate the engine. Most of the heavy vehicles, such as lorries and buses require a lot of fuel consumption when accelerating after each stop. The fuel cost used is very high if the frequency it stops too often as it should accelerate again after that. At the same time, when the heavy vehicle brakes, energy that released is wasted. When the circuit or the flowing fluid are frequently open and closed, and when the flow is suddenly closed, it will cause the transient pressure or hydraulic transient occurred. It is very dangerous to the piping used in the circuit of the system. Based on the problems that occur, it will try to be solve by using a various variable to determine the causes of the hydraulic transient and to reduced it from happened in the system.

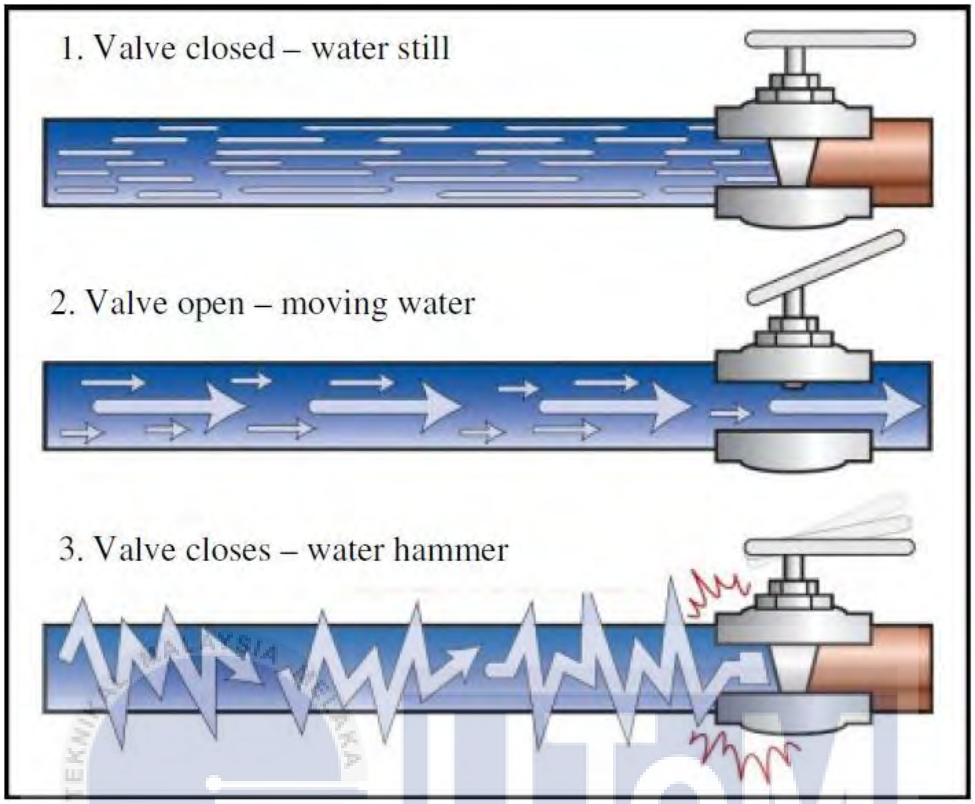

Figure 1.1: Hydraulic Transient (Water Hammer) Description

1.3 Objective

The objectives of this projects are as follows:

1. To study the effect of Hydraulic Transient/ Water Hammer on difference type of variables.
2. To analyze the data of Hydraulic Transient/ Water Hammer between simulation and Joukowsky Equation.

1.4 Scope of Project

The scope of this project is:

1. Develop a hydraulic transient /water hammer circuit in various type of variable by using MATLAB. (Objective 1)
2. Simulate the effect of hydraulic transient/water hammer by changing the variables of pressure, fluid used and length of pipeline. (Objective 1)
3. Analyze data gained by comparing from the variables used. (Objective 1)
4. Develop a hydraulic transient /water hammer circuit by using MATLAB. (Objective 2)
5. Simulate the effect of hydraulic transient/water hammer happened in circuit. (Objective 2)
6. Analyze data to measure the water hammer by using Joukowsky Equation. (Objective 2)

1.5 General Methodology

The actions that need to be carried out to achieve the objectives in this project are listed below.

1. Literature Review

   Journals, articles, and any materials that related about the rate of water hammer and its simulation, and how the water hammer/hydraulic transient working on the hydraulic hybrid system

2. Simulation

   Simulation of the water transient/water hammer in regenerative braking system will be made based on the data input. The data gained and compared after completing the whole hydraulic hybrid system of Tele-Operated Electro-Hydraulic Actuator by using MATLAB.

3. Analysis and proposed solution

   Analysis will be presented on how the hydraulic transient/water hammer occur in the hydraulic hybrid system. Solution will be proposed based on the analysis.

4. Report writing

   A report of this study will be written at the end of this project.

The methodology of this study is summarized in the flow chart as shown in Figure 3.

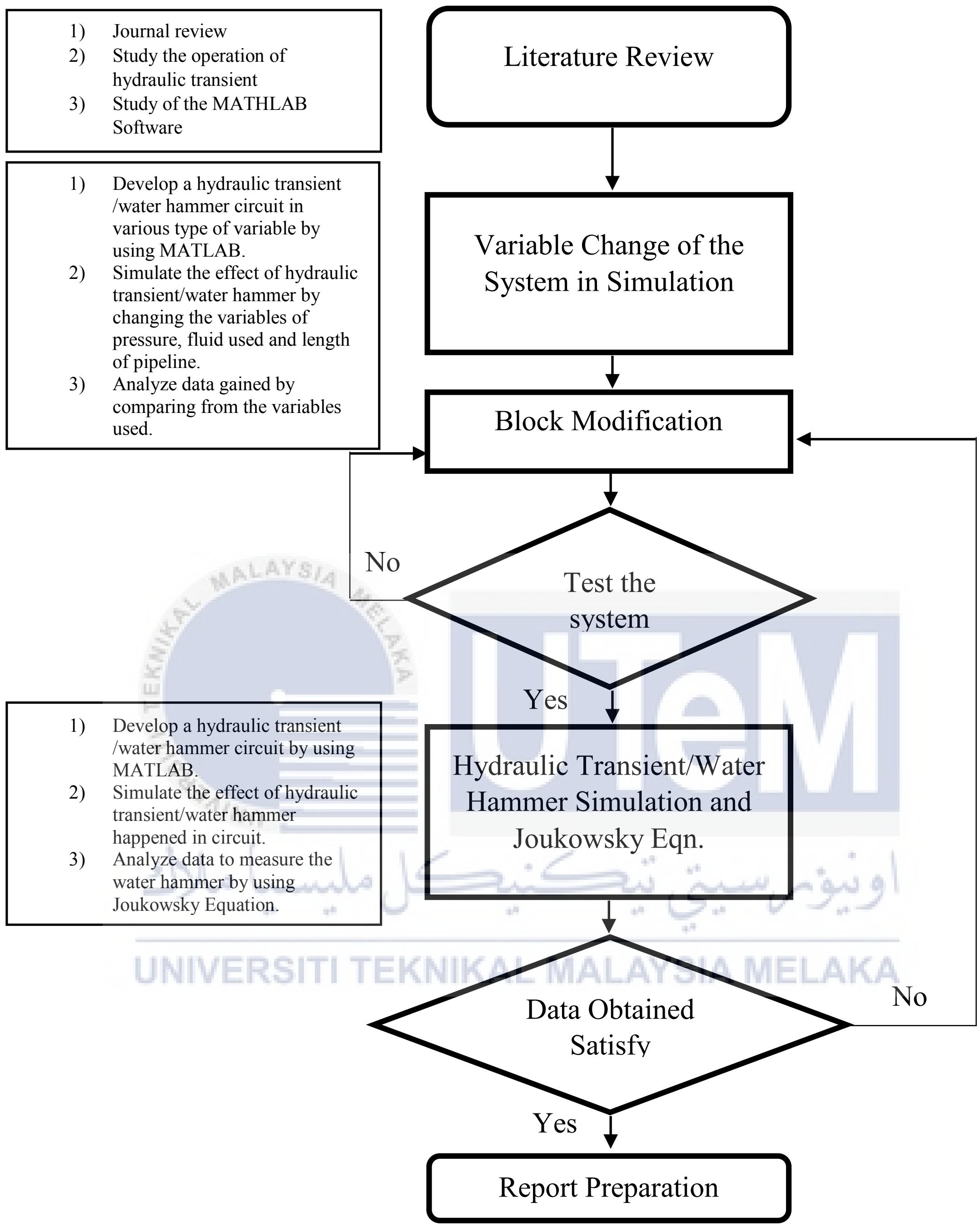

Figure 1.2: Flow chart of the methodology.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review is a report assessment to discover information in the literature based on the selected area of study. The topic of the sources must identify and relate with the point and topics of the project so that improvement of the project can be continued.

Some related topics should be focused around, such as:

1. Fluid Power of Hydraulic System
2. Water Properties and their Effects
3. Joukowsky Equation
4. Hydraulic Transient/Water Hammer

2.2 Fluid Power of Hydraulic System

Liquid power is the innovation that identifies with the generation, control, and transmission of force utilizing pressurized liquids. Fluid power is called hydraulics when fluid is utilized as a medium to move in the system and pneumatics when gasses is utilized as a medium to move vitality in the system. Hydraulic transmit the power through pressure. Hydraulic that usually used as a part of industry is petroleum, oils, and synthetics oils. Compared to hydraulic oil, water is the first liquid used in the hydraulic system because it is readily available. By using the water hydraulic, the addictive need to put into the water to prevent freezing, rusting, and improved lubricants.

Fluid system has two different types, which is fluid transport and fluid power. Fluid transport system is used to achieve some purpose by using the moving of the liquid from one location to another location. Example include pumping stations for pumping water to homes, across pipes or gas lines, and system where chemical preparing or processing happens as different fluid are brought together (Esposito.A., 2009)

Fluid power system is designed to perform work by pressuring the fluid bearing in the cylinder or motor. Fluid cylinder produced only one axis motion of forced while the torque is produced by fluid motor. Actuator is the other name for fluid cylinder and fluid motor.

2.2.1 Components in Hydraulic System

Hydraulic system required about six (6) basic components in the circuit to operate, which are:

1. Reservoir (tank) – to store the hydraulic fluid used in the system
2. Pump – to force the hydraulic fluid to circulate through the system
3. Motor – using the electrical source in order to operate the pump
4. Valve – used to control the fluid direction, pressure and flow rate
5. Hose – to connect or carries the fluid around the hydraulic system (to another components)
6. Actuator – converts the fluid pressure (hydraulic energy) into mechanical force or torque. Actuator consists of two (2) which is cylinder(to provide linear motion) and motor(to provide rotary motion)

2.3 Water Properties and Their Effect

2.3.1 Density

Density of the hydraulic fluid will affect the losses of the hydraulic energy in the system. changes of the temperature and pressure in the hydraulic system will affect the density of a hydraulic fluid and it needs to keep the density as low as possible to reduce the losses of pressure and dynamic effects on the control valve. Water has about 10% higher of mass density than mineral oil (Trostmann and Clausen 1995).

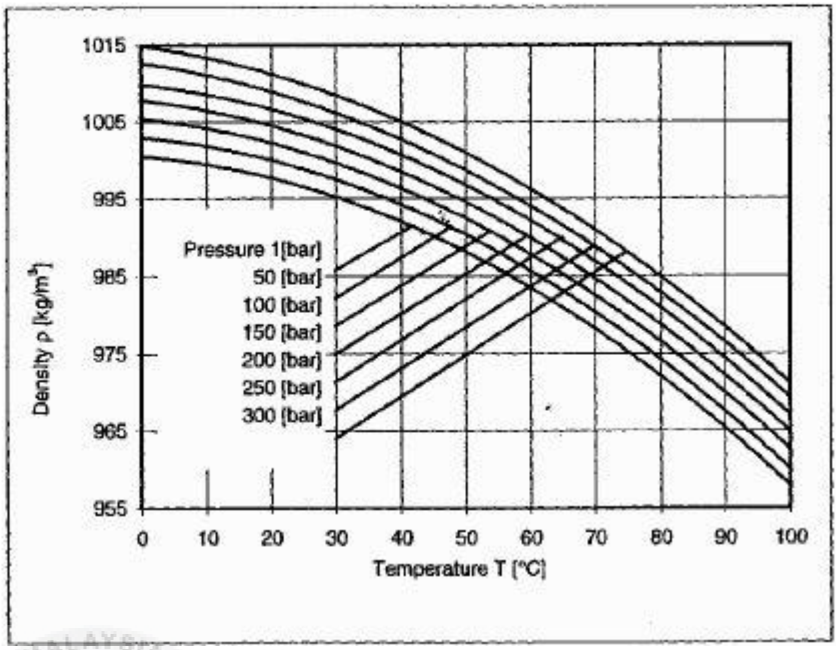

Figure 2. 1: Variation of mass density of pure water with temperature and pressure (Trostmann et al.2001).

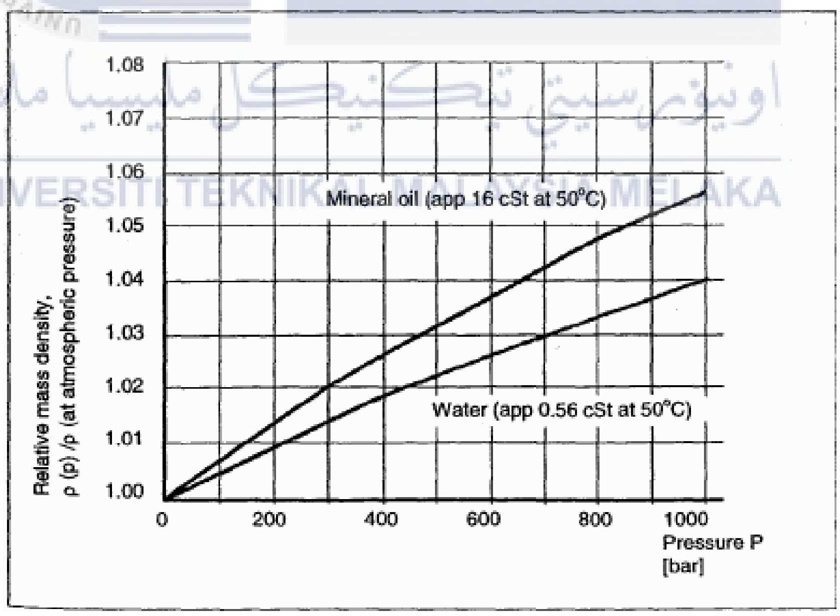

Figure 2. 2: Comparison of the mass density of water with that of mineral oil at a given temperature as pressure varies (Trostmann et al.2001).

2.3.2 Specific Heat Capacity

Definition of the specific heat capacity at constant pressure is the amount of energy needed to change the temperature of one kilogram (kg) of a substance by 1 degree Celsius(°C). Water takes longer time to be heated up because the specific heat capacity of water is 2.2 times higher than mineral oil and this is the benefits of the water since the ability to absorb heat is higher than mineral oil. It is high for water compared to most substances and it is twice that of mineral oil (Trostmann and Clausen 1995).

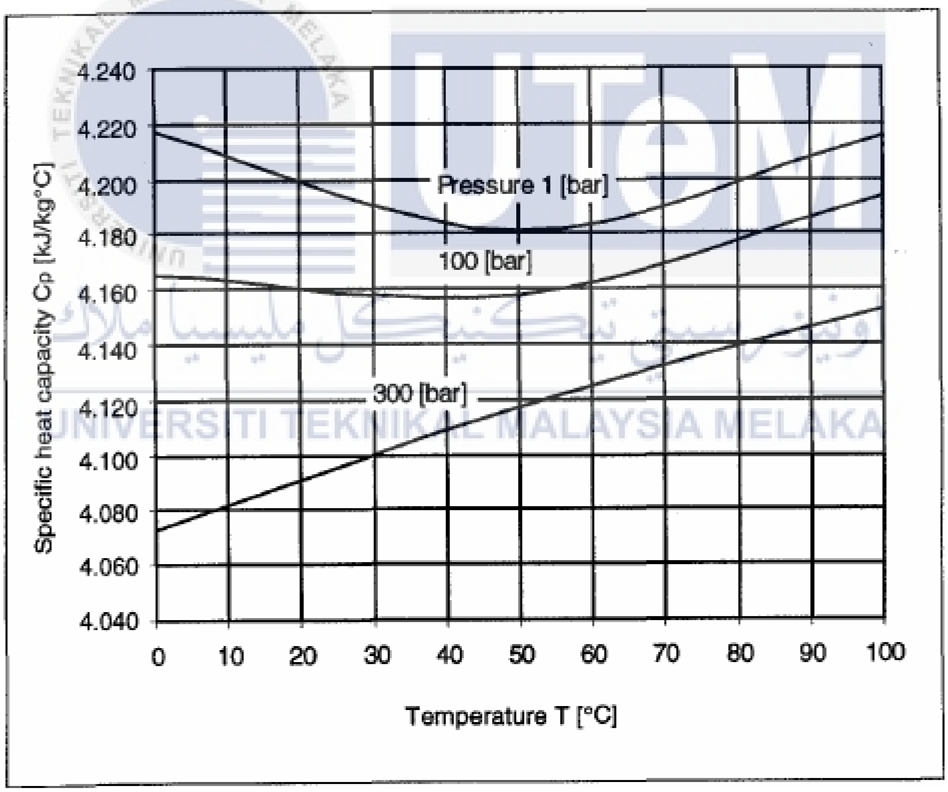

Figure 2. 3: Specific heat of water as a function of temperature and pressure

(Trostmann et al. 2001)

2.3.3 Viscosity

Viscosity is a measure of internal friction in a fluid when one layer moves to another, or in brief, viscosity is a fluid's resistance to flow (Krutz and Chua 2004). The pressure is influenced by the viscosity, where high viscosity causes high pressure drops in system and low viscosity can make low pressure drops in the system which is more efficient in the hydraulic system. The viscosity of water is typically less than $1/30^{th}$ of mineral oil at 50 $^{\circ}$C (Trostmann and Clausen 1995).

Water hydraulic system, efficiency and velocity flow within a wide range of operating temperature is more stable than oil hydraulic system. Low viscosity caused the higher internal leakage in water hydraulic systems. Reduce the component's tolerance used in water hydraulic system is needed to prevent the internal leakage.

At a temperature range 3 $^{\circ}$C until 50 $^{\circ}$C and a pressure range of 1-1000 bar, the viscosity of water varies by a factor of approximately 3 while in the same pressure range, but that of oil varies by a factor of about 10 in the temperature range 20 $^{\circ}$C until 70 $^{\circ}$C (Krutz & Chua, 2004).

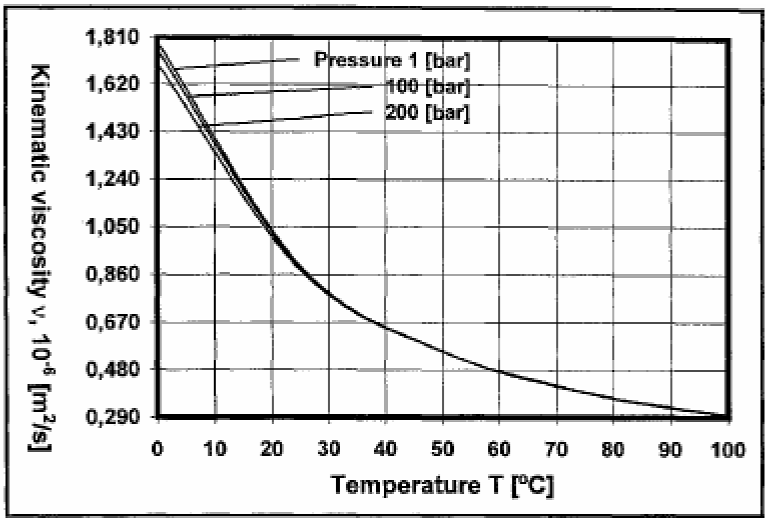

Figure 2. 4: The kinematic viscosity of water as function of temperature and pressure (Trostmann et al. 2001).

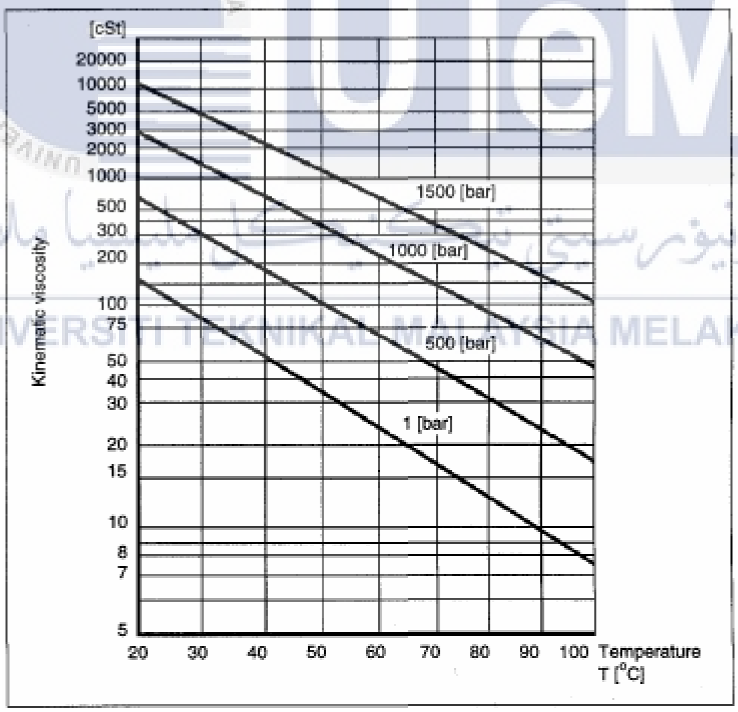

Figure 2. 5: Variation of the kinematic viscosity of mineral oil with temperature and pressure (Trostmann et al.2001).

2.3.4 Thermal Conductivity

The thermal conductivity of a substance is the property to transfer energy from temperature differences between adjacent parts of the substance (Krutz and Chua 2004). Water temperature is easier to control when it's thermal conductivity in the water hydraulic systems is higher because water can easier transfer the heat compared to the oil in the mineral oil hydraulic system. Typical values of the thermal conductivity of water at constant pressure and temperature of 20 °C is 4 to 5 times higher than mineral oil (Trostmann and Clausen 1995).

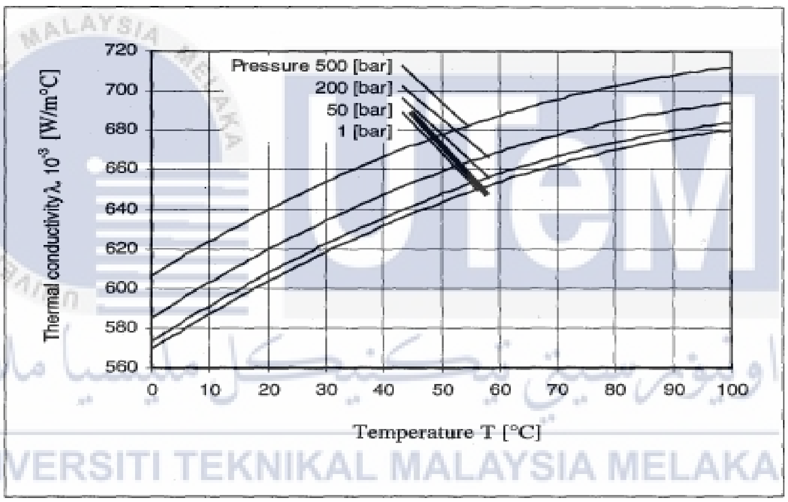

Figure 2. 6: Thermal conductivity of water as a function of temperature and pressure (Trostmann et al.2001).

2.3.5 Bulk Modulus

Bulk modulus is the compressibility character of fluid which the bulk modulus elasticity of water is 35% greater than mineral oil. There are 10% of the air solubility in water of mineral oil (Trostmann and Clausen 1995). Presence of the air bubble make the compressibility of a fluid increase. Velocity is inversely proportional to the viscosity. The viscosity of the surrounding fluid can affect the velocity of small air bubble. Bubble also can be formed in the oil but bubbles in water at low viscosity escape about 30 times faster than bubbles in oil and the variation in compressibility of water in a hydraulic system is small compared to the oil in similar hydraulic system (Urata 1999). Rigidity of water is higher than oil and it provide responsivity and stiffness of pressure fluctuation. During sudden closures of valve, water hammer will happen because of high pressure wave propagation high due bulk modulus.

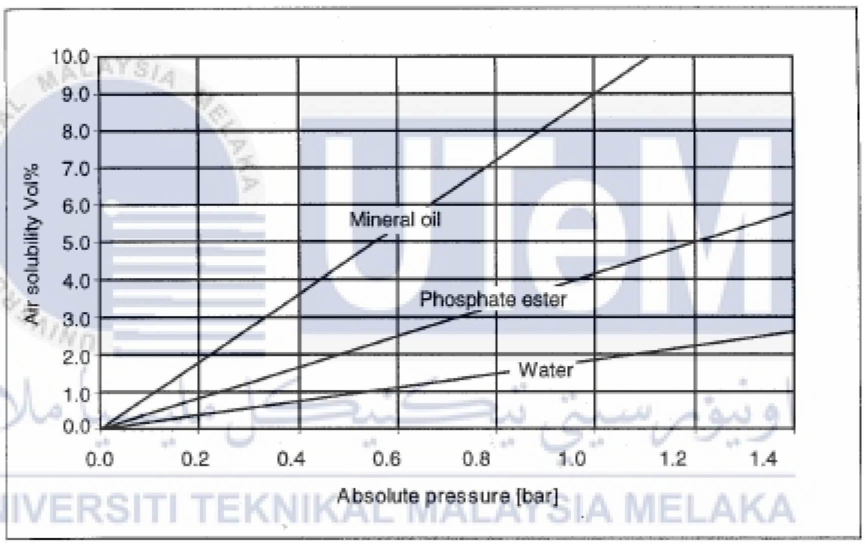

Figure 2. 7: comparison of the solubility of air in water with of the other hydraulic pressure media as a function of absolute pressure (Trostmann et al.2001).

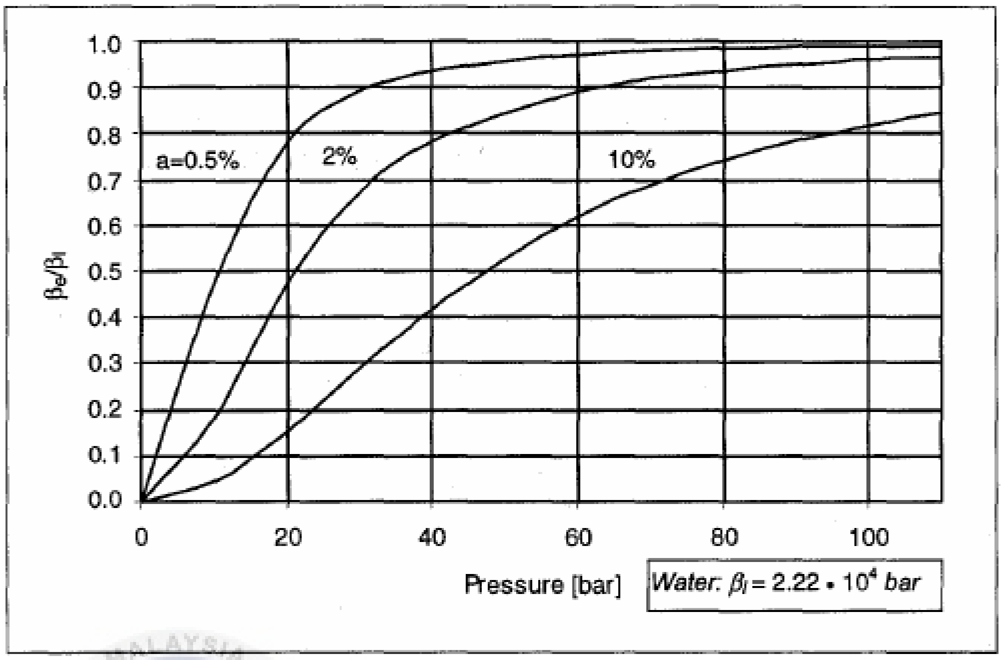

Figure 2. 8: Effect of undissolved air/water ratio on bulk modulus (Trostmann et al.2001).

2.4 Joukowsky Equation

2.4.1 Historical Context of Joukowsky Equation

The origination of the theory of water hammer can, among others, be followed to Me'nabre'a(1858), interpreted by Anderson(1976), Me'nabre'a(1862), Michaud(1878), Von Kries(1883), Frizell(1898), Joukowsky(1900), Gibson(1908) and Allievi(1902, 1913). Joukowsky conducted investigations and experiments in Moscow in 1897/1898 when he derived his well-known(famous) law for instantaneous water hammer. This law expresses that the (piezometric) head rise DH coming about because of a fast (T_c<2L/a) closure of a downstream valve is given by

$$\Delta H = \frac{aV_o}{g} \qquad \dots \dots (Eqn. 1)$$

where a is the pressure of wave speed, V_0 the initial flow velocity, g is gravitational acceleration, L the length of pipe and T_c the closure time for valve. The wave speed is assessed from Korteweg's (1878) formula

$$a = \sqrt{\frac{\frac{K}{\rho}}{1 + (\frac{K}{E})(\frac{D}{e})}} \qquad \dots \dots (Eqn. 2)$$

where K is the bulk modulus, ρ the mass density, E the Young's modulus of material of the pipe wall, D the inner diameter of the pipe, and e the thickness of the wall. The period in a pipe, 2L/a, is the ideal opportunity for a pressure wave to go through from the valve to a reflection point (e.g. reservoir) and back. Formula in Eqn. 1 is referred as the Joukowsky condition or equation, however Tijsseling and Anderson (2004) pointed up that Von Kries(1883) was really the first one to determine and approve it. (Tijsseling and Anderson, 2004)

2.4.2 Joukowsky Equation of Fluid

The principal condition in water hammer theory relates with pressure changes, Δp, to velocity changes, Δv, as indicated by

$$\Delta p = \rho c \, \Delta v \qquad \dots \dots (Eqn. 3)$$

where ρ is the fluid mass density and c is the speed of sound. Korteweg's (1878) equation characterizes or defines c for liquid contained in round and hollow channels of roundabout cross-segment:

$$c = \sqrt{\frac{K_*}{\rho}} \qquad \ldots\ldots (Eqn. 4)$$

and

$$K_* = \frac{K}{\left[1 + \frac{DK}{eE}\right]} \qquad \ldots\ldots (Eqn. 5)$$

where K is the bulk modulus of the contained fluid, E is the modulus of elasticity for the wall, D the diameter of the pipe, and e the thickness of the wall. (Tijsseling & Anderson, 2004)

2.5 Hydraulic Transient/Water Hammer

Current hydraulic system work over an expansive scope of working administrations. Any change of flow velocity in the system actuates a change in pressure. The sudden shutdown of a pump or closure of a valve causes fluid transients which may include large pressure variations, local cavity formation, circulated cavitation (bubble flow), hydraulic and auxiliary(structural) vibrations and excessive mass oscillations. Specifically, the event of section separation may significantly impact on subsequent transients in the system. (Bergant, Simpson, & Tijsseling, 2006)

2.5.1 Transient Flow in the system

At the point when the steady state of a flow in a system is adjusted, the estimation values of the initial flow states of the system, described by the measured velocity(V) and pressure(P) at positions along the pipeline(x), change with time(t) until the last flow conditions are built up in another steady-state condition. (Elbashir, Oduro, & Amoah, 2007)

From Figure 2.1, the physical phenomenon that happens during the time interval T, between the initial and last steady-state conditions is known as the hydraulic transient. Generally, surges are unsteady flows that outcomes from relatively slow flow rate changes, and hydraulic transient or water hammer result from fast or rapid flow rate changes.

It also shows how the transient evolution in a system looks like and it represents a view of the transient at a fixed point (x) only upstream of the valve that is being closed. This diagram explained that the pressure(P) is represented to as an element of time(t) resulting from the operation of a control valve. In the figure, P_i is the underlying or initial pressure toward the begin of the transient, P_f is the final pressure toward the end of the transient event, P_{min} is the base or minimum transient pressure, and P_{max} is the greatest or maximum transient pressure. (Elbashir et al., 2007)

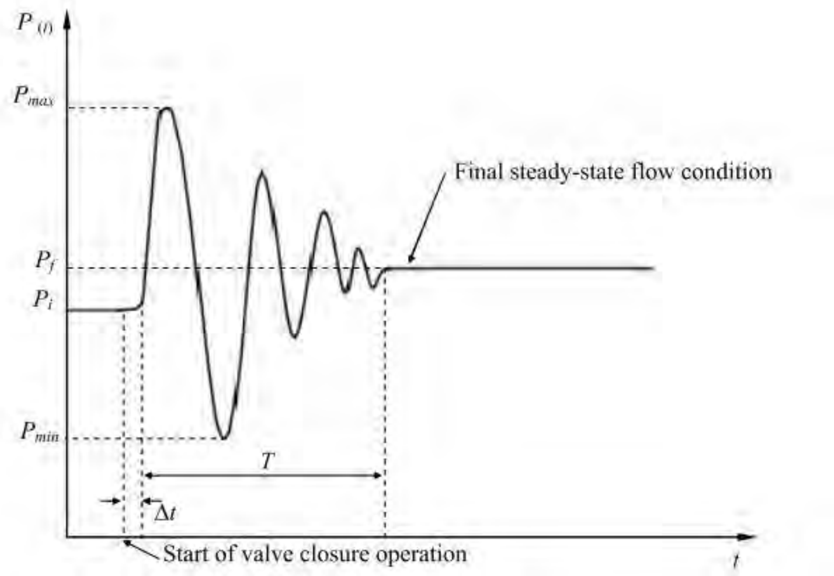

Figure 2.9: Hydraulic transient at position x in the system

(Elbashir et al., 2007)

2.5.2 Causes of the Hydraulic Transient/Water Hammer

Hydraulic Transient are most important when the rate of flow is changed quickly or rapidly, for example, flow that going through on the pipeline and the valve is rapid closure or pump stoppages. Such disturbances, regardless of whether brought on by design or accident, may create travelling pressure and large magnitude of velocity waves.

These transient pressures are superimposed on the steady-state conditions present in the line at the time the transient pressure happens. The seriousness of transient pressure must be resolved so that the piping can be properly intended or design to withstand these extra and additional loads. (Karl Kolmetz, 2014)

2.5.3 Impact of the Hydraulic Transient/Water Hammer

In general, the sources that may influence the water hammer weakening, shape and timing would be the pressure in pipe, velocity flow in pipe, and sudden change of velocity flow. However, there is different sources that may influence the waveform established anticipated water hammer theory incorporate by viscoelastic behavior of the pipe-wall material, blockage and spillage(leakage) in addition to the unsteady friction, cavitation and liquid structure interactions. These inconsistencies depend on the determination or derivation of the water hammer equations for the fluid unsteady pipe flow. (Choon, Aik, Aik, & Hin, 2012)

Joukowsky's equation expresses that the magnitude of water hammer is directly proportional to the velocity of the wave propagation. Wave propagation velocity depends on the elasticity of the pipe walls and the compressibility of the fluid. A commonplace esteem for wave propagation velocity in PVC pipes containing water is 300 m/s (985 ft/s), for steel funnels 1,100 m/s (3600 ft/s). The pipe dimensions will likewise influence the wave. (Karl Kolmetz, 2014)

Hydraulic transients can cause hydraulic equipments in a pipe network to fail if the transient pressures are too much high. When the pressure are too much higher then the pressure limits of the pipeline, failure through pipe or joint break, or curve(bend) or elbow movement may happen. On the other hand, over the top low pressure (negative pressure) can bring about buckling, implosion and spillage(leakage) at pipe joints during subatmospheric stages. Low pressure transients are ordinarily experienced on the downstream side of an end(closing) valve. (Elbashir et al., 2007)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will explain the research methods for this study, which included in design phase and the system analysis. The design phase for this research is by fully using MATLAB Software(Simulink) for the simulation. For the design part, it used sensor of pressure along the circuit and flowrate sensor to determine the real situation of the fluid in the simulation. This chapter also shows the overall circuit of the test rig created to determine the hydraulic transient/water hammer in the flow.

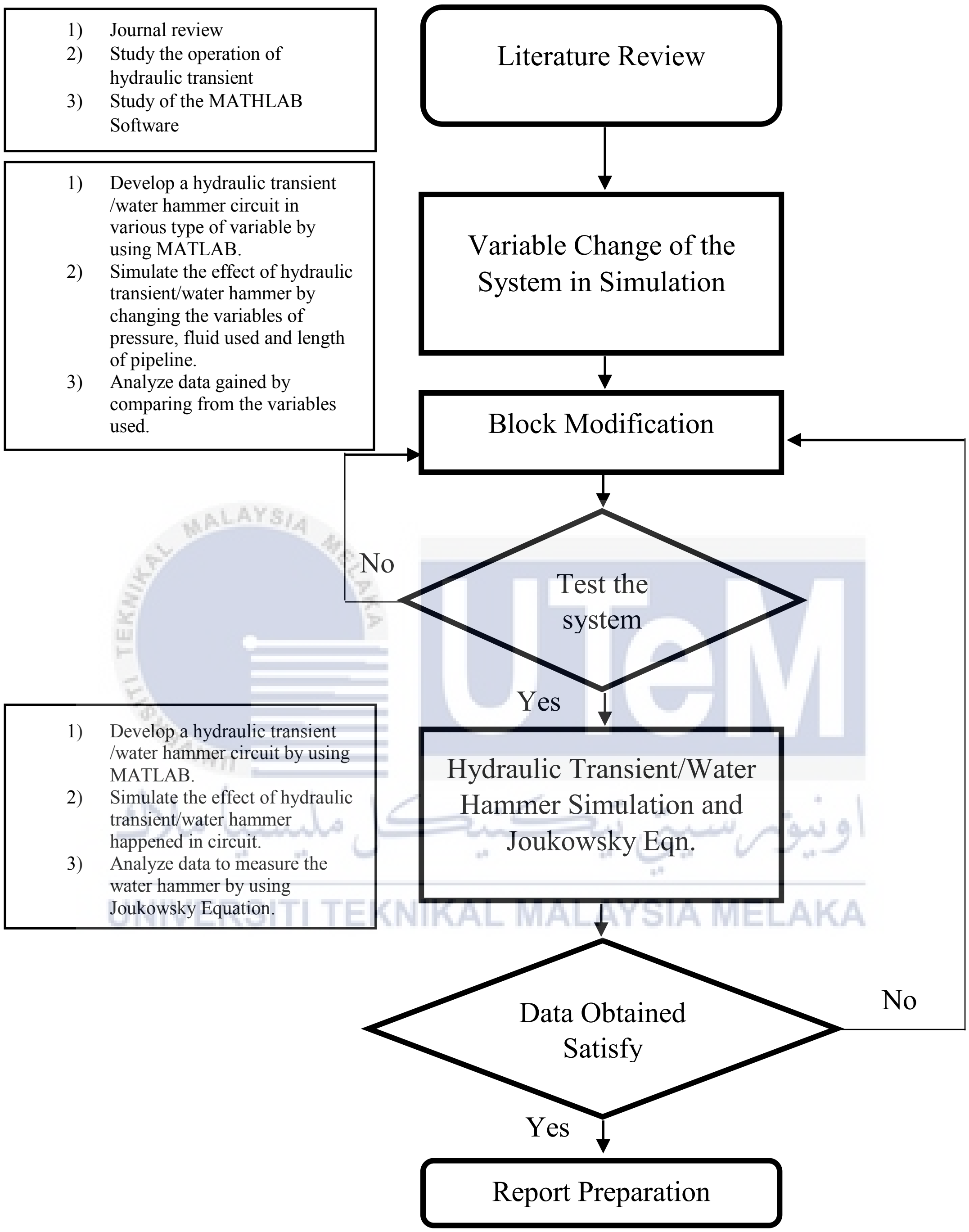

Figure 3. 1: Flow chart of the methodology.

3.2 Design Phase

The research will incorporate broad study on the mathematical modeling(displaying) and simulation by using MATLAB(Simulink). MATLAB(Simulink) is a software which help in designing a whole circuit of the hydraulic test rig system. Rather design, this software also can perform simulation to test all the circuit and give all the data needed before doing the actual assembly. MATLAB gives many advantages, one of it is, can minimize the time for gaining the information and data that is need. It can also show the pressure, flow rate and how the circuit operated. This will help to determine what is need to be modify. The test rig system with hydraulic transient is created by using this software. The hydraulic transient of the water-based and oil-based hydraulic hybrid system are done and measured on the simulation data gained.

3.2.1 Test Rig Circuit Design

Overall Circuit

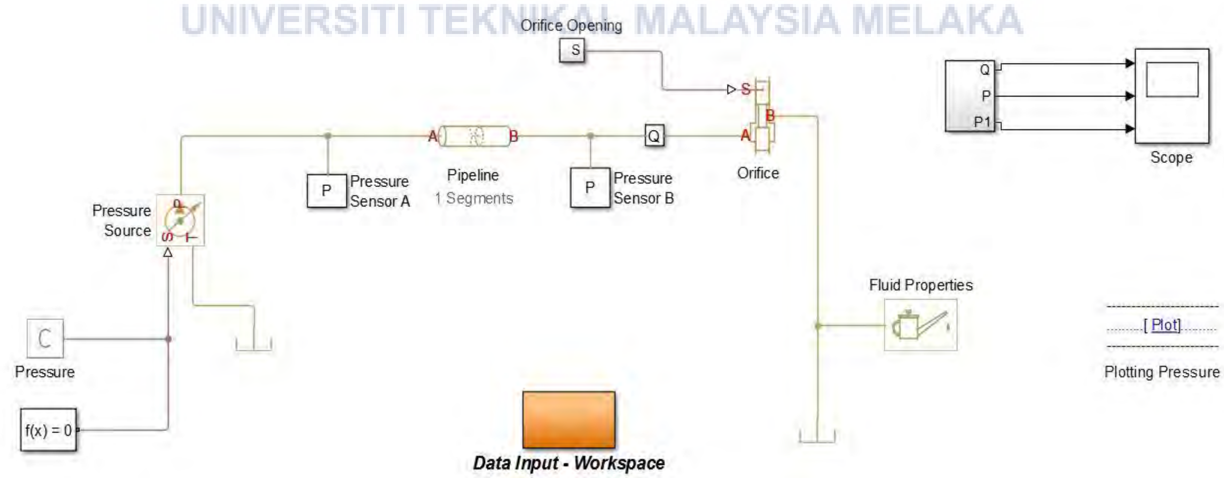

Figure 3. 2: Test Rig System of Hydraulic Circuit.

3.2.2 Hydraulic Transient on System

The Hydraulic Transient in happened when the flow is suddenly closed and it will cause the fluid flow to automatically stop in high velocity, so that the hydraulic transient will happen. From the system that had been created, it consists the main parts or sources which is the pressure regulator of the system, the pipeline and fluid properties. From this research, it will focus on this section or area only. From the Figure 3. 2, it shows the circuit for the test rig of the hydraulic circuit. From that, it has two (2) pressure sensors and one (1) flow rate sensor.

The pressure sensor is put between pipeline block to determine the different value of the initial fluid pressure and final fluid pressure. The flow rate sensor will show the actual flow that happen in the circuit while the hydraulic transient occurred. Data gained is based on the value put in three (3) different parts that acts as variables change to the simulation, which is the amount of pressure, types of fluid and the length of the pipeline. The exact amount will be gained and it can be easy to calculate by using the simulation on MATLAB.

3.3 System Analysis

Hydraulic Transient/Water Hammer occurred when the fluid is on moving and the valve is suddenly closed. That action will increase the pressure of the system due to the impact occurred in flow on the pipeline. For this simulation, it used three (3) types of variable to obtaining the data and find the main factor that caused the hydraulic transient/water hammer in the hydraulic circuit, which is the system pressure of fluid, types of fluid and the length of the pipeline used.

These three (3) variables will show the difference value of the hydraulic transient/water hammer and it can be compared to obtained the data that what is needed to observe. The data for simulation will also be compared to the Joukowsky Equation to get the difference between actual and theoretical value for this effect.

3.3.1 System Pressure of Fluid

Pressure is the main factor that need to be observe when the hydraulic transient/water hammer happened. The pressure inlet is set up at the inlet of the flow to ensure the whole circuit under the pressure value needed. There are two (2) pressure values that is use in this simulation to observe the water hammer/hydraulic transient happened in two (2) difference pressure which is 50bar and 100bar.

The maximum pressure when the water hammer happened will subtract with one of these two (2) pressure inlet value depends on the system pressure setting. The biggest difference that gained between the two (2) pressure inlet (subtract with maximum pressure of water hammer) will cause very high impact for hydraulic transient/water hammer.

3.3.2 Length of the pipeline

Hydraulic circuit is connected from one part to the others by using the pipeline to make the fluid flows through the circuit. Length of the pipeline is one of the factor that cause the different value of pressure in the hydraulic circuit. For this simulation, it used only two (2) different length of the pipeline which is 1 meter (m) and 0.5 meter (m).

This length is suitable and almost same for laboratory hydraulic pipeline length, so the data of hydraulic transient/water hammer obtained can be used to overcome the water hammer/hydraulic transient from happened on the hydraulic circuit in the laboratory. In the factory, the length of the pipeline used is quite long because the size of the hydraulic components and the system is large.

3.3.3 Types of Fluid

Fluid is a form of liquid state that has their own properties for each type. The major properties of fluid that always been considered to run for a test is like density, bulk modulus, thermal conductivity etc. These properties will show their characteristics and it will affect the test or experiment depends on the value of its properties.

This hydraulic simulation, it is using the basic fluid for the hydraulic system which is Hydraulic Oil. The hydraulic oil that is use in this experiment has 3 types, there are VG22, VG33 and VG46. It also used the basic fluid that we can easily get around us in this simulation, which is water. These fluids had their own properties and it can be compare which of its cause the greatest effect of the hydraulic transient/ water hammer in this system.

3.3.4 Joukowsky Equation

Hydraulic Transient/Water Hammer in this simulation is conduct to determine the difference of pressure by putting the 2 pressure sensors at inlet and outlet of the pipeline, and to determine the flow rate of the fluid after hydraulic transient/water hammer occurred. There is an equation, which called Joukowsky Equation that been used in many research to calculate the water hammer/ hydraulic transient in the flow.

$$\Delta p = \rho c \Delta v$$

Data that get from the simulation which are pressure and flowrate will be calculated to determine the difference of velocity by using formula of flow rate, Q = A V where the area, A is fixed. The total value of difference of velocity that been calculated will be put in the Joukowsky Equation to determine the total difference of pressure. The total difference of pressure will be plot on the graph against time to get the exact graph pattern of the Joukowsky Equation. The simulation graph and the Joukowsky Equation will be compared.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will present the data of the hydraulic transient (water hammer) occur in the hydraulic system when the valve of the fluid flow is suddenly closed. The data were computed from simulation of the hydraulic system in term of pressure and flow rate. Together with this experimental data, it can compare the water hammer occur in the simulation, actual and also can be calculated by using Joukowsky Equation.

4.2 Results

4.2.1 Water Hammer Measurement on Simulation

Hydraulic Transient (Water Hammer) on Hydraulic System simulation shown in Figure 4.1 below is the actual system that have in the basic hydraulic system in form of simulation. The focused part that need to measure the water hammer is on the pipe before entering the valve. Water hammer will occur when the flow of the fluid suddenly closed, and the pressure of that space will automatically increase. In this system, the fluid will circulate around the system when the valve is open.

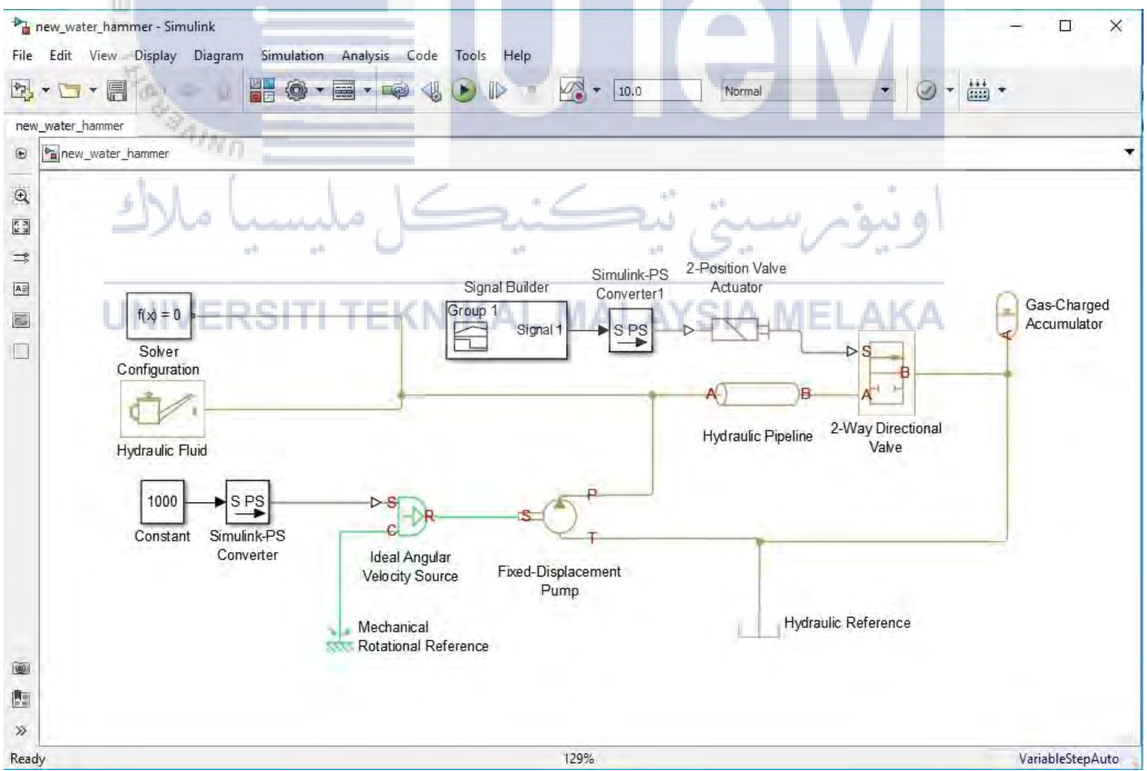

Figure 4.1 Simulation of the hydraulic system

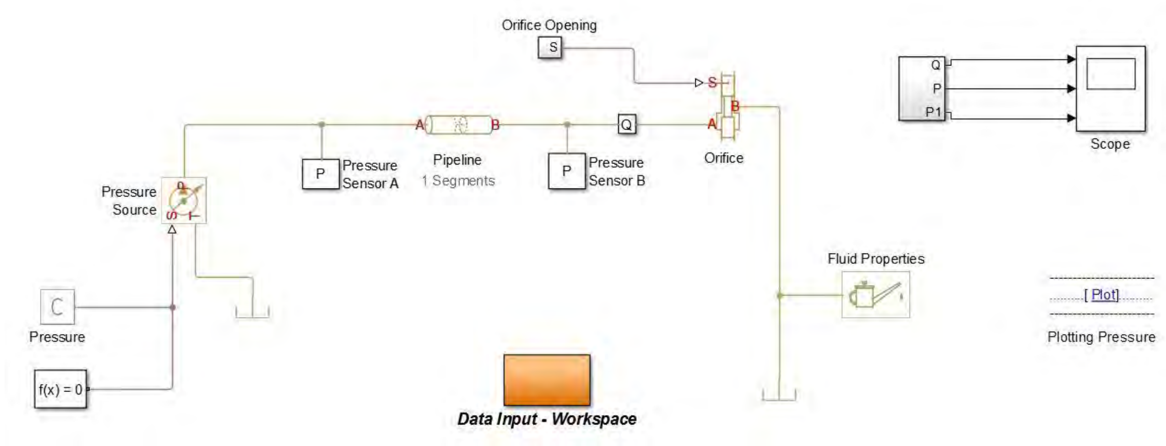

Figure 4.2 Focused part for analyze the Hydraulic Transient/Water Hammer

Figure 4.2 above shows the focused part of Hydraulic Transient/ Water Hammer in the hydraulic system that been simulated. The water hammer is related with Joukowsky's equation. Form the data obtained, it can calculate the actual pressure difference when the hydraulic transient (water hammer) occur by using Joukowsky's equation.

In this case, the flow in the pipeline to the valve will be calculated, and the sensors were placed before and after the pipeline of the flow to obtain the data needed in this equation when the hydraulic transient (water hammer) occurred. The pressure different shows that the hydraulic transient/water hammer occurred. Many variables were used in this system to relate with the pressure itself whether the hydraulic transient/water hammer will be reduced or not, and the effects to the flow or pipeline of the system.

4.2.2 Water Hammer Results on Simulation

Hydraulic transient (water hammer) simulation was run and the data obtained is recorded in form of graph. The fixed value for this simulation is the thickness of the pipeline(e) =1.25mm, pipeline diameter(D) = 0.03m and Modulus Elasticity of pipeline(E) = $2x10^{11}Nm^{-2}$. There are many variables used versus the pressure reading to show the increase of the pressure in the graph during hydraulic transient (water hammer).

The variables that is compared in this simulation which is the type of fluid used in this simulation which is Hydraulic Oil (VG22, VG32, and VG46) and Water. It also compared the length of the pipe for about 0.5 meter and 1.0 meter. There is also comparison between two different pressure, 50 bar and 100 bar. The graph for all the variable is compared to the types of fluid used which the diameter, thickness, modulus elasticity and the initial pressure same shown in Figure 4.3 until Figure 4.14. The value for all the graph reading is shows in Table 4.1 until Table 4.4.

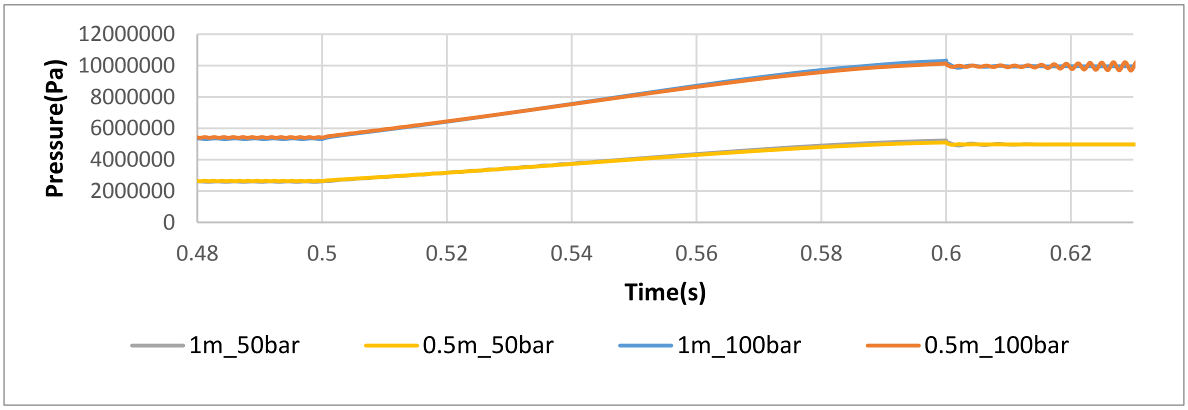

Figure 4.3: Pressure versus Time of specimen using Hydraulic Oil (VG22) for different length and pressure used

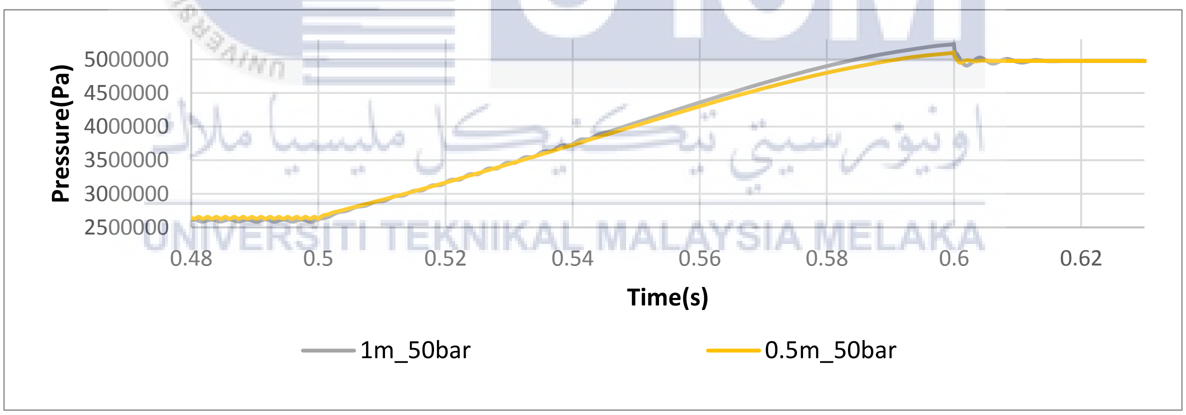

Figure 4.4: Pressure versus Time of specimen using Hydraulic Oil (VG22) for different length of 0.5m and 1m working under same pressure of 50bar

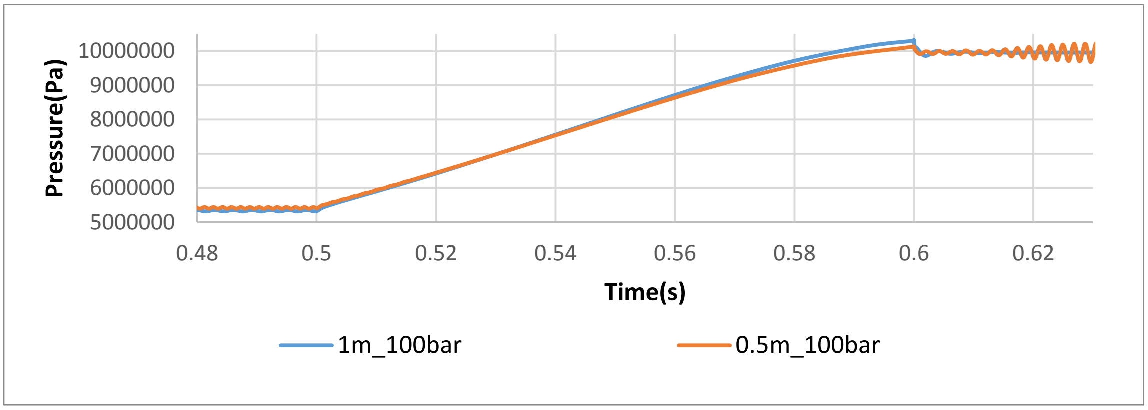

Figure 4.5: Pressure versus Time of specimen using Hydraulic Oil (VG22) for different length of 0.5m and 1m working under same pressure of 100bar

STATE	1m_50bar	0.5m_50bar	1m_100bar	0.5m_100bar
MAX. PRESSURE(Pa)	5231747.27	5112468.254	10330974.74	10135237.31
INLET PRESSURE(Pa)	5000000	5000000	10000000	10000000
ΔPRESSURE (Pa)	231747.2696	112468.254	330974.7391	135237.3088

Table 4.1: The data for maximum difference pressure value of each variables using Hydraulic Oil (VG22)

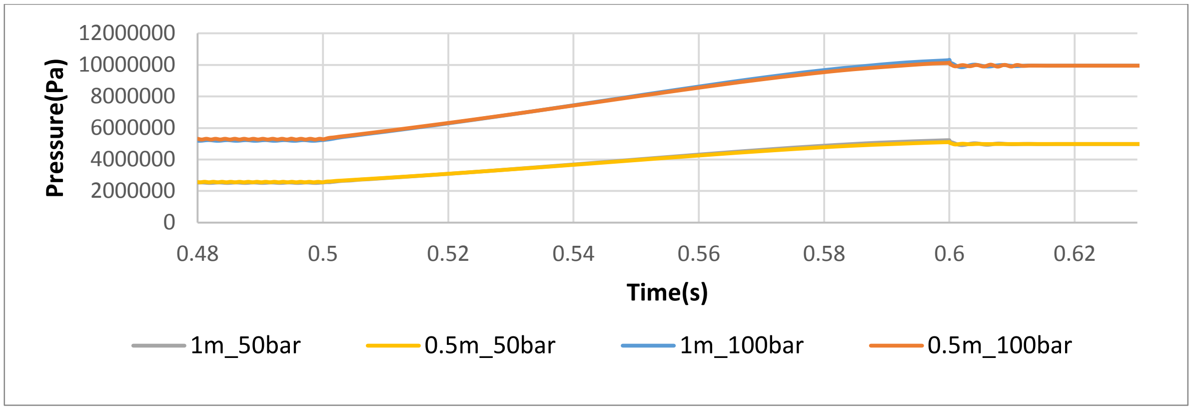

Figure 4.6: Pressure versus Time of specimen using Hydraulic Oil (VG32) for different length and pressure used

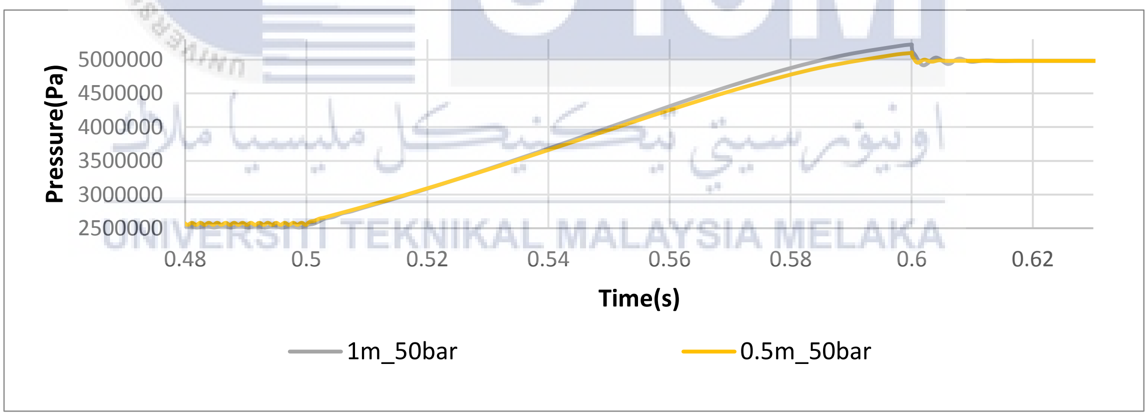

Figure 4.7: Pressure versus Time of specimen using Hydraulic Oil (VG32) for different length of 0.5m and 1m working under same pressure of 50bar

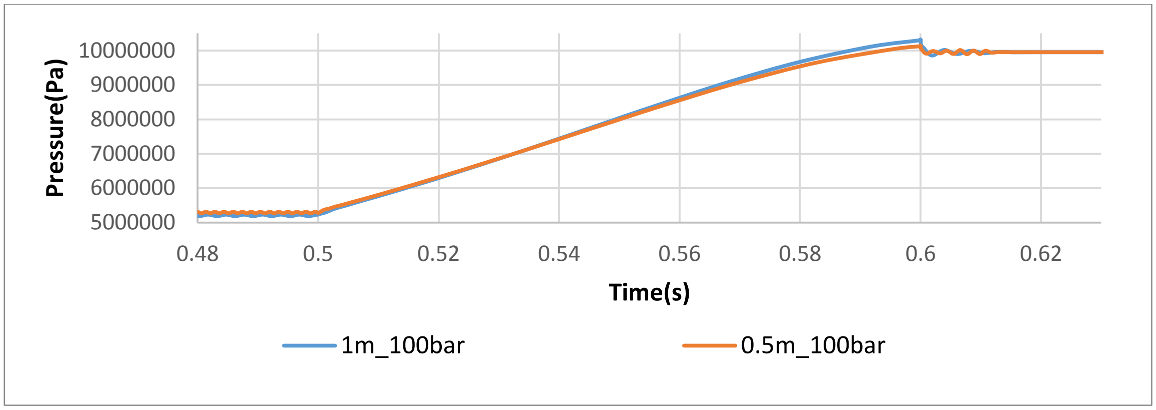

Figure 4.8: Pressure versus Time of specimen using Hydraulic Oil (VG32) for different length of 0.5m and 1m working under same pressure of 100bar

STATE	1m_50bar	0.5m_50bar	1m_100bar	0.5m_100bar
MAX. PRESSURE(Pa)	5223330.769	5106925.598	10325683.35	10148287.29
INLET PRESSURE(Pa)	5000000	5000000	10000000	10000000
ΔPRESSURE (Pa)	223330.7686	106925.5975	325683.3468	148287.2893

Table 4.2: The data for maximum difference pressure value of each variables using Hydraulic Oil (VG32)

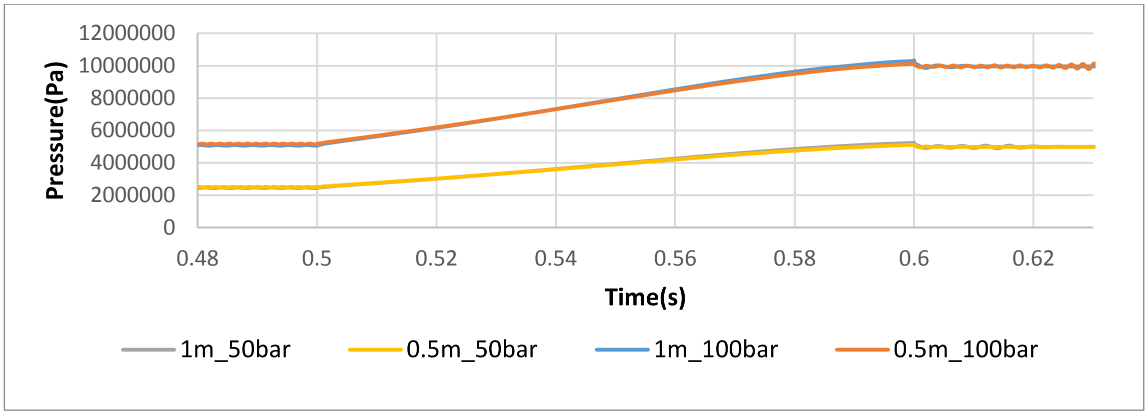

Figure 4.9: Pressure versus Time of specimen using Hydraulic Oil (VG46) for different length and pressure used

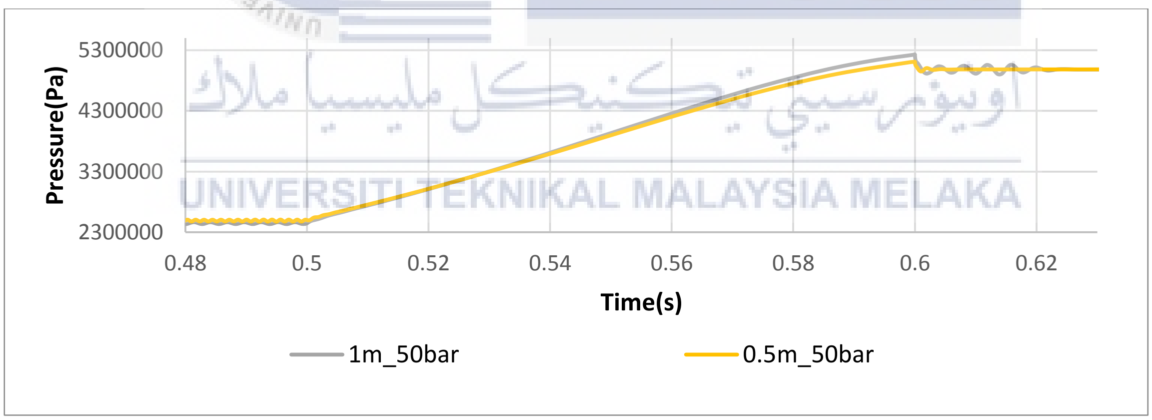

Figure 4.10: Pressure versus Time of specimen using Hydraulic Oil (VG46) for different length of 0.5m and 1m working under same pressure of 50bar

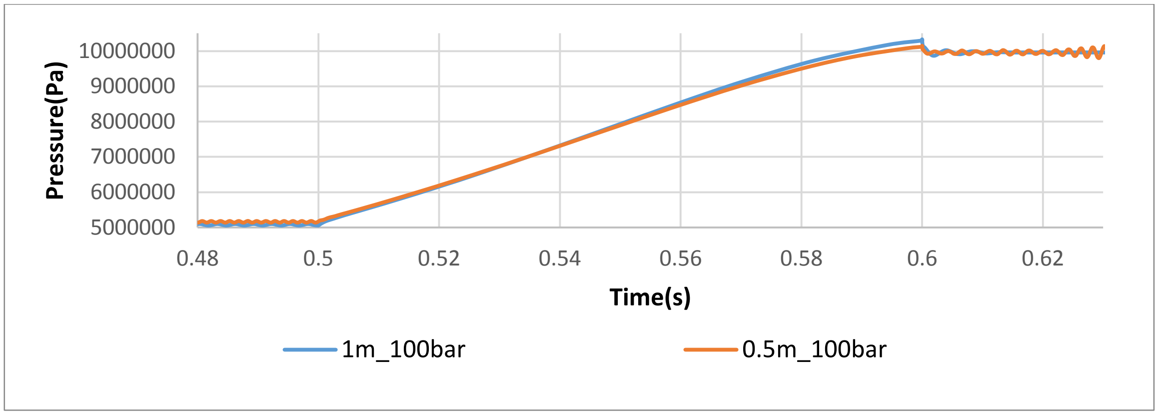

Figure 4.11: Pressure versus Time of specimen using Hydraulic Oil (VG46) for different length of 0.5m and 1m working under same pressure of 100bar

STATE	1m_50bar	0.5m_50bar	1m_100bar	0.5m_100bar
MAX. PRESSURE(Pa)	5230740.552	5109934.723	10331320.74	10149831.93
INLET PRESSURE(Pa)	5000000	5000000	10000000	10000000
ΔPRESSURE (Pa)	230740.5523	109934.7234	331320.7404	149831.9257

Table 4.3: The data for maximum difference pressure value of each variables using Hydraulic Oil (VG46)

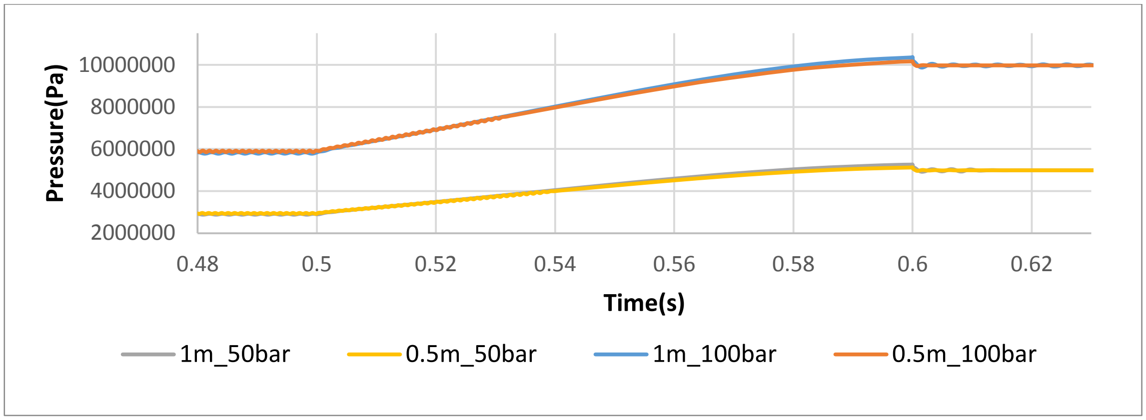

Figure 4.12: Pressure versus Time of specimen using Water for different length and pressure used

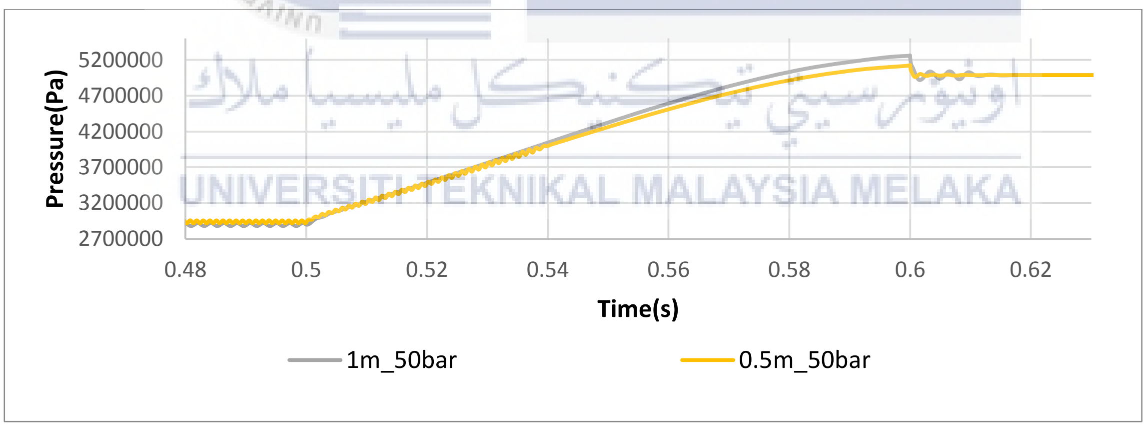

Figure 4.13: Pressure versus Time of specimen using Water for different length of 0.5m and 1m working under same pressure of 50bar

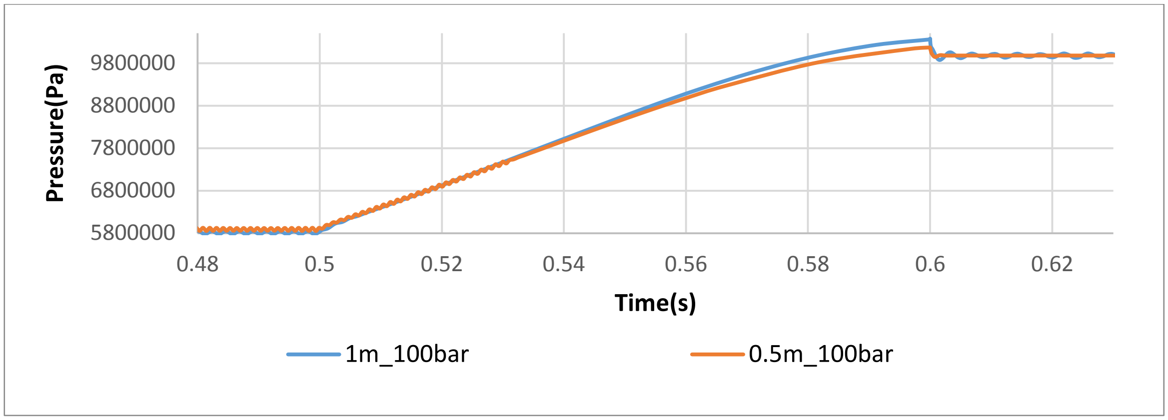

Figure 4.14: Pressure versus Time of specimen using Water for different length of 0.5m and 1m working under same pressure of 100bar

STATE	1m_50bar	0.5m_50bar	1m_100bar	0.5m_100bar
MAX. PRESSURE(Pa)	5264751.244	5129717.915	10374823.63	10167813.5
INLET PRESSURE(Pa)	5000000	5000000	10000000	10000000
ΔPRESSURE (Pa)	264751.2437	129717.915	374823.6284	167813.5012

Table 4.4: The data for maximum difference pressure value of each variables using Water

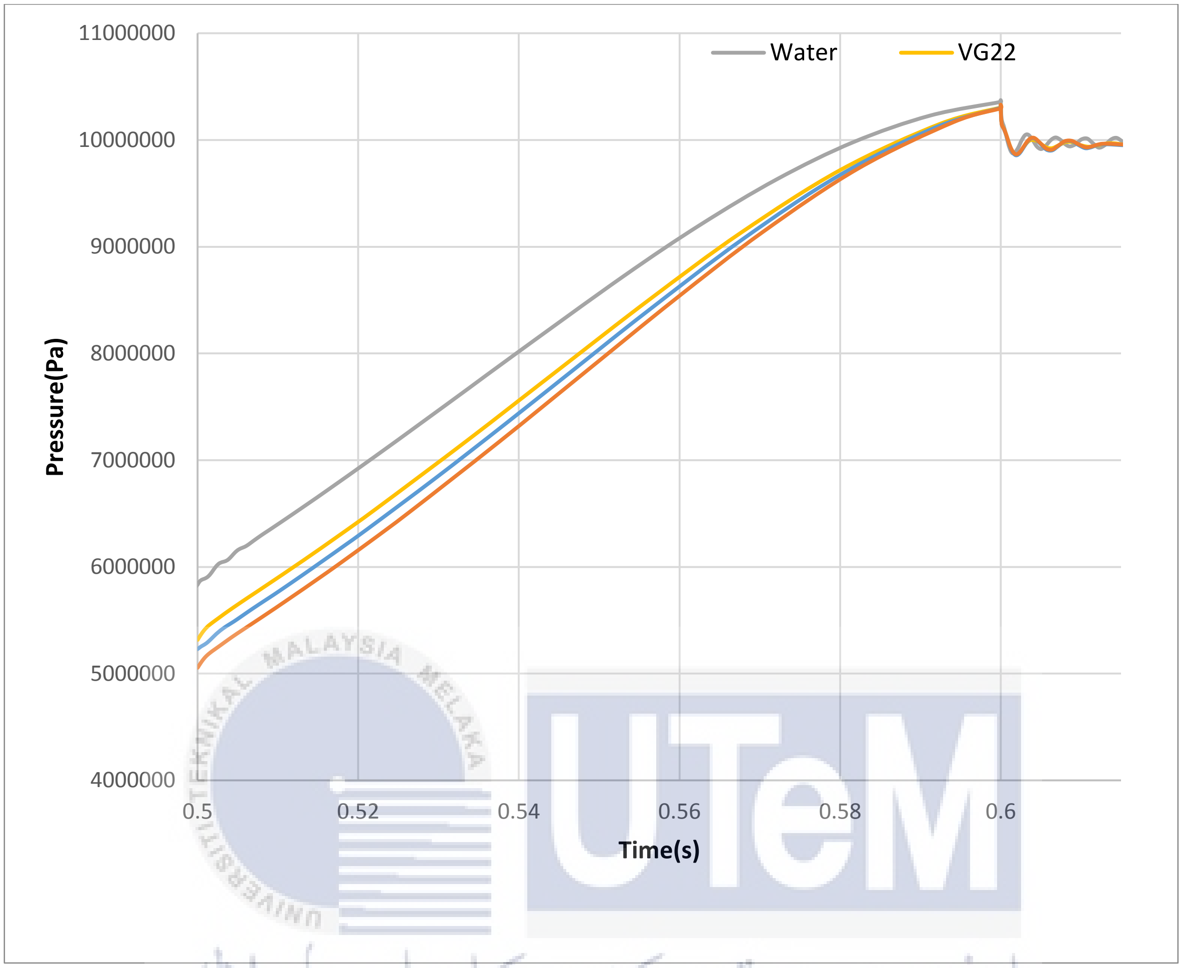

Figure 4.15: Pressure versus Time of specimen using all types of fluid for 1meter length of working under pressure of 100bar

FLUID	Water	VG22	VG32	VG46
MAX. PRESSURE(Pa)	10374823.63	10330974.74	10325683.35	10331320.74
INLET PRESSURE(Pa)	10000000	10000000	10000000	10000000
ΔPRESSURE (Pa)	374823.6284	330974.7391	325683.3468	331320.7404
Density(kg/m^3)	984.328	841.24	844.4	855.692
Bulk Modulus (Pa)	2.28973e9	1.24741e9	1.26653e9	1.29503e9

Table 4.5: The data for maximum difference pressure value of each fluids used

4.2.3 Water Hammer Results by Joukowsky Equations

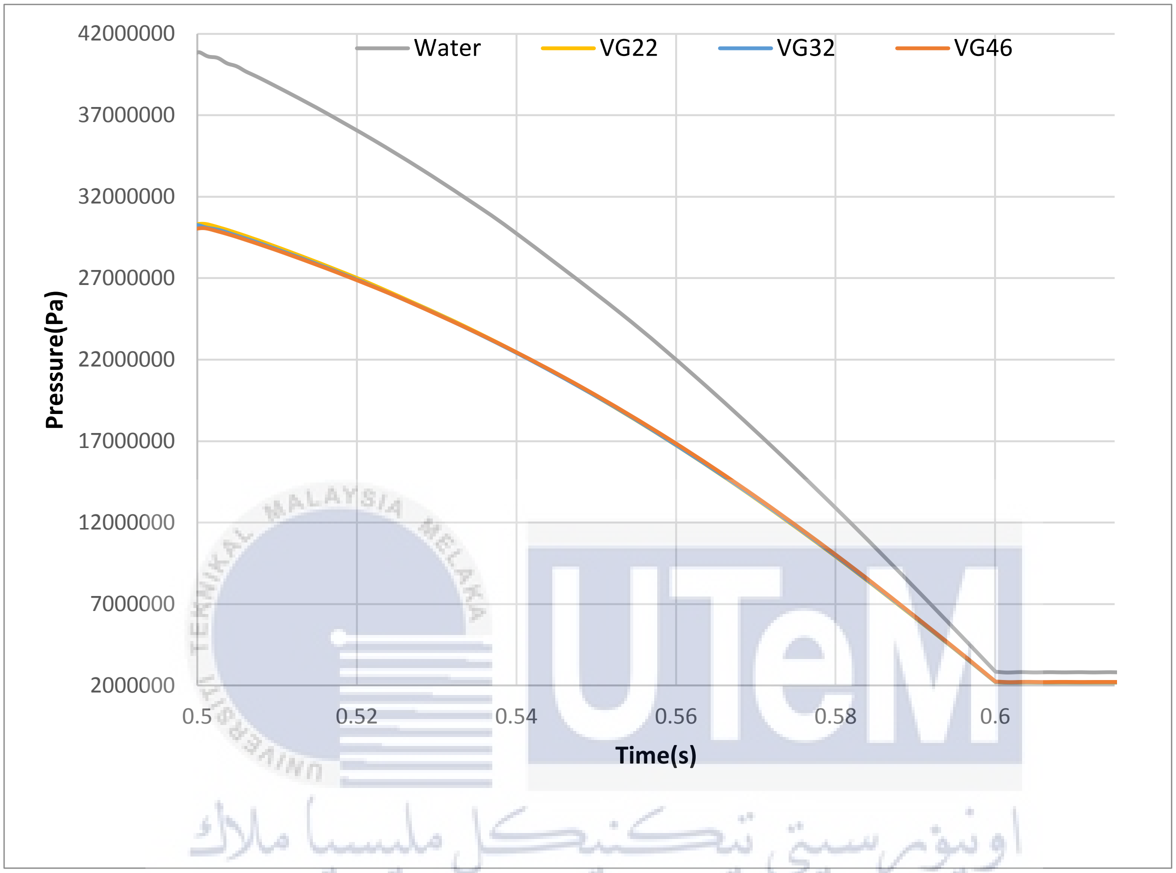

Figure 4.16: Pressure versus Time of specimen using all types of fluid for 1meter length of working under pressure of 100bar by using Joukowsky Equations

4.3 Analysis

4.3.1 Analysis of Water Hammer on Simulation

From Figure 4.3, Figure 4.6, Figure 4.9, Figure 4.12, the graph shows the comparison of the effect of water hammer between the 0.5meter pipe and 1.0meter pipe under pressure of 50 bar and 100 bar. The difference only on the length of the pipe and the system pressure, but the diameter of pipe, pressure level and material of pipe is all the same.

Figure 4.4 shows Pressure versus Time of specimen using Hydraulic Oil (VG22), Figure 4.7 shows Pressure versus Time of specimen using Hydraulic Oil (VG32), Figure 4.10 shows Pressure versus Time of specimen using Hydraulic Oil (VG46) and Figure 4.13 shows Pressure versus Time of specimen using Water, for different length of 0.5meter and 1meter working under same pressure of 50bar.

Besides, the Figure 4.5 shows the Pressure versus Time of specimen using Hydraulic Oil (VG22), Figure 4.8 shows Pressure versus Time of specimen using Hydraulic Oil (VG32), Figure 4.11 shows Pressure versus Time of specimen using Hydraulic Oil (VG46) and Figure 4.14 shows Pressure versus Time of specimen using Water for different length of 0.5meter and 1meter working under same pressure of 100bar.

From the Table 4.1, it shows the data from the maximum pressure difference for both graph on Figure 4.4 and Figure 4.5. The higher-pressure difference is on the long pipeline which is 1meter pipe for 50bar and 100bar compared to the 0.5meter pipe, but the highest value of the pressure difference is for 1meter and 100bar which is about 330974.7391 Pascal(Pa).

Table 4.2, it shows the data value for both Figure 4.7 and Figure 4.8 and the highest-pressure difference is for 1meter long pipe and working under 100bar of pressure which is 325683.3468 Pascal(Pa). Simulation data from Table 4.3 shows the value of data getting from Figure 4.10 and Figure 4.11 and the higher-pressure difference also on the 1meter pipe length for 50bar and 100bar and the highest value of the pressure difference is for 1meter and 100bar which is about 331320.7404 Pascal(Pa).

Water simulation data can get from the Table 4.4 that shows the value of the Figure 4.12 and Figure 4.13. The higher-pressure is the same as the Hydraulic Oils, which is on the 1meter pipe length for 50bar and 100bar. The highest value of the pressure difference is also on 1meter and 100bar result which is about 374823.6284 Pascal(Pa). From the data obtained, we can conclude that the pipe with the higher length and higher pressure will produce the large water hammer effect to the system.

The highest-pressure difference value of all types of fluids is on the 1meter long pipeline and under 100bar system pressure. By taking all its value on that state for each types of fluid, the result is shown in Figure 4.15 and the data on Table 4.5, where the highest-pressure difference value is for water, which the value is 374823.6284 Pascal(Pa) because water has big value of density compared to the three types of Hydraulic Oil. It can be concluded that water will caused the higher effect value of water hammer in the system.

As a summary, the higher supply of pressure in system, the longer the pipeline and the higher density of the fluid used will cause the higher water hammer/hydraulic transient effect in the system.

4.3.2 Analysis of Water Hammer on Joukowsky Equation

Joukowsky Equations is a formula to calculate the hydraulic transient/water hammer in a fluid flow. The basic equation for Joukowsky Equations is $\Delta p = \rho c \, \Delta v$, where ρ is the fluid mass density and c is the speed of sound. Korteweg's (1878) equation characterizes or defines c for liquid contained in round and hollow channels of roundabout cross-segment, $c = \sqrt{\frac{K_*}{\rho}}$ and $K_* = \frac{K}{\left[1+\frac{DK}{eE}\right]}$.

The value for diameter of pipe(D), thickness of the pipeline(e) and the modulus elasticity(E) for this system is fixed, which D = 0.03m, e = 1.25mm and E =$2x10^{11}$ Nm^{-2}. The bulk modulus for each fluid is different from one to the others same goes to its density that can be refer to Table 4.5. The value of K_* can be calculated from its formula for each types of fluid. Then, the value of K_* is used to get the value of c. To use the Joukowsky Equation, it need to find the change of velocity value for this system.

So, this formula is used, Q = AV, while Q is the flowrate that I can get the data from the system on the flowrate sensor. A is the area of the pipeline by using the formula $A = \pi r^2$, which the value is fixed for all the calculations.

Velocity data that get from the flowrate Equation is used to calculate the value of pressure difference or getting the value of hydraulic transient/water hammer in this system. Same to the Figure 4.15, Figure 4.16 is also used the condition of comparing all types of fluid by using 1meter long pipeline under 100bar working pressure system. The data is calculated for each types of fluid and the graph had been plotted in Figure 4.16 above.

The graph of the Joukowsky Equation in Figure 4.16 is not the same pattern as the graph shows for the simulation in Figure 4.15, where the graph for Joukowsky Equation is reduced due time while the graph for simulation is increase due to the time. This shows that this Joukowsky Equation is not compatible with the simulation data that we get from this system. The exact equation that can get from the simulation data will be come out or created to ensure it is compatible to calculate the value of hydraulic transient/water hammer happened in this system. It can be concluded that the data from simulation will produce the graph that not same pattern to the graph of Joukowsky Equation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

From the data obtained, the conclusion that can be made is the pressure of the system, length of the pipeline and the types of fluid is the main factor that can have caused the hydraulic transient/water hammer to occur. Every fluid has their own properties in term of its density, bulk modulus etc. The fluid that have higher density will caused the higher impact of hydraulic transient/water hammer due to the equation of kinematic viscosity, $\nu = \eta/\rho$. The higher length of the pipeline also can make the higher water hammer/hydraulic transient effect to the system. This is due to the higher velocity of fluid flow in the pipeline and when the valve is suddenly closed, the effects will be higher. Hydraulic system that undergoes the high pressure will caused the high effect of water hammer/hydraulic transient because it is also related to the velocity of the fluid flow in the system.

Recommendations for further research is to get more readings of pressure and other readings to get the value needed on the Joukowsky Equation and have same pattern of graph between simulation graph and Joukowsky Equation graph.

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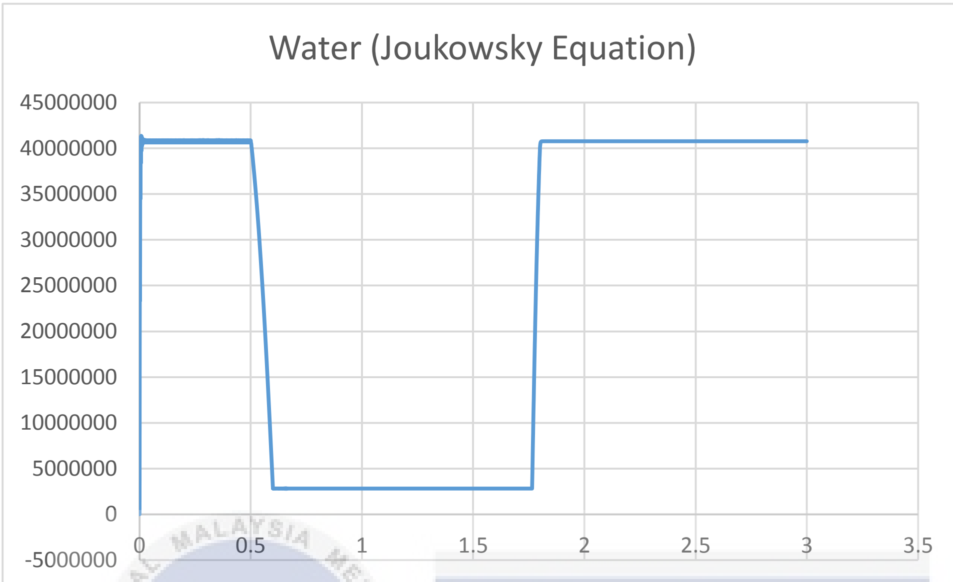
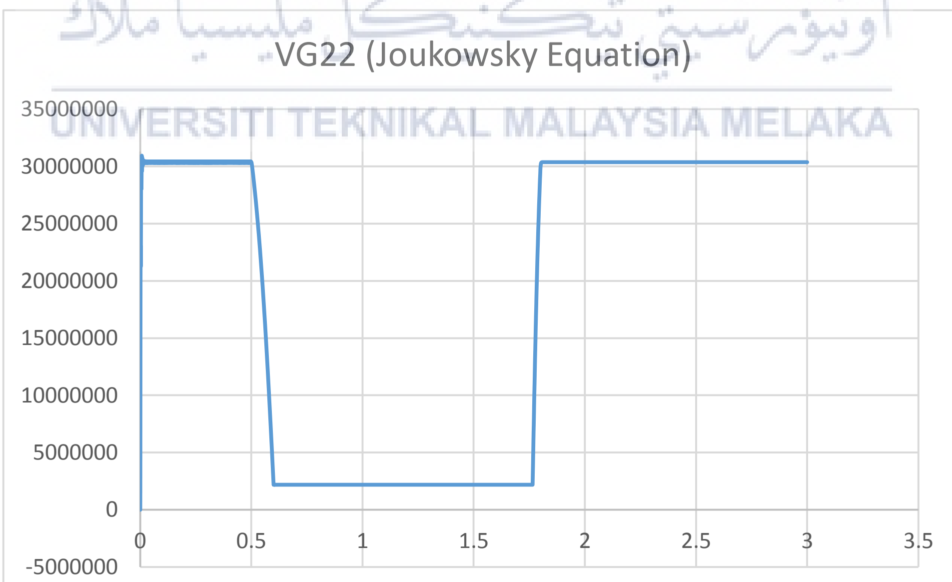
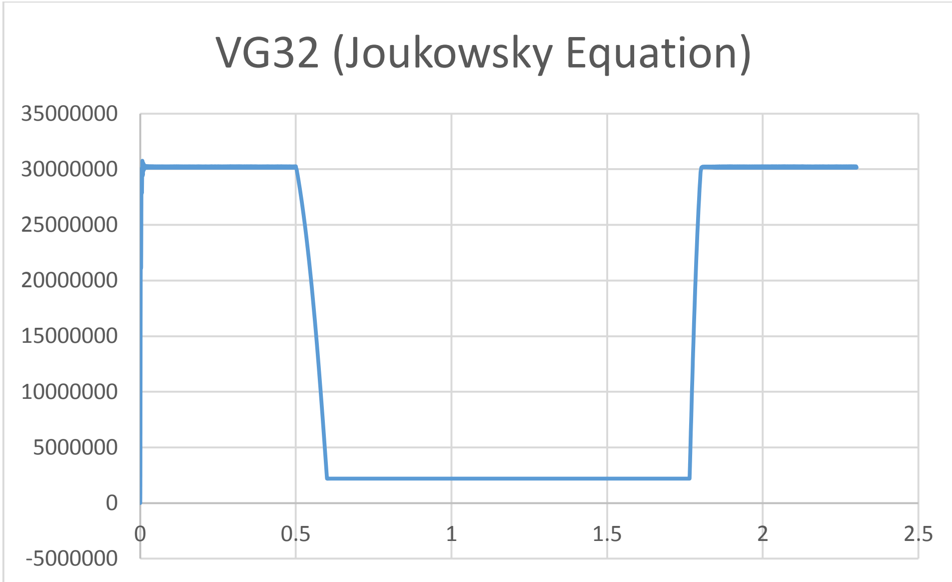
APPENDIX A



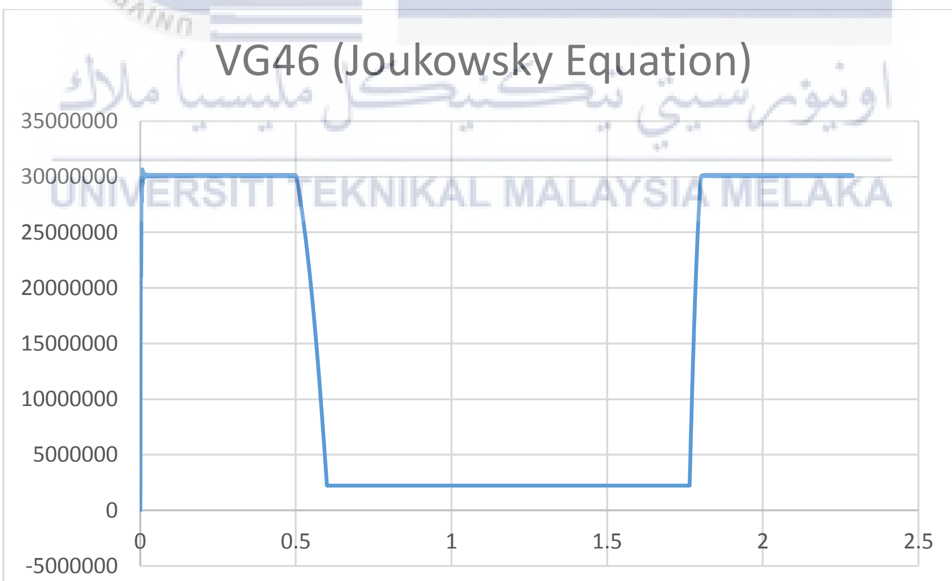
Graph ΔP against time of 1meter long pipeline under 100bar system pressure of water by using Joukowsky Equations



Graph ΔP against time of 1meter long pipeline under 100bar system pressure of Hydraulic Oil (VG22) by using Joukowsky Equations



Graph ΔP against time of 1meter long pipeline under 100bar system pressure of Hydraulic Oil (VG32) by using Joukowsky Equations



Graph ΔP against time of 1meter long pipeline under 100bar system pressure of Hydraulic Oil (VG46) by using Joukowsky Equations