

4/25/2017



University of Wales Trinity Saint David

BEng (Hons) Mechanical & Manufacturing Engineering

Computer Modelling of Hydraulic Transient

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25 April 2017

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Abstract:

Water hammer, also known as a hydraulic transient, is a sudden change in flow, the cause is not clear most of the time. When it does get noticed, it can be as a little as a light banging noise, or it can be huge enough to move pipes from their lines, by affecting and rupturing the supports. It can cause serious leaks or even make pipes and vessels to explode.

The phenomenon has been familiar for centuries, however, the formulas for calculating it, are very difficult and compound and it is only lately that engineers have been managed to work out the magnitude of the phenomenon in different situations. The advance technology has helped engineers to form a mathematical analysis of the issue, and to generate precise procedure of minimizing potential damage can occur.

This project tests one of the calculation procedures for hydraulic system and the best way to solve the complex hydraulic system could be analysed. Main factors are the comprehensive volume of the pipe network system and the velocity of the valve closure.

This is already familiar; however, the analysis is indicated that simple techniques of occurring of hydraulic transients look to be almost as influential as complex procedures, and that in various issues it may be potential to clearly assess the likely magnitude of the water hammer in a simple framework. While the system become extremely complex, it is also pure that this is no longer to be a choice, and advanced emulation is the perfect path to determine what is required to protect the phenomenon damaging the pipe network.

In general, there are various types of techniques to process the calculation of water hammer, however, the procedure which have been chosen for this project is the explicit finite difference method (FDM). This particular method is considered because of its accuracy and simplicity of calculation than such as implicit finite difference methods. On the other hand, in many minimum risk systems either can be operated with a similar standard of success.

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Chapter 1

Section 1.1: Introduction:

Hydraulic transient is a pressure flow or wave that happens when there is a sudden momentum change of a liquid. The movement of a fluid is unexpectedly forced to stop or change in an enclosed area. This normally happen in pipelines systems when a valve is closed suddenly at the end of a pipe system where the speed of the liquid is high (DavidFerràs, et al., 2016).

A pressure wave generated will increase with the pipeline. When this happen, it produces a loud noise of hammer banging with vibrations which can be delivered through the pipe (Water Hammer). The pressure wave generated from this incident can seriously damage pipelines. The size of the hydraulic transient can be affected by various factors, inclusive, a flow rate, valve closure time, pressure and pipe diameter (Tijsseling, et al., 2008).

This project will define a hydraulic process using Matlab and will refer points on the system where the transient influence occurs. The fatigue properties of components of the system at these risk points will be rated using other emulation Finite Element Analysis (FEA) carried out using such computer aided design (SolidWorks, CFD and FEM) (Sun, et al., 2016).

How to protect water hammer needs a fundamental comprehension of fluid characteristics, governing formulas, and the design and activity of pipe systems, valve, pumps, and pump stations. The report will present the simple principles of water hammer application equations, and the potential harm, as well as techniques of evaluating hydraulic transient and reducing or eliminating the consequences of this sort of water hammer phenomenon. Figures 1 and 2 are showing the impact of hydraulic transient in the pipeline.

Figure 1: The image is displaying how the water hammer affect the pipelines (Johnson, 2010)



Figure 2: The image displayed the issue cause by water hammer (Archer, n.d.).



Chapter 2: Objectives and Aims of the project:

The main purposes of this project are to define particular engineering problems and to suggest some suitable solutions which can associate engineers to select convenient equipment for the structure of the identical system.

Section 1. 1 Objectives:

Clearly define a mathematical emulation of pipe network system in which water hammer can be calculated at several points, times and next valve closure situation. In addition, to display the stage of forces required in the system equipment to ensure that damage does not happen because of the transient (Pumps, 2015).

Section 1. 2 Aims:

The project will distinguish and represent in details, type of the issues that can emerge in a hydraulic system, which can help to find potential weakness through the pipeline system. To

provide a suitable procedure to solve the issues likely occur within the system (Broens, et al., 2012).

Section 1.3 Time Scales and Provisional Work Plan:

A time frame work should be planned in order to display all the operations required to be done during the project stages. These will be layout as a road map of the project and should give close assessment for the time required to finish every section of the project. For this project, a provisional time scale is displayed in the next page.

Time	Task
Week 3	Researching and studying the background of Hydraulic Transient.
Week 5	Define the constitutive equation of the problem
Week 6	The numerical techniques to solve the constitutive equations.
Week 10	Write a code in Mat Lab environments to calculate rise of the flow conditions.
Week 14	Analysis of results
Week 16	Documenting and writing up the final report

Chapter 3: Literature Review:

Section 1.4 A history of Hydraulic Transient:

Water hammer in the pipe net system includes a various phenomenon recognized by engineers for centuries, including problems caused by valve working (Tijsseling & Anderson, 2007).

There was attention to the issue for a long time before it was known by the name of water hammer, and the scientists investigated as there were archives of water-pipes destroyed in this method in the time of the Roman (Chaudhry, 2014).

Scientists were dedicated to researching this phenomenon and one of the scientist, called Johannes Kries successfully noticed it in blood vessels in 1883. And within the engineering circles Nikolay Yegorovich Zhukovsky, provided engineers with a method, an equation in order to work out the effects of the phenomenon. The formula is associates in pressure

change (Δp) to shift in the velocity (Δv), this can be displayed and as Joukovsky's equation (Itzner*, (2002)).

Equation 1: Joukovsky (Zhukovsky) Equation ((Bergant, et al., (2006))

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

where ρ = fluid mass density (kg/m^3)

c = speed of sound (m/s)

Δp = Change in Pressure (Pa or N/m^2)

Δv = Change in Velocity (m/s)

In addition, the speed of sonic used in the equation below, indicates the velocity of the sound in the cross-sectional area of the pipes, and this could be calculated by employing Kortewg's equation (Tijsseling & Anderson, 2007)

Equation 2: Joukowsky's formula for the speed of the sound through the pipes system (Chaudhry, 2014).

$$a = \sqrt{\frac{1}{\rho \left[\frac{1}{K} + \frac{D}{Ee} \right]}} \quad m/s$$

Where:

a: Velocity of the fluid (sonic wave) (m/s)

ρ : The density of the fluid (kg/m^3)

D: The pipe diameter (m)

K: Bulk Modulus (Pa)

E: Young's Modulus (Pa)

e: Wall thickness of pipe (m)

These equations were first introduced and studied in the nineteenth century and in the early of twentieth century. Tijsseling and Anderson found out that;

The research on the hydraulic transient are unusual because of their clarification and maturity in the theory and experimentation. The transient incident was very hard to realise in their time, this major activity was very significant to the new pipe network engineers and other who are working on hydraulic systems, as it formed the groundwork for much research (Tijsseling & Anderson, 2007)

In the end of Twentieth Century and early of Twenty – First, with the introduction and support of computers technology, faster processing improved calculation of the mathematical models of water hammers which look at the damage of hydraulic transients. This is the essential field of the investigation for this literature review (Chena, et al., 2013).

Calculations of sonic wave velocity of different type of ISO Oil grades at the pipeline comparing with water (Chaudhry, 2014):

$$\text{ISO Oil Grade 32: } a = \sqrt{\frac{1}{857 \left[\frac{1}{1.8 \times 10^9} + \frac{0.6}{120 \times 10^9 \times 0.01} \right]}} = 1051.403 \text{ m/s}$$

$$\text{ISO Oil Grade 46: } a = \sqrt{\frac{1}{846 \left[\frac{1}{1.3 \times 10^9} + \frac{0.6}{120 \times 10^9 \times 0.01} \right]}} = 965.038 \text{ m/s}$$

$$\text{ISO Oil Grade 100: } a = \sqrt{\frac{1}{869\left[\frac{1}{0.6 \times 10^9} + \frac{0.6}{120 \times 10^9 \times 0.01}\right]}} = 728.78 \text{ m/s}$$

$$\text{ISO Oil Grade 220: } a = \sqrt{\frac{1}{875\left[\frac{1}{0.1 \times 10^9} + \frac{0.6}{120 \times 10^9 \times 0.01}\right]}} = 329.914 \text{ m/s}$$

$$\text{Velocity of Water: } a = \sqrt{\frac{1}{998\left[\frac{1}{2.15 \times 10^9} + \frac{0.6}{120 \times 10^9 \times 0.01}\right]}} = 1018.991 \text{ m/s}$$

Section 1.5 What are the reasons for causing high pressures?

The alteration in pressure is related to a change in the speed of a fluid. These variations can be the result of forces within the pipeline itself. Sometime these pressures are small in their magnitude, so they are difficult to notice (Stopford Projects Ltd, 2006).

However, if the average of the shift of flow-rate rises enough, the forces are likely to cause the pipeline to move. In this situation, the pipeline has to be attached properly with its support, otherwise it is likely to fail. If a valve that minimizes the flow-rate of a fluid running by the force of gravity from a reservoir, as the valve is shut off the pressure in front of the valve rises, and that will slow the fluid in the pipeline (Boulos, et al., 2005).

As the flow-rate reduces, the pressure will fall until it is reduced value. Slow closing of the valve will minimize the flow and finally when the valve is completely shut off the flow rate will stop without

affecting the equipment. Usually, liquids are not incompressible when compared with gases, the compressibility of the fluids are very small, however; they have a compressibility of 2.2 GPa (water, at °C). (Stopford Projects Ltd, 2006).

A pressure surge will move at speed, usually similar to the speed of the sonic, along the pipeline, transferring this shift of pressure upstream versus the flow. When the sonic wave at the front meets the travelling fluid that is still moving, it reduces it to a halt. The fluid that is in rest among the wave front and the valve will likely be compressed by the high pressure.

The length of the pipeline has significant effect with rising pressure. The shorter the pipeline the quicker the speed of the wave. This shows that the process is rapid, and the column can reduce more steadily. This means that the situation of the hydraulic transient is very precise (Wood, et al., 2005).

However, if the opposite is true, and specifically if the valve time closure is the same as the period the wave takes to reach the length of the pipeline, this can result in compression impact. Russian scientist Joukowski is the first person to explain this impact. Joukowski displayed both experimentally and theoretically that there is a maximum pressure that can be formed, and it recognized by “Joukowski pressure”, shown by the equation below (Barten, et al., 2008).

$$h = \frac{v * a}{g}$$

where,

a = Speed of the sound wave in the pipe, recognised by “wave celeric”, m/s

v = Initial velocity of the fluid, m/s

g = 9.81m/s²

h = Joukowski head, m

This for the liquid in a solid pipe, where the wave is e.g. 1600 m/s, for the initial liquid velocity of 3m/s, then unexpectedly stopping the flow with a rapid valve operation will outcome in a head of about 326.2m, or 32.62bar.

$$h = \frac{2*1600}{9.81} = 326.198\text{m}$$

The longest closure time that will provide this head is given by flowing equation;

$$t = \frac{2 * l}{a}$$

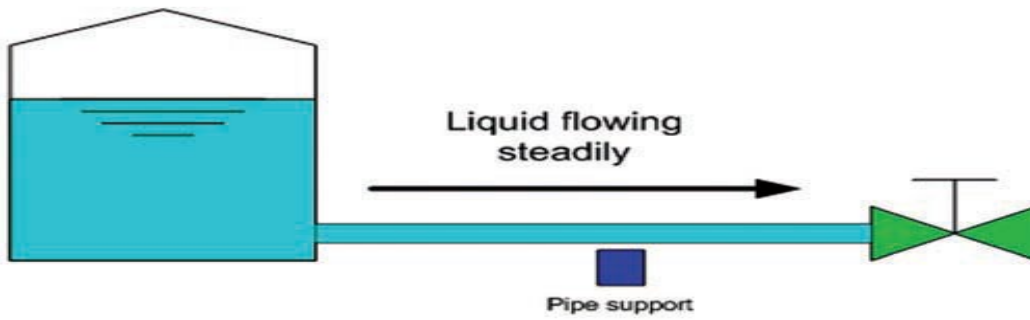
Where;

L = the pipe's length in meter

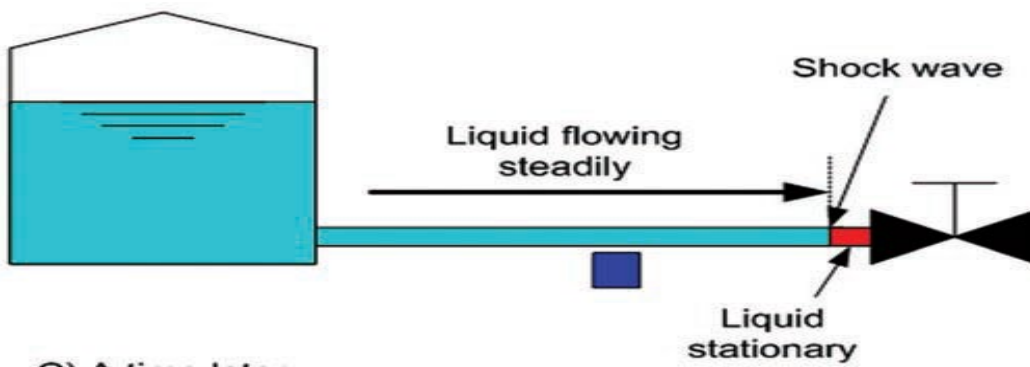
T = The time taken to pressure wave to reach the pipe length and return back again.

Figure 3: Explains liquid flowing through a valve (Stopford Projects Ltd, 2006).

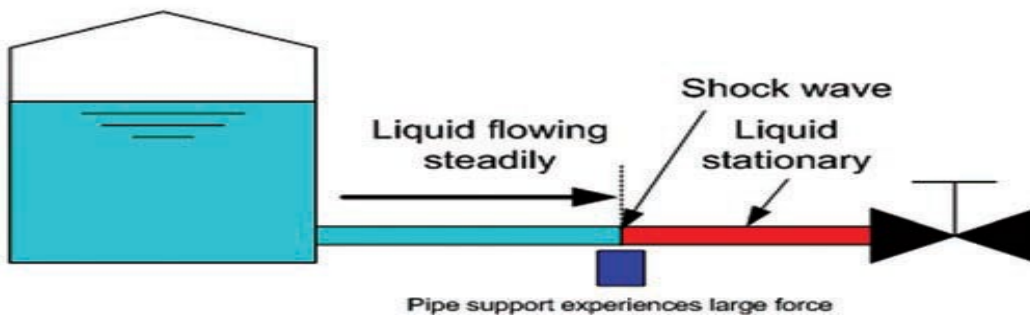
A) Valve open



B) Valve closes suddenly



C) A time later



Section 1.6 A problem of high forces:

In order to recognize the cause of elevated forces, the project is referred to a pipe as displayed below in the figure. The example illustrates a pressure wave accelerating down a pipe that has bends in it. For the pressure moving unsteadily, the traveling wave front forms a force on the pipe. E.g. for a 0.1m diameter, the traveling of the 32.62 bar wave explained above generated a force of given by the following formula;

$$F = \frac{\pi}{4} * D^2 * P$$

Where;

F = force in Newton

P = The pressure equivalent of the Joukowski head

It is recognized that;

$$P = h * \rho * g$$

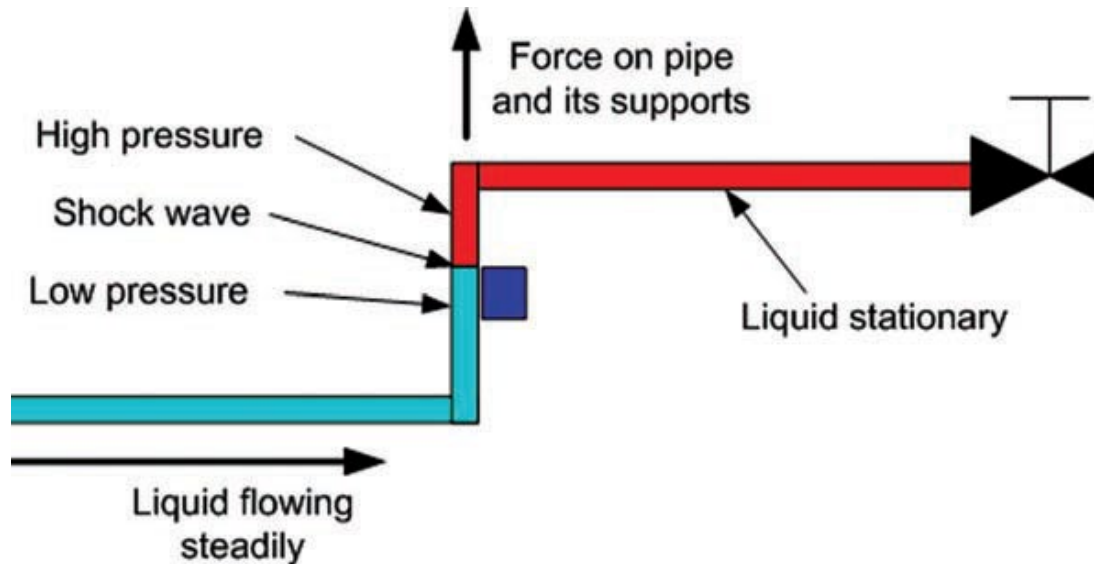
In this cause, the Joukowski pressure would be;

$$P = v * c * \rho$$

Where ρ = fluid density.

In this situation if the force F is great and about 2.5te or more, this could make a serious damage to the pipe and its supports.

Figure 4: Show the pressure wave traveling through the pipe with bends (Stopford Projects Ltd, 2006).



Section 1.7 Beyond the simple theory:

The forces and pressures counted above are for particular dynamics and quick situations. There are many examples of pressure comparing with Joukowski situation and gradual shift in fluid velocity that provides perceptible wave forces. Therefore, in lots of situations, the complex analysis required has to be carried out properly to avoid potential risk.

This typically include transient designing of the pipe to view how huge the wave pressure will be. This can provide a solid base to calculate the highest and lowest pressures the pipe will examine during the transient.

The condition for the forces on the pipes and their supports are more complex, even when the analysis of transients are perfectly complete, the kinetic reply of the pipe operation to take into the consideration.

“This comes from vibration theory and regard of the time for which the forces act”. If the pipeline is short and then the time of vibration is long, this means the pressure surge will travel through the pipe quickly. The factor amending the force result is known as the Dynamic Load Factor (DLF). The formula below is for force.

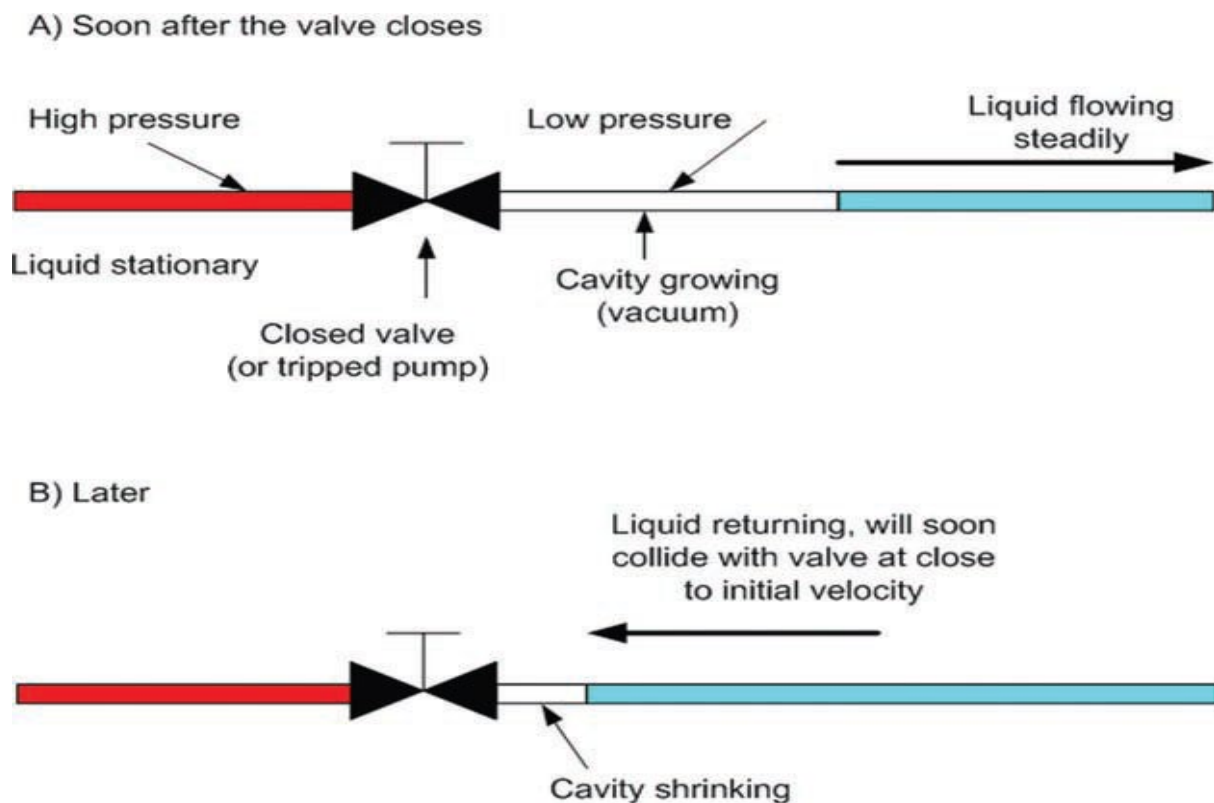
$$F = \frac{\pi}{4} * D^2 * v * c * \rho * DLF$$

Section 3.4 What are the other factors can cause rise in hydraulic transient?

Downstream of the valve

The previous studies above are considered of transient due to appropriate pressure rise in front of the valve, but for pipes have valves far from the pipe end, their issues will be experienced downstream of the valve. The pressure will likely to drop to the steam pressure of the fluid, and boiling can happen. This means, if the boiling happens, the cavity will form. in the normal condition like displayed at the figure 5 below, the fluid downstream of the gap return back to forms up nearly the same speed as the fluid had when the cavity began to create. However, the returning of the fluid toward the valve or to the fluid remining before the gap, this can be cause catastrophic transient (Zuo, et al., 2013).

Figure 5: Show the cavity is forming downstream of the valve (Stopford Projects Ltd, 2006).



Section 1.7 Computer Modelling:

There are many different procedures for mathematical modelling transients in a basic and complex pipeline system, involving simulation in Matlab which will be used in this project.

Hanif Chaudhry illustrates the complexity of the pressure wave extension and the hardness increased by reflected pressure waves. The activity of previous mathematicians, like Newton and Euler generated formulas which can provide partial responses to the issues of the wave propagation, however, they were never able to get formulas that covered every aspect (Chaudhry, 2014).

Many scientists have tried to come up with results in order to solve the problem of hydraulic transients. Lagrange came close. However, as Chaudhry points out, there so many factors, including the flexibility of the liquid and the pipe walls, internal friction, air cavities and other materials so they could only come up with partial solutions. The activity of Zhukovsky and Korteweg (Tijsseling & Anderson, 2007) eventually came up with answers, but until computerised mathematical modelling became familiar, calculations were very difficult and took a long time.

Izquierdo and Iglesias (2002) devised a computerised emulation for basic system as displayed in figure 3, which is recognized by DYAGATS (Diseño Y Análisis de Golpe de Ariete en Tubería basic Spanish for Design and Analysis of hydraulic transient in simple pipe network. In fact, DYAGATS utilizes integration of the MOC and finite difference methods, because these have benefit that they are able to remove the computational restrictions previous displayed (Izquierdo & Iglesias, 2002, p. 803). (Izquierdo and Iglesias (2002), their system is validated by comparing the outcomes from operating some different simulations. The consequence is, the DTAGATS system is reckoned to be a perfect approach of transient case in p pipe operation system.

Among the difficulties, the world could face in the near future are shortages of water and pipe explosions. These are other reasons of taking the transients into the consideration. Many scientist have predicted that there will be shortages of fresh water Weiss and Slobodian (2014).

According to Weiss and Slobodian (2014), they expected that in the near future there will be a greater demand for fresh water than at present. Lots of countries are predicted to be water exhausted by this century. Already there are some places in the worlds that are already in

need. The authors stress the importance of water to human life as well as creatures (Weiss & Slobodian, 2014, p. 717).

Figure 6: Displaying a basic hydraulic system for the test (IZQUIERDO & IGLESIAS, 2002)

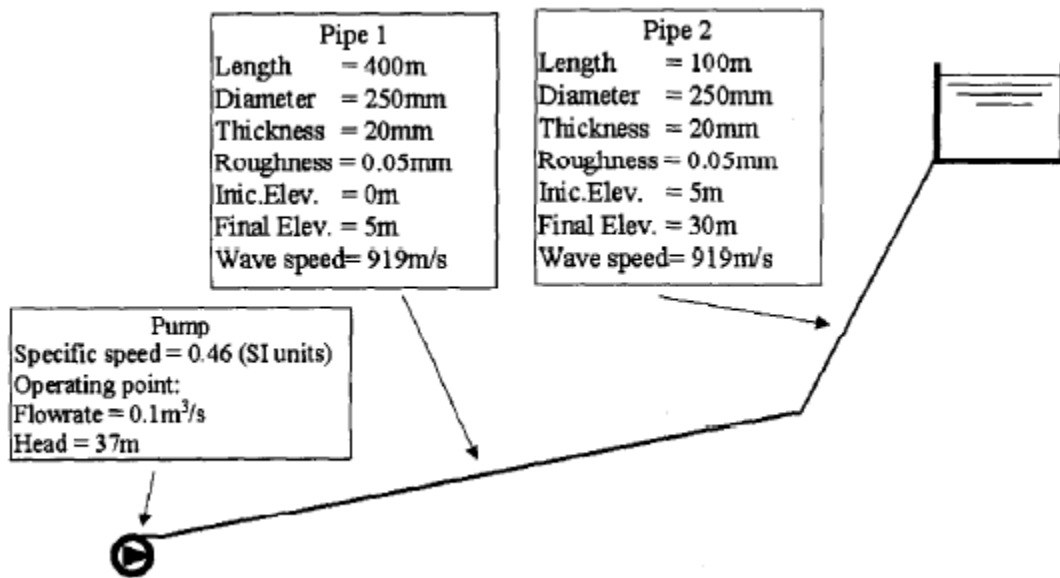
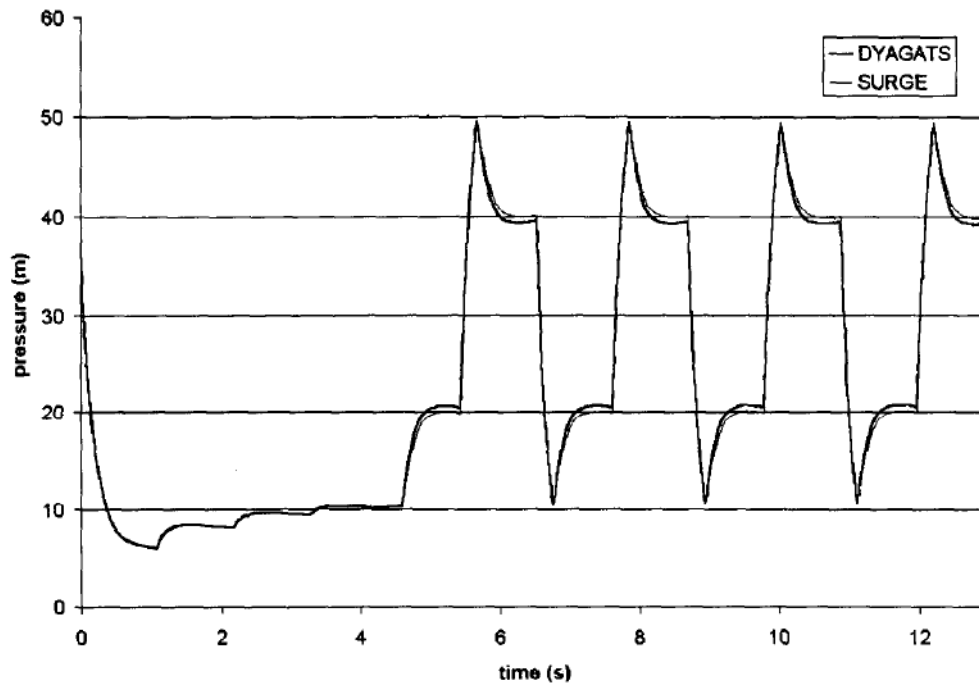


Figure 7: Comparing the results (IZQUIERDO & IGLESIAS, 2002)



Although, the plan of this process is to promote the management of water hammer simulation examples, instead of improving its capability to estimate the size and the results from the place of the tests (IZQUIERDO & IGLESIAS, 2002).

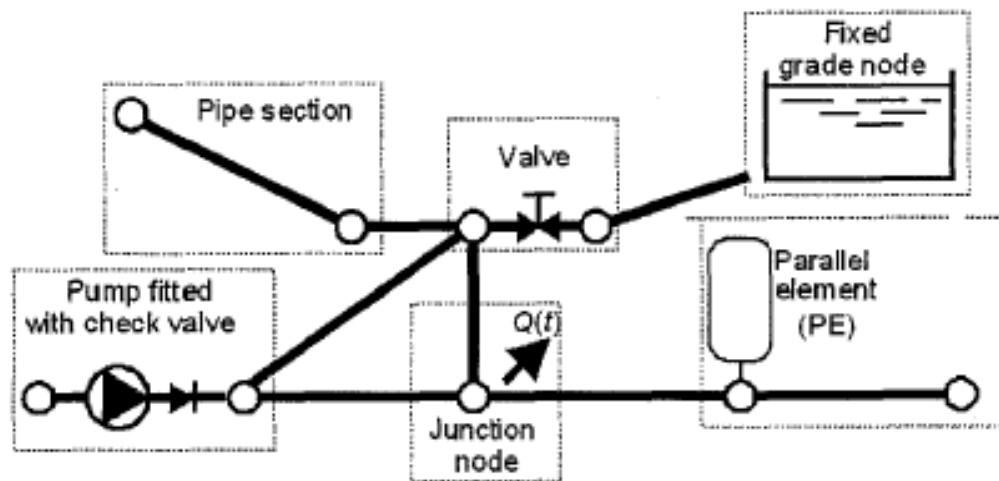
The basic explanation on the above in figure 3 has been applied to compare the outcomes. The graph of the pressure downstream from the pump, when the power fails, provided by the both approximation is shown in the figure 4. The approached approval between both examples can be noticed. From the author's standpoint, it shapes an acceptable validation of the example displayed in this report (Riasi, et al., 2013).

DYAGATS is operated as a computer emulation, but it was not perfect in predicting hydraulic transients in extremely complex system, therefore, the writers preferred to enhance (Izquierdo & Iglesias, 2004). The system has been divided into sections of points and elements as shown in the figure 5 below.

One of aims for researching and studying the impact of the hydraulic transient at these particular points is the steady rise of civilization of the world. It is estimated that during the twenty-first century 80 to 90% of the world population will be living in cities (Kaliatka, et al., 2014).

There will be bigger than ever demand for dependable pipe supplies. Even the developed countries will have concerns about access to water (Weiss & Slobodian, 2014). Some observers propose that water will become more significant than other fluids (Tarlock, 2008). Tarlock believes that the threats over water security and prospective shortages due to climate change are more critical than previously thought. It will not get any easier.

Figure 8: Explaining a System by using points and elements (Izquierdo & Iglesias, 2004).



The different designing system is provided by Kochupillai, Ganesan and Padmanaban (Itzner, (2002)) with some others; Epstein, Izquierdo, Pérez, & Iglesias, and Jianghe factor that all designs ignore is the impact of friction, because the transient situations are very short.

This means, the explicit finite different method which is used in this project, is more accurate than other various ways of calculating hydraulic transient (Chaudhry, 2014).

This emulation programme can generate outcomes which directly benefit industries, as it is expected that they will find weak places in a pipeline system, allow engineers to change the system and minimize the impacts of water hammer. This is significant as the need for both oil

and water are rising while supplies of both are falling (Weiss & Slobodian, 2014). Any waste of any sort should be stopped or minimized.

Some simple equations are used for estimating and to solve the problems that occur in the pipeline. These equations are connected to partial differential equations on a time dependent with non-linear boundary conditions (Epstein, 2008). The system substitutes the partial differential equations used in normal hydraulic transient calculations with approach established on system of first order differential equation (Epstein, 2008).

These approximations suppose that there will be trapped air on the system, but when the simulations are carried out there is no locked air within the system. Therefore, the hydraulic fluids on this system is incompressible (Tijsseling, 2007). This design is a useful tool and it indicates that the system is secure from potential damage and it is appropriate for use in modelling new pipe network system (Epstein, 2008).

Some researches illustrate that the calculations of hydraulic transient can be effected easily (Wood, 2005). The article states that the main purpose of hydraulic transient analysis provides engineers with some complicated methods but it is possible to make the method simple and logical with consideration of the operation of pressure waves (Wood, 2005).

The approximation will provide the engineers with logic understanding of pipe hydraulic transient which will result in promoting some new models and improving the performance of the pipe network system (Wood, 2005).

The Wave Characteristic Method (WCM) can be operated by using computer calculations and analysis, but some similar results in precisions could be obtained with WCM applying some minimum calculations than those need to use in the different Method of Characteristic (MOC) system. Clearly, both methods are provided appropriate and correct results.

However, MOC has to calculate the inside points to grip the wave spreading and impacts of pipe friction. The Wave Characteristic Methods (WCM) can hold these influences using pressure waves. Hence, for similar moulding precisions, the WCM has smaller calculations and quicker execution periods. Furthermore, the period of computations per time step does not raise for the WCM when more accuracy is needed (Wood, 2005).

After testing these different ways of assessment or calculating hydraulic transient, the computations of the system to be applied in the simulation is Explicit Finite Difference Method. This will be explained later in chapter 6. The suggestions by Wood (Wood, 2005) and Epstein (Epstein, 2008), provide a perfect approach to the impacts of hydraulic transient. In order to obtain good outcomes, the system

requires more accurate finite element method emulations. And these are very important equipment for pipe network engineers.

Figure 9: Complex of graphic of pipe network as shown.

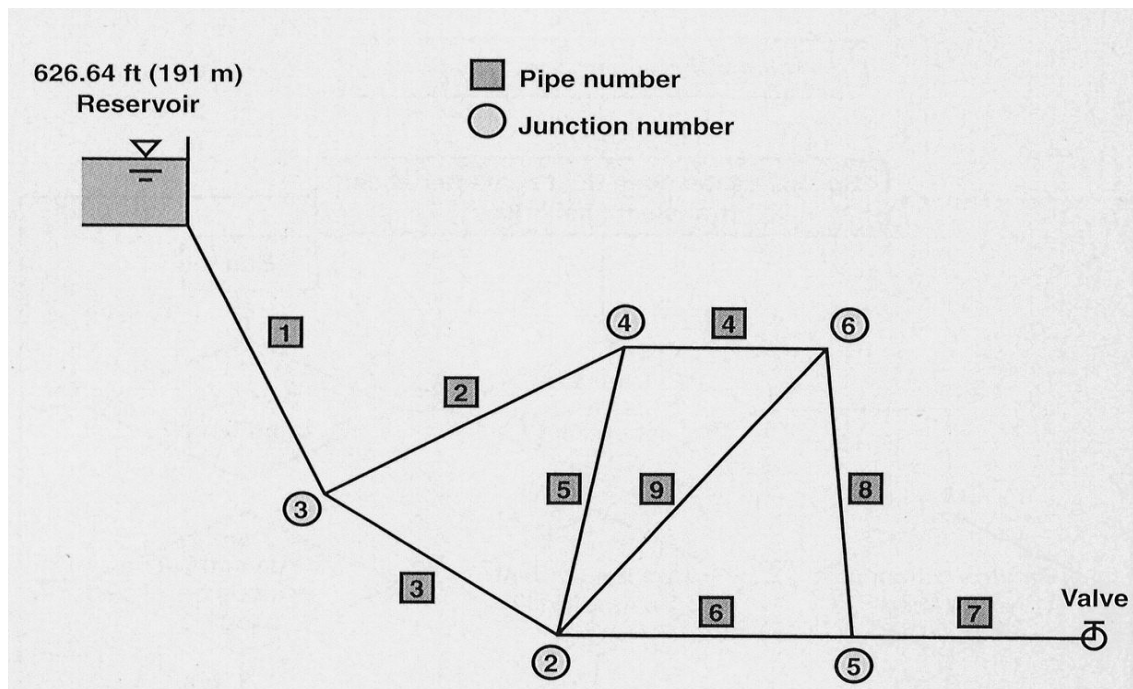
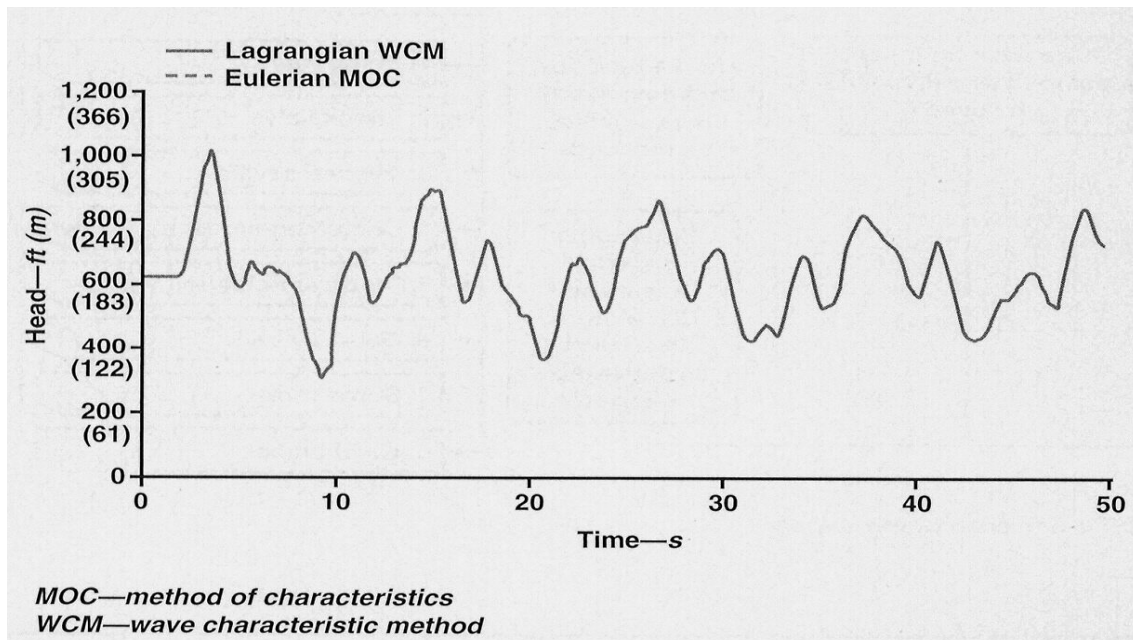


Figure: Displaying the result of compression head at the node 3 from above sketch.



The Lagrangian WCM and the Eulerian MOC are generated similar results referred by the single line.

Chapter 4 - Governing Equations:

Section 1.1 Governing Formulas

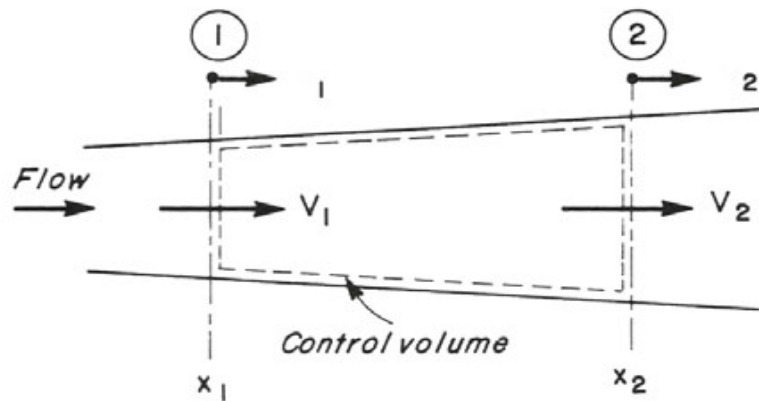
These equations are the principles for the preservation of mass and momentum and explain the transient motion in closed canals. Governing equations are indicated by the continuity and momentum equations (Alberto Conejero, et al., 2016).

They are also known as the equations of motion or dynamic equation. Usually, these formulas are groups of partial differential equations because the flow speed and pressure in the transient flow are a function of the time as well as dimension. Therefore, these equations are the main tools of the simulation, and the computations will be worked out within the simulation and manipulating the magnitude and the direction of transients which occur (Chaudhry, 2014)

Section 1.2 Continuity Equation:

This equation applies the law of conservation of mass to a control volume by considering the flow of a compressible liquid in a conduit which has linearly flexible walls. Parts 1 and 2 show the slightly widening inside surface of the pipe here in figure 1.

Figure 11: Explanation sketch for continuity (Chaudhry, 2014).



Control volume will shorten or lengthen as the pressure changes.

If the speed with respect to the coordinate axis of parts 1 and 2 as constructed below, and expansion to be W_1 and W_2 , respectively. We can assume that that motion is one dimensional and the stress at the end part of the control volume is constant. The space X , velocity V , and the outlet Q will be positive in the downstream direction (Chaudhry, 2014).

Equation 3: Continuity Equation (Chaudhry, 2014).

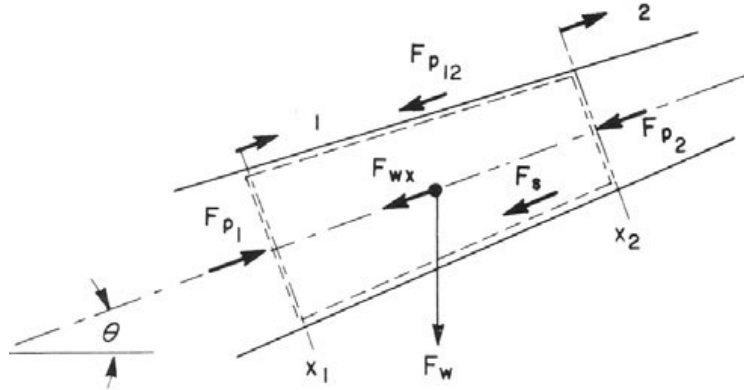
$$\frac{\partial H}{\partial t} + \frac{a^2}{gA} \frac{\partial Q}{\partial x} = 0$$

Section 1.3 Momentum Equation:

By applying the Reynolds Transport Theorem in order to determine the momentum equation. The extensive property for the purpose is the momentum of the liquid that is equal to mV .

According to Newton's second law of motion, the time average of change of momentum of a system is similar to the consequences of the forces spent on the system by its boundaries.

Figure 12: Explanation for momentum equation (Chaudhry, 2014).



Equation 4: Momentum Equation:

$$\frac{\partial Q}{\partial t} + gA \frac{\partial H}{\partial x} + \frac{fQ|Q|}{2DA} = 0$$

Where:

$$H = \text{the pressure head in } m \left(H = \frac{P}{\rho g} + z \right)$$

$$Q = \text{the volumetric flow rate } m^3/s$$

$$a = \text{the wave velocity } m/s$$

$$A = \text{the cross sectional area of the pipe } m^2$$

$$f = \text{the friction factor } (f = 0.00)$$

$$D = \text{the diameter of the pipe in } m$$

Chapter 5- The Modelling Methodology.

Section 1.1 Project Methodology.

Project methodology is the theory of how the investigation carried out, or to find a different procedure to examine and analysis the allegations, essentials and methods in a particular approximation (Ghidaoui, et al., 2005).

The main aim of the methodology is to determine the issue in a various way that could be inspected, this mean the methodology is can be explained almost empirical, and the methodology can be derived using computer aid or mathematical modelling will be a significant process to employ (Wang, et al., 2008).

This project will be completed using mathematical modelling with involve of finite difference method in the laboratory using Matlab packages to resolve the formulas required to gauge and predict hydraulic transients due to shift on the hydraulic system.

Mathematical example or emulation on several stages let the investigation of the “a number of fixed and random impacts” and the methodology can be moreover progressed (Keramat, et al., 2012). The advances of technologies and support of computers makes the mathematical modelling is potential to be carried out easily, and the accuracy and validity of the computer simulations will persistent to progress (a, et al., 2000).

It is passable that the practice of facilitate mathematical model is fundamental and any simplification should be perfectly justified (Placeholder14). According to Alexandre Dit, Trombettoni and Dany, the investigation of any reduction model applied is fundamental. They also suggested that the period test is agreeable method to prove models of this sort. This analysis methods have been utilized since Archimedes period (Broens, et al., 2012).

The below issues are examined; what is the rate of clarification.

$$x = \frac{a + b}{(a - b)c}$$

“If a similar amount of a, b and c are recognised to lie in particular provided periods, by putting in that provided intervals the term for x would be range of x.

Difference mathematical ideas employed for assessing the pipe net transients is the procedure of Method of Characteristics calculations (MOC) and this section will be explained in details and matched to some different within the literature review Ouchiha, et al., (2012) .

Method of Characteristics is utilized in order to calculate the transients in the natural gas pipe network, the liquid is compressible, this means the transients are reduced in making damage to the pipes.

Basically, in the natural gas the pipe lines are involved a part of the storage facilities, so if there any transients happened it would be easy to detected.

Pipe type:

The magnitude of the fluid is necessary for the transient computations, also the length of the pipe has a huge impact, as the pipe is long the mass of the fluid is also bigger within the pipe (Chaudhry, 2014).

In addition, the elasticity of the pipes will influence the power of the phenomenon; this means, some sold pipes will show a higher level of hydraulic transient than the fixable pipes, that will resort to digest the shock waves informed (GomesdaRocha & Rachid , 2012).

Fluid type:

Actually, the fluids viscosity has a major impact, because it is one of the factors that locate the size of the hydraulic transients. Changes in the liquid flow velocity, means the faster shift happens, the bigger the acceleration, and the power (pressure) of the transients, which is established by the equation below.

Equation 5: force = Mass * Acceleration

$$F = MA$$

The other factor involves the characteristics of fluid is the magnitude of the gas locked within the liquid. The rising ratio of enclosed gas in the fluid, the bigger impacts of cavitation would be, in other hand the less the influence of hydraulic transients (Chaudhry, 2014), this because the gas will absorb the power of the transient.

Preventive Devices:

The main aim of defensive tools is to minimize the overall effectiveness of any hydraulic transient by shifting the capacity within transient into different forms, that dissolves the effectiveness (Meniconi, et al., 2012).

Actually, when these devices are perfectly chosen and fitted accurately, definitely it will reduce the hydraulic transients, however, the aim of the emulation in this plan is to detect whether the preventative tools are required, and their positions within the pipe systems (Milivojevic, et al., 2014).

There are some other factors involve in affecting the hydraulic transient, which are the how fast the valve closure or opening, coefficient of the friction inner the pipeline also resorts to cause impact. Essentially, the emulation will utilize a fixed, estimated value for the coefficient friction, and will emulate extra than one valve closing velocity to get the alternative of one factor (Cesana & Bitter , 2014). The project is significant, because whether the pipelines include water, oil, or several other liquids, it is vital which deterioration like that provided in figure 13 and figure 14 below.

There is prediction that the oil and some other minerals are likely to be run out by 2025 nearly in the most of the world will suffer from lack of drinking water.

Consequently, the situation will case a nature, human and the environment cost of explosion within the pipeline is likely to rise, and the condition should be stopped at whatever cost (Chena, et al., 2015).

Figure 13: Piston is used to reducing water hammer (Atta, 2011).

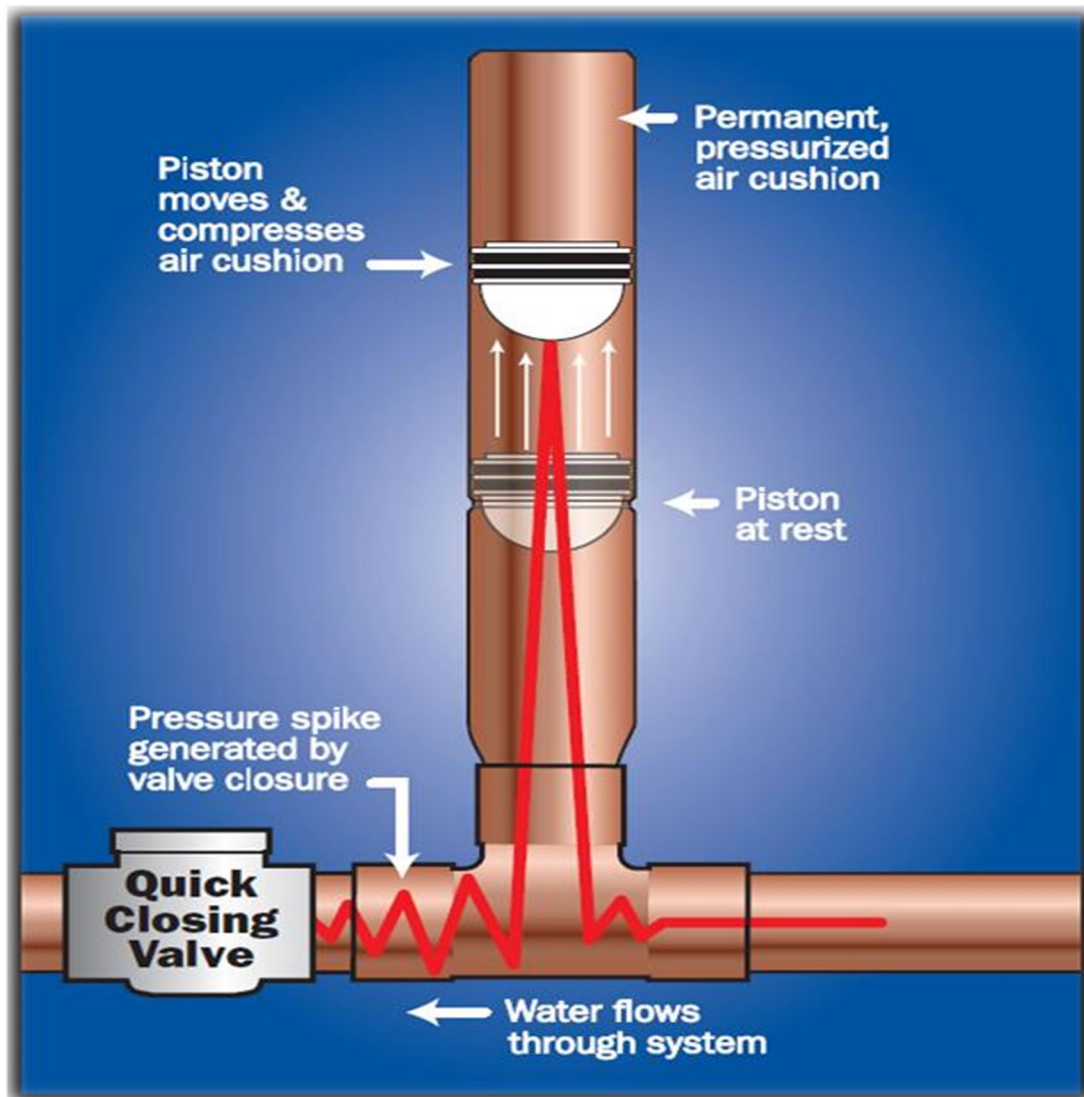
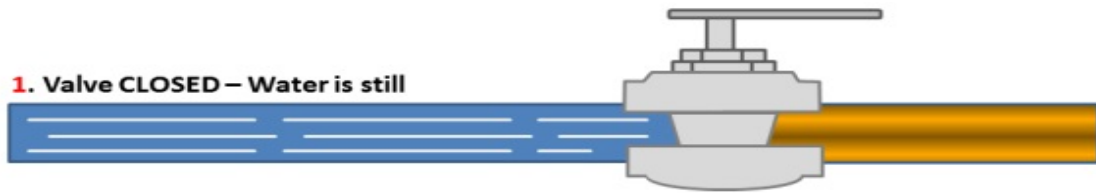
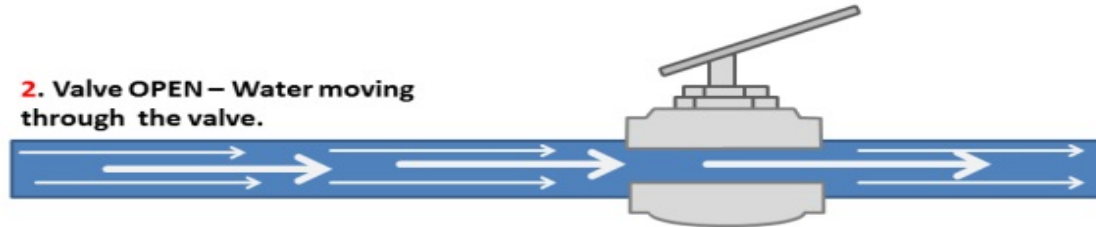


Figure 14: The piston is type for water hammer arrestors (Professionals, 2017)

1. Valve CLOSED – Water is still



2. Valve OPEN – Water moving through the valve.



**3. Valve CLOSES – WATER HAMMER
Pressure spike generated!**



4. Arrestor Installed - Spikes generated by valve closure arrested.

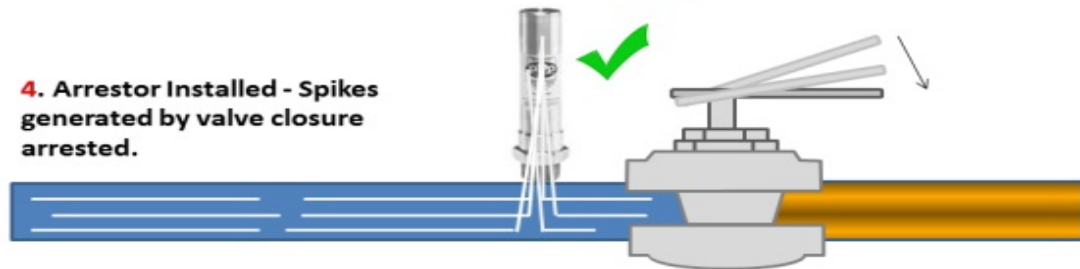


Figure 15: Propsed system for the project with varous dimater ranging between $0.05 < D < 1\text{m}$.



Straight Pipeline: $L = 1000\text{m}$, $D = 0.05\text{m}$



Step Pipeline: $L = 1000\text{m}$, $D = 0.1\text{m}$



Step Pipeline: $L = 1000\text{m}$, $D = 0.4\text{m}$



Step Pipeline: $L= 1000\text{m}$, $D= 0.6\text{m}$



Step Pipeline: $L= 1000\text{m}$, $D= 1\text{m}$

Chapter 6: The Explicit Finite Difference Methods Simulation (FDM):

Section 1.1 Introduction:

The explicit finite different methods are variously employed for analysing non-linear mechanical operations. In many procedures, the energy contained in the high iteration domain is small. By concentrating a synthetic mass scaling on the domain, the crucial time step can be raised ultimately without affecting minimized frequency (Olovsson, et al., 2005).

The simulation established modelling in general, and especially the explicit finite different method, significantly became the most powerful equipment in industry. Regarding the simulation of fast transient phenomena, explicit period integration is the dominating method (O'SULLIVAN & O'SULLIVANx, 2011).

The time step magnitude required to solve the transients is situational settlement of the integrated time planner. Explicit time combination is highly powerful in simulating some low fast processes, like sheet metal forming activities (Sousa, 2012).

A medium artificial rise in the loading average and moderate artificial magnitude measuring do not importantly shift the aim of the system.

The explicit finite different method design of low speed processes, most dynamic energy generally resides in the smaller frequency domain, whereas, the less important fractions are included in activated maximum iteration manners (Zhitnikov1, et al., 2016).

When designing and simulating a model using explicit finite difference method in Matlab environment, it is important to sketch a theoretical hydraulic system which can be tested.

The major issue could engineer face is trying to measure or emulate (Croft & Lilley, 1977). This would be one of the benefits from computational mathematical modelling - and the governing equations (continuity and momentum) could be calculated simultaneously. These two governing equations, involving the friction factor, will validate the precision of the simulations.

Section 1.2 System Explanation:

Usually, a hydraulic system for examining, starts with header reservoir or a tank with a constant liquid head of 600 metres. It is constructed with a pipe of 1000m in length, which is prevented with a quick closing valve.

The project is comparing between transient in individual and straight pipe, with these different in its diameter (D) which are, from (0.05, 0.1, 0.4, 0.6 and 1) all in meters. The valve time closure is also various which are T_{close} (0.05, 0.1, 0.3, 0.5 and 1) second, the time take to valve shut fully is maximum time available, which is (T-max).

Normally, the governing equations (continuity and momentum) are most important in this causes and they employed to calculate the simulation and modify the to give the magnitude and the direction of the transient's location.

Section 1.3 Theoretical Background:

According to Tylor series, the main concepts of finite difference method (FDM) is the replacement of the derivatives in the governing equations (continuity and momentum) equations by forward, backward and central difference (Croft & Lilley, 1977).

Section 1.4 Taylor Series:

Brook Taylor is an English mathematician (1685-1731), right now his theory is accepted as a mathematical expression or characterization for a task which involves an infinite series.

Normally, the three sections of the Tylor series, which are forward, backword and central differences give almost a close approach of the finite figure with its starts terms. The term of Tylor series is provided below (Croft & Lilley, 1977).

.

Equation 6:

$$f(x) = \sum_{n=0}^{\infty} \frac{f^{(n)}(a)}{n!} (x - a)^n$$

Where n = factorial value of real n

$f^{(n)}$ = the n^{th} derivative of the function f

By utilizing the numerical differentiation, the Tylor series term can be used to transients in pipeline, and the approaches can be displayed as shown below;

Forward Difference Approximation:

The forward approximation or distance is approached by testing how the function f change as X_0 raises. The first formula is imported and from that forward approximation could be translated for the function under consideration (Croft & Lilley, 1977).

Equation 7: Forward Difference Approximation:

$$\begin{aligned}
f(x_0 + h) &= f(x_0) + h \cdot f'(x_0) + \frac{h^2}{2!} f''(x_0) + \frac{h^3}{3!} f^{(3)}(x_0) + \dots \\
\frac{f(x_0 + h) - f(x_0)}{h} &= f'(x_0) + \frac{h}{2!} f''(x_0) + \frac{h^2}{3!} f^{(3)}(x_0) + \dots \\
f'(x_0) &= \frac{f(x_0 + h) - f(x_0)}{h} + O(h)
\end{aligned}$$

The approximation is depending on order $O(h)$. This indicates that, when (h) becomes small the error for forward difference approximation will decrease in a linear manner. This means, it will be more precise in the result.

Backward difference approximation:

The backward differences approximation is formed by examine, how the function varies as it decreases.

Equation 8: Backward Difference Approximation:

$$\begin{aligned}
f(x_0 - h) &= f(x_0) - h \cdot f'(x_0) + \frac{h^2}{2!} f''(x_0) - \frac{h^3}{3!} f^{(3)}(x_0) + \dots \\
\frac{f(x_0 - h) - f(x_0)}{h} &= -f'(x_0) + \frac{h}{2!} f''(x_0) - \frac{h^2}{3!} f^{(3)}(x_0) + \dots \\
f'(x_0) &= \frac{f(x_0) - f(x_0 - h)}{h} + O(h)
\end{aligned}$$

Clearly, this approximation is of order $O(h)$ too.

Section 1.5 Central Differences Approximation:

The central difference approximation is more complicated than other equations, and it can be divided into several parts as displayed below. Normally, the function $F(x)$ will be evaluated first to positions between two points (Croft & Lilley, 1977).

Equation 9: Central Difference Approximation (section 1)

$$\begin{aligned}
f(x_0 + h) - f(x_0 - h) &= \left[f(x_0) + h.f'(x_0) + \frac{h^2}{2!}f''(x_0) + \frac{h^3}{3!}f^{(3)}(x_0) + \dots \right] \\
&\quad - \left[f(x_0) - h.f'(x_0) + \frac{h^2}{2!}f''(x_0) - \frac{h^3}{3!}f^{(3)}(x_0) + \dots \right] \\
&= 2. \left[h.f'(x_0) + \frac{h^3}{3!}f^{(3)}(x_0) + \dots \right]
\end{aligned}$$

This will take to;

Equation 10: Central Difference Approximation (section 2)

$$\frac{f(x_0 + h) - f(x_0 - h)}{2.h} = f'(x_0) + \frac{h^2}{3!}f^{(3)}(x_0) + \dots$$

Eventually, the central difference approximation can be written as,

$$f'(x_0) = \frac{f(x_0 + h) - f(x_0 - h)}{2.h} + O(h^2)$$

The central difference approximation is precise to order $O(h^2)$ and therefore, for a tiny value of h , normally, better than forward and backward approximations, the fault of the approximation is provided below,

Equation 11: Error of a Central Difference Approximation

$$\epsilon_c \equiv f'(x_0) - \frac{f(x_0 + h) - f(x_0 - h)}{2.h} = -\frac{h^2}{3!}f^{(3)}(x_0) + \dots$$

Section 1.6 The Explicit Finite Difference:

This is another numerical technique used to solve Hyperbolic Partial Difference equations, which are involved in finite difference methods. This procedure could be directly applied to the pipe network processes, and there is a three type of faults are detected.

- Iteration Errors, these could be clearly detected as a big deference between the particular solation and the numerical solution.
- Modelling faults, can be issued by the difference between the exact solution and the physical motion through the system
- Discretisation faults, these are errors can be between the exact solution and the partial differential equations

The governing equations (continuity and momentum) equations are partial differential formulas, and they can be minimized into differencing equations with fulfilment of the central and backward approximations (Chaudhry, 2014).

Equation 12: Finite difference Equation shape.

$$\begin{aligned}\frac{\partial H}{\partial t} &= \frac{H_i^{j+1} - \bar{H}_i}{\Delta t} \\ \frac{\partial Q}{\partial t} &= \frac{Q_i^{j+1} - \bar{Q}_i}{\Delta t} \\ \frac{\partial Q}{\partial x} &= \frac{Q_{i+1}^j - Q_{i-1}^j}{2\Delta x} \\ \frac{\partial H}{\partial x} &= \frac{H_{i+1}^j - H_{i-1}^j}{2\Delta x}\end{aligned}$$

This would lead to,

$$\bar{H}_i = 0.5 \left(H_{i+1}^j + H_{i-1}^j \right)$$

And

$$\bar{Q}_i = 0.5 (Q_{i+1}^j + Q_{i-1}^j)$$

These two equations above can be generated as below, and it is perfect to deals in Matlab environment to create a code.

Equation 13: Equation for a Matlab,

$$Q_i^{j+1} = \frac{1}{2} (Q_{i-1}^j + Q_{i+1}^j) - \frac{1}{2} gA \frac{\Delta t}{\Delta x} (H_{i+1}^j + H_{i-1}^j) - R \Delta t \bar{Q}_i | \bar{Q}_i$$

$$\text{And } H_i^{j+1} = \frac{1}{2} (H_{i-1}^j + H_{i+1}^j) - \frac{1}{2} gA \frac{\Delta t}{\Delta x} \frac{a^2}{gA} (Q_{i+1}^j + Q_{i-1}^j)$$

The consideration that must be taken into the account, is the stability criterion, because if the moulding is not meets the requirement or went beyond the stability criterion the errors will be occurs. The stability criterion is provided below;

Equation 14: stability Criterion for simulation

$$\frac{a \cdot \Delta t}{h} < 1$$

In order to complete the simulation for the system it required the initial conditions and boundary condition equations and they will be provided with the explanations below.

Section 1.7 Initial Conditions:

The initial conditions are required to calculate the transient situations. Normally, the initial conditions matched to first steady state motions. The study flow can be considered a particular issue, in which the time differences of flow speed, $\partial V / \partial t$ and of pressure, $\partial p / \partial t$ are both equal to zero. This means, the governing equations (continuity and momentum) for steady motions will be derived from these two formulas by putting expressions explaining the local changes of pressure and flow speed with respect to the time t; e.g., $\partial p / \partial t$ and $\partial V / \partial t$ are equal to zero (Chaudhry, 2014).

If the initial status matched to steady flow and all the expressions of the governing formulas to be involved in the test, then the initial conditions can be determined. However, almost of the engineering purposes, a quantity of terms of the governing equations are tiny when matched to the other

expression and should be ignored. This extremely minimizes the test without importantly impacting the precision of the computed outcome (Chaudhry, 2014)

Equation 15: Initial Conditions:

$$Q_i = Q_0 \quad \text{where } Q_0 \approx 1 \text{ m}^3/\text{s} \quad \text{where } 1 < i < N + 1 \quad (\text{with } N=L/\Delta x)$$

$$H_i = H_{res} - (i - 1) \cdot \frac{fL}{2gD \frac{L}{\Delta x} A^2} \cdot Q_0 \quad \text{where } 1 < i < N + 1$$

Section 1.8 Boundary Conditions:

The project is dealing with a mathematical boundary conditions, and they are not connected to the boundary conditions of laminar motion (Chaudhry, 2014). These could be some major causes of error in pipeline simulations.

The boundary conditions are very important sections in simulating the pipe network, and they are excessive limit conditions of the system as disagree to the initial conditions (Huang, et al., (2016)).

Normally, the boundary conditions are inclusive in the Matlab environment and their precision will be shown clearly in the final simulation. According to Izquierdo and Iglesias they are focus nearly most of their article investigating on the boundary conditions, as they refer that it is a failing of other different simulation (Li, et al., 2016).

They also refereed to various ways in which the boundary condition could be as to some stages. This can be minimized the connections and the tools which exist in the pipeline system. The boundary conditions are also considered by Kochupillai, Ganesan, and Padmanabhan, this because of their importance and impact to the systems.

And their simulations are related to the Fluid Structure Interactions (FSI) and the flow speed. It is explained below in details the outcome of the different systems that integration of simulations.

Boundary Conditions (Chaudhry, 2014): A mathematical representation of the reservoir on the left end side and valve on the right side at all period.

Equation 16: Boundary Conditions

$$H_{i1} = H_{res} \quad \text{where } H_{res} = 600 \text{ m (Reservoir level above datum)}$$

$$Q_{i1} = Q_{i2} + \frac{gA}{a}(H_{res} - H_2) - R\Delta t Q_{i2}|Q_{i2}| \quad \text{where } R = f/2 \cdot D \cdot A$$

$$Q_{iN+1} = \begin{cases} Q_0 \left(1 - \frac{t}{T_{clos}}\right) & \text{for } 0 \leq t \leq T_{clos} \\ 0 & \text{for } t > T_{clos} \end{cases}$$

$$H_{iN+1} = H_N - \frac{a}{gA}(Q_{iN+1} - Q_N) - \frac{a}{gA}R\Delta t Q_{iN}|Q_{iN}|$$

This will be depending on the t-close. If the value of the time close is choose very small, the valve will shut down quickly, and if the t-close value chosen to be a big value, the valve closing will take longer.

Chapter 7 - Results:

Section 1.1 The consequences

The generated in Matlab was is run firstly for a single and straight pipe of length of 1000 meters, as explained above. Specific presumptions made with connection to the situation;

- The pipe walls are thin and fixed thickness
- The pipe is cylindrical in shape
- The is no potential of locked air within the system, and there are no cavitation problems (Brennen, 2014)
- The pipe is straight and length of 1000 meters

- There is a flexible connection between the liquid and the pipe walls (Chaudhry, 2014).
- All the non-linear sonic phenomenon is disregarded (Izquierdo & Iglesias, 2002).

The linkage Matlab settings for parameters of the pipe diameter, grid spacing, time steps, the valve time closure and friction coefficient are all illustrated below, with all clarifications where significant. The propositions above guarantee that this is ideal system, and the results are accurate.

For all modelling and simulations, the following details are considered;

Reservoir height (H_{res}) = 600m

The length of the pipe = 1000

Darcy- Weisbach friction factor (f) = 0.00

The grid spacing (X) is ranging from (10,5,1,0.5,0.1 and 100) meter

The time step t_s = 2s

T_{close} = (0.5s, 0. 1s, 0. 3s, 0. 5s and 1s)

The code run time = T_{max}

The length of the pipe is represented the space from the reservoir to the valve, which is 1000 meters in all situations.

The grid spacing (X), is small than the length of the pipeline. This means, if the length of the pipeline is divided by the grid spacing of (X) it will give the number of the points along the pipe length, where the pressure will be measured.

The valve closure time (T_{close}), is the number of time chose to run the code several times and in this test, it chosen the time vary from (0.5s, 0. 1s, 0. 3s, 0. 5s and 1s). of time taken in order to the valve close completely.

The diameter of the (D) is the interior diameter of the pipe, and the wall thickness is neglected, which is supposed to be sold.

The time steps (t_s) is the time taken to the close the valve completely, which is (T_{max}).

The consequences are, the straight pipe is compared with those gained by (Chaudhry, 2014). The transient state is directly proportional to the pipe diameter. The pipe with small diameter is more

effected by high pressure and more hydraulic transient can be occurred, whereas, the bigger pipe diameter is less effected by hydraulic transient.

Section 1.1 Test 1: The code run for constant diameter of 0.4 m, constant grid spacing of 0.5m and different valve closure times of (0.3s, 0.5s and Tmax), for ISO grade oil of 32.

During the test, it is noticed that, the valve closure has a major impact with pressure increase. The quicker valve close is can cause pressure shock and the transient will be bigger.

When the time of the valve closure is take small at 0.3s the pressure rise quickly from 600m to above 2000m, but in the other hand when the time closure taken greater at 0.5s and Tmax, the pressure can reach to the maximum length of the pipe, but it will reach slowly and effect will be minor.

E.g. “when someone punched at the face in smaller time which is fast, this can be painful, whereas, if someone punched in greater time or slowly it will be minor and does not affect much”.

This will show that if the time chosen for the valve closure is great, it will take time to reach the maximum pressure height and the opposite. These results can be shown clearly on the three graphs of different valve closure time below. In the tow graphs of valve closure time of (0.5s and Tmax) the behaviours of the pressure are rising slowly comparing with the first graph of the valve closure time of (0.3s).

In the first result the pressure of the valve closure time of 0.3s, all pressures are started in one point of approximately 600m and they move to about 1512m, 1094m, 780m height respectively for these different valve closure time 0.3s, 0.5s and Tmax.

In the second result when the valve closure time is chosen at 0.5s, all pressures began in same points of approximately 600m and their behaviours can show as rising. For the 0.3s, 0.5 and Tmax the pressures are increased to almost 2078m, 2064m and 1267m respectively.

For the third graph, when the valve closure time taken at Tmax, the pressures are also stared in same point of nearly 600m. The behaviours of the pressures are moving up slowly and it can display perfectly on the graph in figure 16. They reached height of 2095m, 2090m and 1636m in series of 0.3s, 0.5s and Tmax.

The results are demonstrated that the valve closure time does not mean the pressure will not reach to the maximum points, but it will take time to reach. As it displayed in three different graphs, it shown clearly the valve closure time in the 0.3s and 0.5s are almost reaches together at the height point, but the Tmax is still far to reach the maximum point.

The results of the pressure effect are illustrated below in the figures 16, 17 and 18. The sonic velocity (a), friction factor (f) and the time take to completely run the code are likely to be consistent. The increase of pressure has a connect with the Tclose. Three graphs are chosen to explain the behaviour of the pressure with different valve time closure of (0.3s, 0.5s and Tmax).

Figure 16: The code run for pipe dimeter of 0.4m and valve closure time of 0.3s for ISO 32.

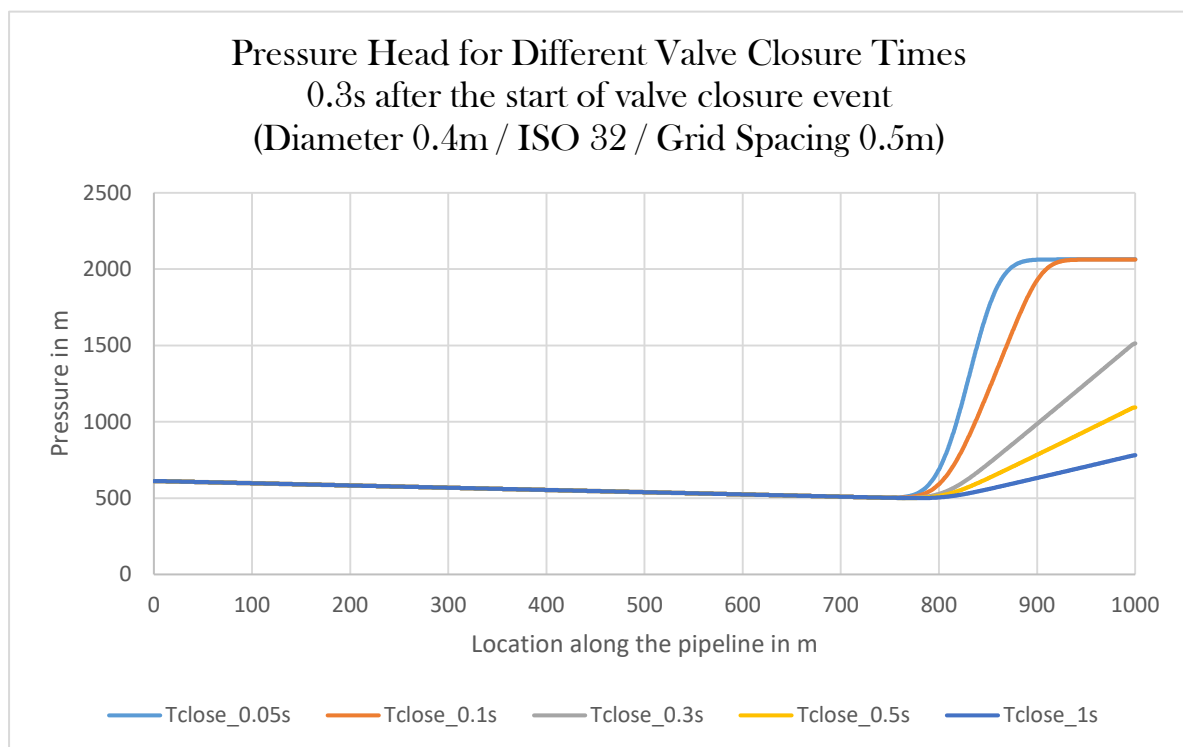


Figure 17: The code is run with pipe dimeter of 0.4m, valve time close of 0.5s for ISO 32.

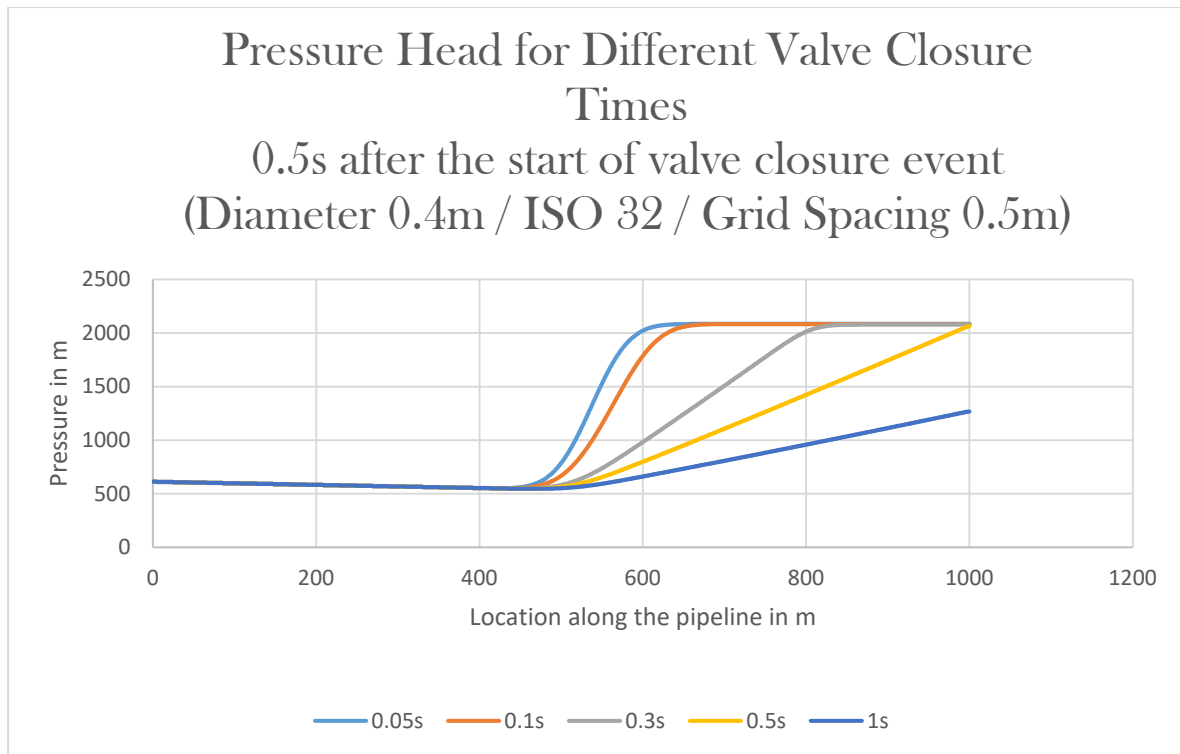
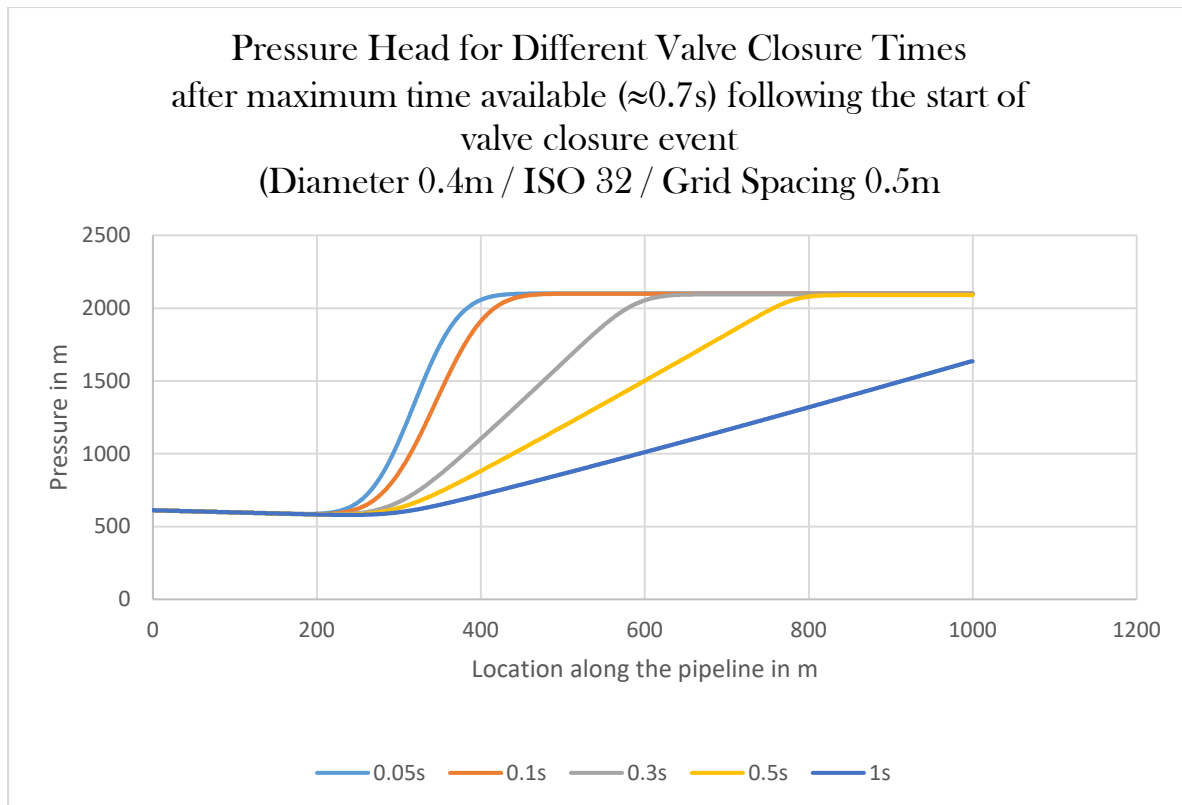


Figure 18: The code is run with pipe diameter of 0.4m, valve time close of Tmax for ISO 32.



Section 1.2 Test 2: The code run for constant valve closure time of 1s, constant grid spacing of 0.5m with different pipe diameter ranging from (0.1m, 0.4, 0.6 and 1m) for grade oil of ISO 32.

The aims of the report are to examine and determine, how the change in pipe diameter can affect the result of the pressure in the pipe.

During the test by operating the code several times and the results are clearly different in the pressure rising.

When the valve closure time is chosen to be constant with value of (1s) and different size of diameter (D) of (0.1, 0.4, 0.6 and 1) meter, grid spacing (x) of 0.5m for grade of oil ISO 32.

The consequences are as displayed on the figure 19 below.

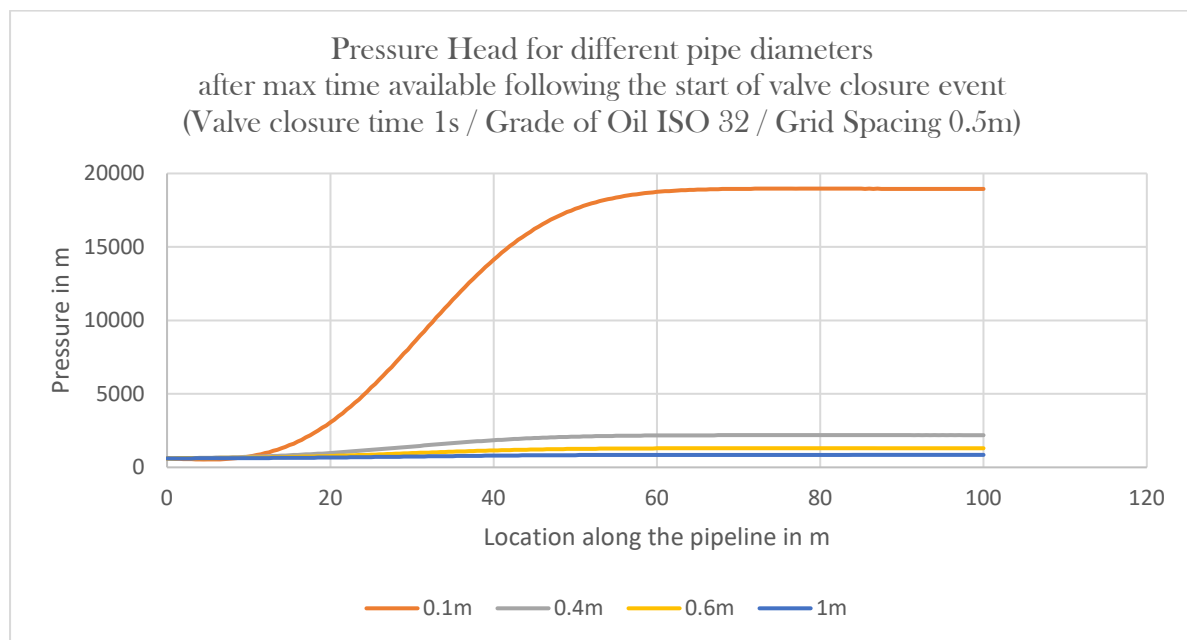
The result show that the smaller diameter of 0.1m is more effected with the pressure rise, and the pressure raised from almost 600 to almost 18950m, when comparing with the greater diameter of 1m, the pressure is low and it raised from 600 to 850m.

This mean the smaller diameter is greater pressure rising and this can be result of hydraulic transient in the pipeline. The results also show that the greater diameter of 1m is takes short time than the small diameter to elapsed.

The sonic velocity (a) is big different between the greater dimeter and the smaller dimeter, in the smaller dimeter of (0.1) the sonic velocity is very high, and this can cause high pressure which can lead to hydraulic transient.

However, in the greater dimeter of 1m, the velocity is slow. The investigation can show that the level of the hydraulic transient has a relationship with the size of the pipe dimeter and the length of pipe.

Figure 19: The code run for pipe dimeter of (0.1m, 0.4m, 0.6m and 1m) and valve time close of 1s.

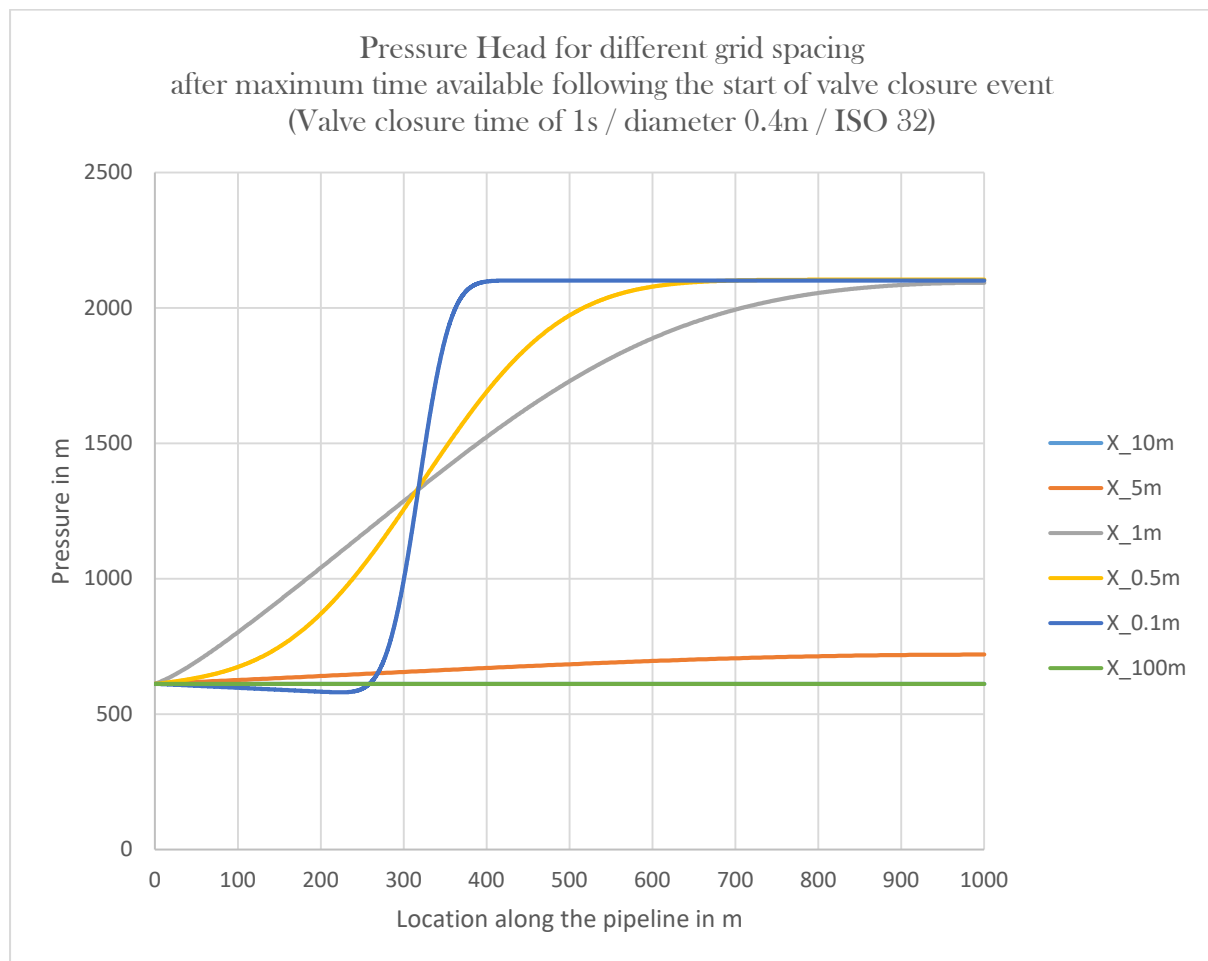


Section 1.3 Test 3: The code run for one ISO grade oil of (32), and constant dimeter of (0.4), constant valve closure time of (1s) and different grade spacing of (X) ranging from (10m, 5m, 1m, 0.5m, 0.1m and 100m).

Code is run for several times for different grid spacing (X) ranging from (10,5,1,0.5,0.1 and 100) meter, to investigate the pressures behaviours in the pipeline. The test is carried out for ISO grade oil of 32, constant dimeter of 0.4m and constant Tclose of (1s). The results for all grid spacing are different. The smaller grid spacing is higher pressure rising. As it can show on the graph below, all the test from different grid spacing are started at same point and they rise depending to their size. The smaller dimeter size of (0.1m, 0.5m and 1m) the pressure raised highly and they recorded above 2000m, in the other hand the grid spacing with (5m, 10m and 100m) are showing that pressure is very low. Furthermore, they are almost close to each other. For the three-large grid spacing of (5m, 10m and 100m) their records are nearly

720m, 612 and 612m. Two bigger grid spacing are identical and their pressures are very low. This means, the smaller grid spacing is generate many points on the pipeline and it can take long time to calculate the final result. And the result will be very accurate comparing with the bigger grid spacing. However, small grid spacing also can be include with tiny errors which is normally neglected. If these small errors added together will make difference and can impact the accuracy of the result. The figure 20 below illustrates all necessary details.

Figure 20: The code run for different grid spacing of X (10m, 5m, 1m, 0.5m, 0.1m and 100m).



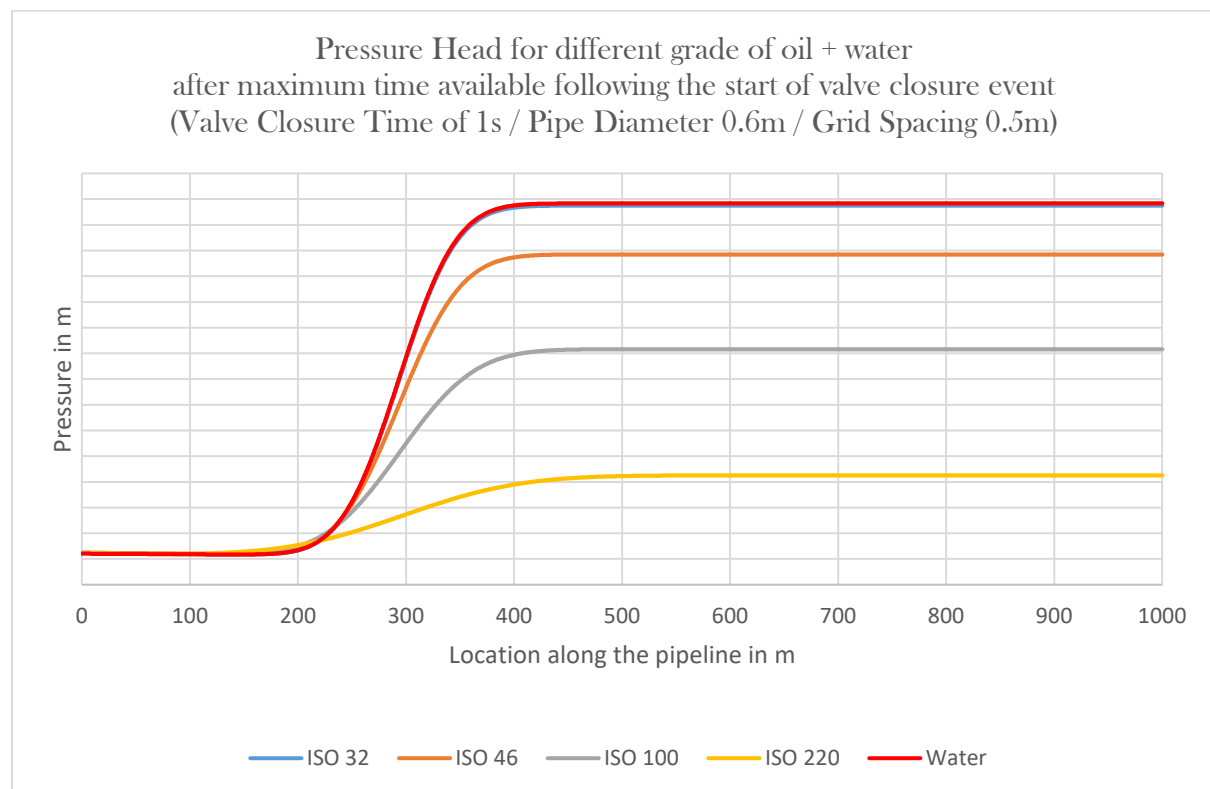
Section 1.4 Test 4: The code run for constant valve closure time of (1s), grid spacing of 0.5m and constant dimeter of (0.6m), Tmax and different fluids of grade oil of ISO 32, 46, 100 and 220 + water.

The run for different type of ISO grade oil and water with constant grid spacing of 0.5m, Tmax of 1s and dimeter of 0.6m. The experiment show that all fluids are started in same points of approximately 600m, but the pressure rising of the water is very high when compared with the rest of the fluids.

The test can indicate that the bulk modules of the fluids and the dynamic viscosity can have major effect on the pressure in the pipeline. In addition, the incompressibility of the fluids. In this case, the water is incompressible so the result of pressure rising is too extremely higher than other fluids.

This will be result of the pipeline with water is most effected with hydraulic transient. The result illustrates that the most pressure increasing is water and followed by ISO 32, 46, 100 and 220 respectively. Therefore, the pipes carrying water and ISO 32 are more likely to be damage by water hammer. Figure 21 displayed below to show the behaviours.

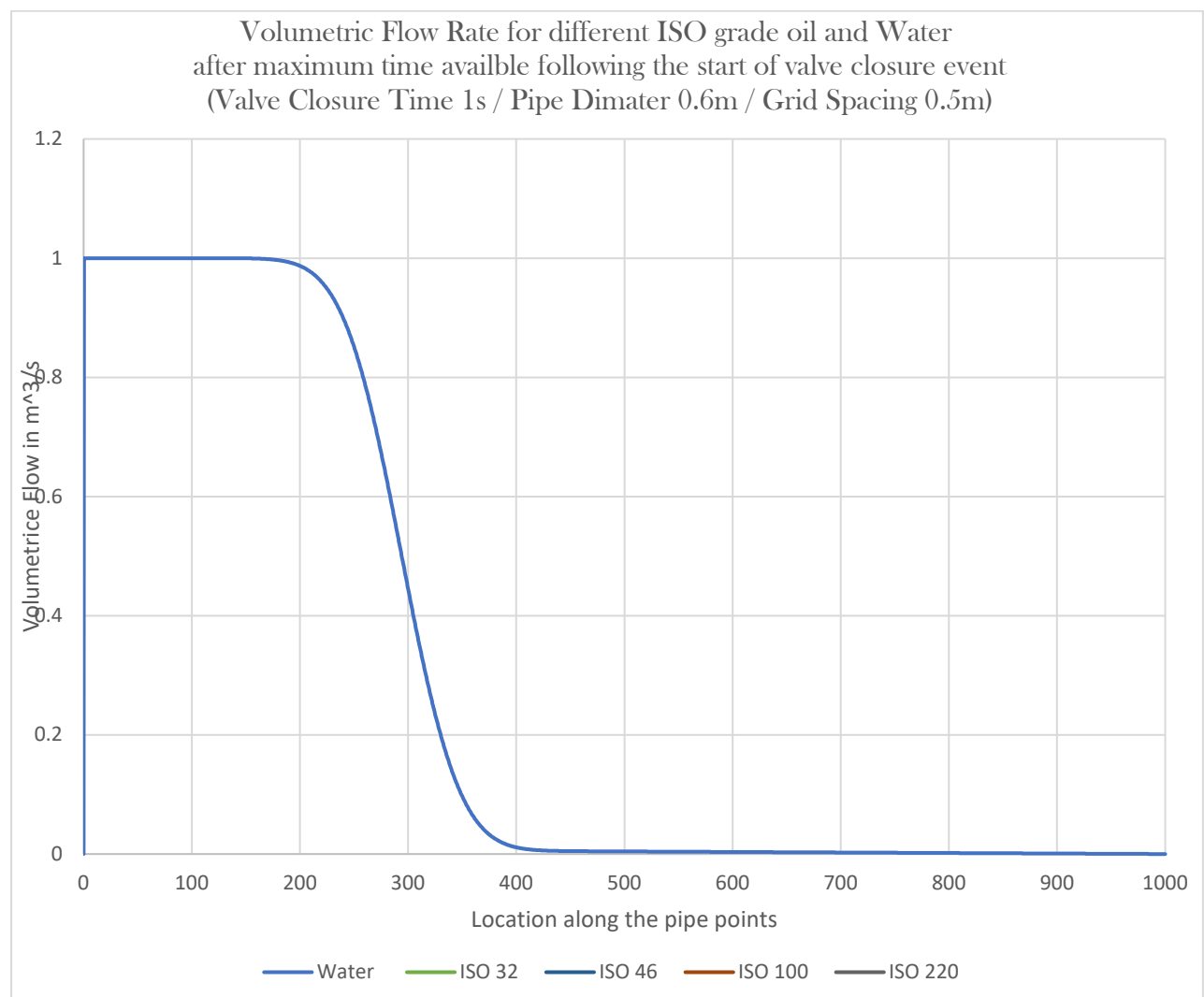
Figure 21: The code tested for different grade oil of ISO 32, 46, 100, 220 and water.



Section 1.5 Test 5: The code run for Volumetric Flow Rate of Different Grade Oil ISO 32, 46, 100 and 220 + Water, after Tmax, with constant of valve closure time of (1s) and constant pipe diameter (D) of (0.6m) and grid spacing (X) of 0.5m.

This test to show the volumetric flow rate of different fluids can slow down to the rest when the valve is fully closed. All selected fluids can be displayed identically or similar to each other. The diameter of the pipe or the grid spacing, Tmax does not affect the result of volumetric flow rate. On the graph in figure 22 below the water is presented clearly as shown but the rest of fluids also present.

Figure 22: The code tested for volumetric flow rate and different grade oil of ISO 32, 46, 100, 220 and water.



Chapter 8 – Conclusions and Discussions:

The project is perfectly done for computer modelling of hydraulic transient for different types of fluids of ISO 32, 46, 100, 200 and water. The initial comparison is carried out for the straight pipeline of 1000m in length and different diameter of (0.05m, 0.1m, 0.4, 0.6 and 1m) as shown in the page of proposed project.

The experiments show that the pressure head for the straight pipe with smaller diameter are likely high. The valve closure time also can be a major problem within the pipe systems, the volumetric flow rate of the all different fluids are not affected while the valve closure time or the difference of the pipe diameter size or the grid spacing. The result for selected fluids are similar and identical for the volumetric flow rate.

The grid spacing (X) has a major effect in the pipe system, the smaller grid spacing offers a more accurate result, but there will be small errors and these errors when added together will make a big difference and the result will be inaccurate. Small errors occur because of the longer time taken for calculations.

The pipe diameters selected for this simulation are greater than the domestic system which normally uses small pipe diameter measure in centimetres. The simulation refers to pipe sizes which are used for transmission pipes, not for the houses. The experiment shows that the smaller diameter pipe is mostly affected with water hammer because of the amount of fluid in pipe. Numerical considerations are taken into account and therefor the recommendations can be concluded from the simulation. Making such pipes strong enough to withstand Joukowski pressures and forces may not be economical. The greater pipe diameter and the valve closure time are more important and it is preferred that when the valve closes extra consideration has to be taken, especially with smaller pipe diameters.

The resilience of pipe materials can also affect the water hammer magnitude and duration. This mean the rigid pipe is more likely to be affected by hydraulic transient. These comments on the design should help pipeline engineers as it will point to the appropriate materials and pipe dimeters along with the pipe shape for the specific applications.

Typically, doubling the diameter of the pipe means multiplying the pipe volume by four and the result can provide a good approximation to the magnitude of the wave needed for the pipeline.

The phenomenon of hydraulic transient has been recognised for centuries - long before scientists like Zhukovsky found a way of measuring it (Tijsseling & Anderson, 2007). The basic pipework extension examined above has been found in systems from the very earliest domestic installations.

The reality is that this procedure of protecting hydraulic transient was efficient and significant for engineers to not only accept and study the advanced concept, but also to be open to traditional solutions.

Perhaps the old traditional solutions to this sort of engineering problem can be as effective - or almost as effective - as the calculated advanced solution. Using the tradition procedures could well be more economical and time-saving especially on the complex installation.

Chapter 9 – Recommendations

Future research will compare Matlab simulation generated for this project with the other models set on the WCM procedures recommended by Wood (Wood, 2005), and on the way of assessment suggested by (Epstein, 2008).

(Izquierdo & Iglesias, 2004) are suggested that the population in the cities is going to increase considerably and forecasts of water shortage indicate that there will be a greater demand for fresh water and therefore the importance of better protection of water pipes.

If this happens the engineers will have to use the method which can provide them with a quicker and more precise respond to issues of hydraulic transient.

Pipeline engineers must ensure the safety of the systems and follow the standard regulations by testing every project carried out for the safety issues. But with more complex pipe systems it is very difficult to get accurate results.

Water suppliers in cities and town appear to be in more difficulty than suppliers of oil through pipelines. It is easy to judge water transient in a basic pipeline whereas, it is hard to do so when the system became more complex, because the branches of the pipes and the length as well as the diameter of the pipe will affect the calculation of the result.

It would be a big advantage if a complex system could be broken down into sections as suggested by (Izquierdo & Iglesias, 2004). But, of course, that is not easy to do and it would

take a lot of complex work. It is a problem that could become worse in the not-too-distant future and it is a problem that has to be looked at now

Chapter 10 - References:

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(David, 2017)

Chapter 11- Appendix:

Completed Code:

```
clc
clear all
tic
disp('CODE RUNNING...')
%%%Liquid Properties
D=0.4; %%Diameter of the pipe in m (0.05m, 0.1m, 0.4m, 0.6m, 1m) (for
tmax, grid spacing 0.5m, Tclose 1s, GO 32)
Tclose=0.05; %s Time valve close (0.05s, 0.1s, 0.3s, 0.5s, and 1s) (for
grid spacing 0.5m, GO 32 and the 3 Time: 0.3s, 1s, tmax))
GO=32; %%Choice of ISO oil grade between 32, 46, 100 and 220 (1 for water)
(for tmax, grid spacing 0.5m, Tclose 1s, D 0.6m)
Time=10; %choice 0.2, 0.5 or tmax (10)
X=100; %%grid spacing that will be a user input (h default 0.5) (for tmax,
Tclose 1s, GO 32, D=0.4)

if GO==32
    Bulk_M=1.8e9; %%Bulk Modulus of the fluid oil ISO 32
    KV = 32E-6; %% Kinematic_Viscosity: m^2/s
    density=857; %%density in kg/m^3
elseif GO==46
    Bulk_M=1.3e9; %%Bulk Modulus of the fluid oil ISO 46 (1.3e9)
    KV = 46E-6; %% Kinematic_Viscosity: m^2/s
    density=861; %%density in kg/m^3
elseif GO==100
    Bulk_M=0.6e9; %%Bulk Modulus of the fluid oil ISO 100
    KV = 100E-6; %% Kinematic_Viscosity: m^2/s
    density=869; %%density in kg/m^3
elseif GO==220
    Bulk_M=0.1e9; %%Bulk Modulus of the fluid oil ISO 220
    KV = 220E-6; %% Kinematic_Viscosity: m^2/s
    density=875; %%density in kg/m^3
elseif GO==1
    Bulk_M=2.15e9; %%Bulk Modulus of the fluid water
    KV = 1E-6; %% Kinematic_Viscosity: m^2/s
    density=998; %%density in kg/m^3
end
rho = density;
K = Bulk_M; %%Bulk modulus in N/m2
Vis = density*KV; %0.000146; %input('Dynamic Viscosity of fluid in kg/ms =
');
Liquidpress = 101300; %input('Gauge pressure of fluid in N/m2 = ');
%%%Pipe Properties
% D = 0.6096; %input('Pipe diameter in meters = ');
Wt = 0.0508; %input('Pipe wall thickness in meters = ');
E = 141e9; %input('Pipe materials Youngs modulus in N/m2 = ');
L = 1000; %input('Pipe length in meters = ');
Rough = 1.5e-5; %input('Pipe internal Absolute surface roughness in meters =
');
while Rough <=0
```

```

    Rough = input('Pipe internal Absolute surface roughness in meters = ');
end
% fc = input ('Pipe internal friction coefficient = ');
Area = (pi*(D/2)^2);
%%%Valve Properties
Cl = Tclose;%input('Valve closure time in seconds = ');
%%%Reservoir properties
Z = 600;%input('Reservoir height in meters = ');
%%%Gravitational Acceleration
g = 9.81;%input('Gravitational acceleration in m/s2 = ');
%%%Sonic Waves Speed Within Pipe c
C = sqrt(1/(rho*((1/K)+(D/(E*Wt)))));
% disp(c);
%%%Piezometric Head Within Pipe
H = ((Liquidpress/(rho*g))+Z);
%%%Grid Spacing
% X = 0.5;%input('Input Grid spacing in x direction = ');
while (X<=0) || (X>L) || rem(L,X)~=0
    X = ('Input Grid spacing in x direction = ');
end
%%%Time Step
Ts = 0.00001;%input ('Input Time step in seconds = ');
% Ts=0.9*X/C;
while (((Ts*C)/X)>1) || (((Ts*C)/X)<=0)
    Ts = input ('Input Time step in seconds = ');
end
%%%Initial conditions at time 0
%%%Flow rate
Q = 1;
%%%Fluid dynamic velocity
Fv = (Q/Area);
%%%Reynolds Number of Fluid
Re = (((rho)*(Fv)*(D))/(Vis));
%%%Nodes within pipe
Np=L/X+1;
%%%Graph X axis
Xaxis = linspace (0,L,Np);
%%%Hydraulic Impedence
Hyd = (sqrt(rho*K))/Area;
%%%Maximum Surge Pressure of Fluid
Hmax = ((Hyd*Q)*0.0001019977334)*3)+H;
%%%Colebrooke-White equation for friction coefficient (fc)
while Re < 4000
    disp('Fluid is not turbulent')
    break
end
dummy_variable=10;
fc = 0.00001;
while dummy_variable>1
    A = 1/sqrt(fc);
    B = -2*log10((Rough/(3.71*D))+(2.51/(Re*sqrt(fc))));
    if abs(A-B)<0.01 || fc>1
        dummy_variable=0;
    end
    fc=fc+0.00001;
end
fc
%%%Pipe-resistance
Res = (fc/(2*D*Area));
%%%Darcy Weisbach Equation for Head Loss Due to Friction if Re>4000
Headloss=((fc)*(L/D)*((Fv^2)/(2*g)));

```

```

%%%Pipe Flow Rate Vector
PVQ=repmat(Q,1,Np);
%%%Pipe Head Pressure Vector
PVH=repmat(H,1,Np);
for i = 1:Np
    PVH(1,i) = H-(i-1)*((fc*L)/(2*g*D*(L/X)*Area^2));
end
PVH1=PVH;
%%% Boundary Condition at Reservoir Node
Hvec(1,1) = PVH(1,1);
Qvec(1,1) = PVQ(1,2)+((g*Area)/C)*(PVH(1,1)-PVH(1,2))-
Res*Ts*PVQ(1,2)*abs(PVQ(1,2));
%%% Boundary Condition at Valve Node
Hvec(1,Np) = PVH(1,Np-1)-(C/(g*Area))*((PVQ(1,Np))-PVQ(1,Np))-
(C/(g*Area))*Res*Ts*PVQ(1,Np-1)*abs(PVQ(1,Np-1));
Qvec(1,Np) = Q;
%%%Populate Flow Vector With Q
Qvec(1,2:Np-1) = Q;
%%%Time taken
if Time>(L/C)
    Time = (L/C);
end
%%%Number of Iterations
Iter = (Time/Ts);
tmax=(L/C);
t = 0;
tt=0;
HP = PVH;
Flow = Qvec;
while t < Iter
    t=t+1;
    for c = 2:Np-1
        Qvec(1,c) = 0.5*(Flow(1,c-1)+(Flow(1,c+1))-
0.5*(g*Area)*(Ts/X)*(PVH(1,c+1)-PVH(1,c-1))-
Res*Ts*(0.5*(Flow(1,c+1)+Flow(1,c-1)))*abs(0.5*(Flow(1,c+1)+Flow(1,c-1))));
        HP(1,c) = 0.5*(PVH(1,c-1)+PVH(1,c+1))-
0.5*(Ts/X)*(C^2/(g*Area))*((Flow(1,c+1))-(Flow(1,c-1)));
    end

    HP(1,1) = H;
    Qvec(1,1) = Qvec(1,2)+((g*Area)/C)*(HP(1,1)-HP(1,2))-
Res*Ts*Qvec(1,2)*abs(Qvec(1,2));

    if (tt+Ts)<Cl
        Qvec(1,Np) = Q*(1-((tt+Ts)/Cl));
    else
        Qvec(1,Np) = 0;
    end
    HP(1,Np) = HP(1,Np-1)-(C/(g*Area))*((Qvec(1,Np))-Qvec(1,Np))-
(C/(g*Area))*Res*Ts*Qvec(1,Np-1)*abs(Qvec(1,Np-1));

    tt=(tt+Ts);
    Flow=Qvec;
    PVH=HP;

    %         figure(1)
    %         subplot(2,1,1);
    %         plot(Xaxis,HP,'b')
    %         axis([0 L 0 Hmax])

```

```

%         title('Piezometric Head Pressure')
%         pause(0.0000001)
%
%         subplot(2,1,2);
%         plot(Xaxis,Qvec,'b')
%         axis([0 L -(Q/10) Q+0.025])
%         title('Volumetric Flowrate')
%         pause(0.0000001)

end
Xx=[0:X:L];
Q=Qvec;
H=HP;
%%FOR CHANGE OF VALVE CLOSURE TIME*****
% xlswrite('Result_Tclos.xlsx',Xx(:),'Pressure1','A2:A2002')
% xlswrite('Result_Tclos.xlsx',Xx(:),'Pressure2','A2:A2002')
% xlswrite('Result_Tclos.xlsx',Xx(:),'Pressure3','A2:A2002')
% if Time==0.2
%     if Tclose==0.05
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure1','B2:B2002')
%     elseif Tclose==0.1
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure1','C2:C2002')
%     elseif Tclose==0.3
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure1','D2:D2002')
%     elseif Tclose==0.5
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure1','E2:E2002')
%     elseif Tclose==1
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure1','F2:F2002')
%     end
% elseif Time==0.5
%     if Tclose==0.05
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure2','B2:B2002')
%     elseif Tclose==0.1
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure2','C2:C2002')
%     elseif Tclose==0.3
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure2','D2:D2002')
%     elseif Tclose==0.5
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure2','E2:E2002')
%     elseif Tclose==1
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure2','F2:F2002')
%     end
% else
%     if Tclose==0.05
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure3','B2:B2002')
%     elseif Tclose==0.1
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure3','C2:C2002')
%     elseif Tclose==0.3
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure3','D2:D2002')
%     elseif Tclose==0.5
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure3','E2:E2002')
%     elseif Tclose==1
%         xlswrite('Result_Tclos.xlsx',H(:),'Pressure3','F2:F2002')
%     end
% end
%%FOR CHANGE OF PIPE DIAMETER *****
% xlswrite('Result_Diameter.xlsx',Xx(:),'Pressure','A2:A2002')
% % xlswrite('Result_Diameter.xlsx',Xx(:),'Flow','A2:A2002')
% if D==0.05
%     xlswrite('Result_Diameter.xlsx',H(:),'Pressure','B2:B2002')
% %     xlswrite('Result_Diameter.xlsx',Q(:),'Flow','B2:B2002')
% elseif D==0.1

```

```

%     xlswrite('Result_Diameter.xlsx',H(:),'Pressure','C2:C2002')
% %     xlswrite('Result_Diameter.xlsx',Q(:),'Flow','C2:C2002')
% elseif D==0.4
%     xlswrite('Result_Diameter.xlsx',H(:),'Pressure','D2:D2002')
% %     xlswrite('Result_Diameter.xlsx',Q(:),'Flow','D2:D2002')
% elseif D==0.6
%     xlswrite('Result_Diameter.xlsx',H(:),'Pressure','E2:E2002')
% %     xlswrite('Result_Diameter.xlsx',Q(:),'Flow','E2:E2002')
% elseif D==1
%     xlswrite('Result_Diameter.xlsx',H(:),'Pressure','F2:F2002')
% %     xlswrite('Result_Diameter.xlsx',Q(:),'Flow','F2:F2002')
% end
%%FOR CHANGE OF OIL GRADE *****
% xlswrite('Result_Grade.xlsx',Xx(:),'Pressure','A2:A2002')
% xlswrite('Result_Grade.xlsx',Xx(:),'Flow','A2:A2002')
% if GO==32
%     xlswrite('Result_Grade.xlsx',H(:),'Pressure','B2:B2002')
%     xlswrite('Result_Grade.xlsx',Q(:),'Flow','B2:B2002')
% elseif GO==46
%     xlswrite('Result_Grade.xlsx',H(:),'Pressure','C2:C2002')
%     xlswrite('Result_Grade.xlsx',Q(:),'Flow','C2:C2002')
% elseif GO==100
%     xlswrite('Result_Grade.xlsx',H(:),'Pressure','D2:D2002')
%     xlswrite('Result_Grade.xlsx',Q(:),'Flow','D2:D2002')
% elseif GO==220
%     xlswrite('Result_Grade.xlsx',H(:),'Pressure','E2:E2002')
%     xlswrite('Result_Grade.xlsx',Q(:),'Flow','E2:E2002')
% elseif GO==1
%     xlswrite('Result_Grade.xlsx',H(:),'Pressure','F2:F2002')
%     xlswrite('Result_Grade.xlsx',Q(:),'Flow','F2:F2002')
% end
%%FOR DIFFERENT GRID SPACING *****
if X==10
    xlswrite('Result_h.xlsx',Xx(:),'h_10','A2:A102')
    xlswrite('Result_h.xlsx',H(:),'h_10','B2:B102')
elseif X==5
    xlswrite('Result_h.xlsx',Xx(:),'h_5','A2:A202')
    xlswrite('Result_h.xlsx',H(:),'h_5','B2:B202')
elseif X==1
    xlswrite('Result_h.xlsx',Xx(:),'h_1','A2:A1002')
    xlswrite('Result_h.xlsx',H(:),'h_1','B2:B1002')
elseif X==0.5
    xlswrite('Result_h.xlsx',Xx(:),'h_0.5','A2:A2002')
    xlswrite('Result_h.xlsx',H(:),'h_0.5','B2:B2002')
elseif X==0.1
    xlswrite('Result_h.xlsx',Xx(:),'h_0.1','A2:A10002')
    xlswrite('Result_h.xlsx',H(:),'h_0.1','B2:B10002')
elseif X==100
    xlswrite('Result_h.xlsx',Xx(:),'h_100','A2:A12')
    xlswrite('Result_h.xlsx',H(:),'h_100','B2:B12')
end
toc
disp('CODE DONE!')

```