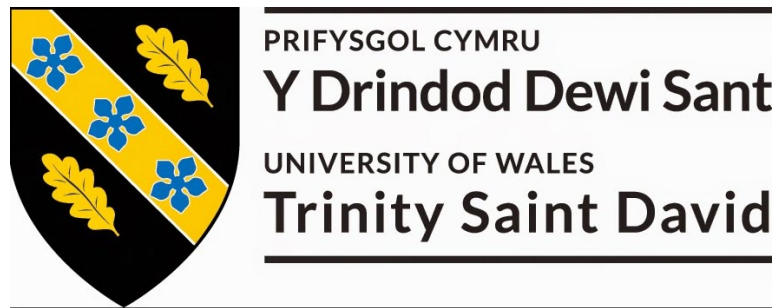


Title of Thesis: Water Hammer (Hydraulic Shock)



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Abstract

Water hammer (also known as fluid hammer and hydraulic shock) is a pressure surge caused by sudden expansion of fluid. The result of the pressure surge is a wave generation in any system of fluids. In the following project, we used Water hammer flow simulations in one differential method for solving ordinary one-dimensional differential equations describing dynamics. The first is Matlab-Simulink -SimHydraulics, which is a commercial software Developed to solve the dynamics of general hydraulic systems. The objective of the said project is to analyze the water hammer in the simulation environment. Once we are successful in implementing the water equations, we will be able to analyze the water hammer characteristics for different ranges of water diameter, injection pressures and we can calculate the output pressures. This will help in analyzing the characteristics of water hammer for the material of water hammer under consideration (Polyethylene). The experimental measurements were performed on a simple test stand consisting of a flexible tube. Strong damping connects two reservoirs. When we quickly close the valve, it causes water hammer. The Physical properties of the elastic parameters of liquids and pipes are taken into account in both simulations. For future, a graphical user interface for the water hammer simulation with advanced GUI can be created which will help in understanding the phenomenon in a much better way. Also development of a mathematical model in hand held devices could be a much useful application for people related to the field.

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Chapter 1: Introduction & Background

1.1 Introduction to water hammer

It is also known as fluid hammer and hydraulic shock. It is a pressure surge caused by sudden expansion of fluid. As a result of pressure surge a wave is generated which can be in any system of fluid. It is a process in which a sudden stop of motion is occurred and pressure is propagated through pipe, which results in pipe burst. These pressure surge or friction and air bubbles trapped in pipeline majorly cause wave.

The following report of water hammer flow simulations uses one differential method for solving ordinary one-dimensional differential equations describing dynamics. The first is Matlab-Simulink-SimHydraulics, which is a commercial software Developed to solve the dynamics of general hydraulic systems. It defines them with block elements.

The experimental measurements were performed on a simple test stand consisting of a flexible tube. Strong damping connects two reservoirs. When we quickly close the valve, it causes water hammer. The Physical properties of the elastic parameters of liquids and pipes are taken into account in both simulations.

1.2 History of water hammer

Before we go into the history, The water hammer causes disturbance, that modify the rotary engine speed is monitored by the governor action that tries to keep the rotary engine at a synchronous speed by adjusting the wicket gates during a Francis kind turbines or by a modification within the position of jet device and shutting or gap of needle valves in Pelton turbines. All of those immediate actions cause changes in turbine flow and different flow

parameters lead to formation of water hammer pressures within the penstock. Tiny hydropower plants square measure terribly liable to effects of water hammer since they're usually equipped with tiny inertia turbines and long penstocks. Specific protecting measures square measure usually used for shielding mechanical instrumentation and also the penstock from harmful effects of water hammer. Contrary to measures applied in giant pipelines and electricity power plants, these instruments square measures are tiny and of low-cost. Pressure relief valves and safety membranes that square measure employed in tiny hydropower plants square measure are safe and economic. Also, it's acceptable to use fly wheels for the security of mechanical instrumentation in hydro technical engineering, associate degree unsteady flow is commonly encountered in pipelines, whereby the variations of flow (and consequently of water speed) cause the conversion of K.E. of water into different forms of energy

As we know, the incidents occurred in yankee Indian purpose Unit No. a pair of on Gregorian calendar month thirteen, 1973 and San On fore nuclear energy Station on Gregorian calendar month twenty one, 1985, resulted from cavity collapse and caused significant losses. Thus a way to verify the harmful force, pressure and avoid this type of events has aroused abundant and significant attention of scientists and flow engineers. Theoretical analysis of this cavity collapse development is not possible because we don't know the amount of fluid, which has break down during flow and converted into gas. And what amount will be converted back to liquid after reaction during flow of fluid.

The square measure Brobdingnag Ian hydropower accidents, which can be caused by water hammer, results in substantial damages and loss of lives within the history. Owing to faulty

operations of rotary engine valves at Bartlett Dam and Oneida Station electricity station within the USA, serious failures occurred and resulted in loss of 5 live. Also in 1997, the penstock of Lapin SHP in Poland burst throughout the acceptance tests of its new governor. Finally, as a results of speedy valve closure at Okinawa Hydropower Station in Japan the penstock burst and 3 staff members lost their lives. Load rejection, instant load rejection, and cargo acceptance cases, mechanical failures of rotary engine wicket gates or valves and unexpected changes within the elevation of fore bay could cause water hammer in tiny hydropower plants. At traditional operative conditions, a hydraulic rotary engine that's connected to a generator feeding associate degree electricity grid should be operated at a relentless movement speed to come up with electricity at a relentless frequency. Any modification in frequency can lead to a modification in generator and rotary engine movement speeds.

1.3 Cause:

When this phenomenon occurs, a large bang like sound is heard that's where its name came from. When area of pipe decrease from sudden level, downstream pressure start building up and when it get high enough, it breaks through weakest part of pipe with a large bang. It can also be caused by air trapped and blocking path of water. that's why there is always a duct of air release air bubble in household pipeline and plants. We need to add damper to avoid this.

For example:

In hydroelectric generating stations, by closing a valve the water traveling along the tunnel or pipeline may be prevented from entering a turbine. For example, if there is 14 km of tunnel of 7.7 m diameter, full of water travelling at 3.75 m/s that represents approximately 8000 MJ of

kinetic energy that must be controlled. Making an open shaft, which will bear its pressure, and wasting it control this pressure generated. The major achievements have gotten the connection between multiphase and multicomponent transient flow equations, water hammer equations, and also the management equations, like Joukowsky equation. Supported the transient flow simulation theory, Colombo et al. planned AN aqueducts fault detection technology, Lee et al. planned the pipe network leak and deterioration over time detection technology by the time domain reflectometry (TDR). As the water rises up the shaft its kinetic energy is converted into potential energy, which causes the water in the tunnel to decelerate. At some HEP stations, such as the Hydro Power Plant, what looks like a water tower is actually one of these devices, known in these cases as a wave drum.

Water hammering can occur at anywhere in homes like in washing machines, toilets, dishwashers or gardening hose. This may result in large wave of shock through whole copper piping system. In case of upstream pressure when water is travelling downhill valve of pipe, it may get close which results in vacuum. This vacuum can cause collapse and implosion in pipes. To prevent this, entire line has larger inner diameter of pipe and open-air ducts at multiple times which can prevent this from happening.

Sometimes it can happen in experimental set ups when water valve got stuck during high pressure like chip stuck in throats. It results in water hammering effect and can results in damaging lag and operator and can be controlled by proper lubricating the valve and flow controller before using them.



Figure 1 water hammer effect

1.4 Precautions

Water hammer is quite dangerous process that can even cause casualties and accidents. It can be prevented with help of proper calculations before setting up piping system. It may also be caused by air bubble and friction of improper castings and design. That's why we need to verify if surroundings contain hazardous gases. Pipelines need proper cleaning and maintenance.

Water hammering can be controlled or reduced by following applications.

- Regulator should be installed to maintain certain pressure in pipeline.
- Control fluid velocity and flow rate according to pipe factor of safety to keep hammering effect lower.

- Use valve, which have slow closing speed like in toilet pressure and pipe diameter, has close relation.
- Use high young's modulus.
- Proper start up and closing system (no sudden movement).
- The mathematical and physical modeling of unsteady flow occurrences in pressure systems and structure is the basis for achieving the safe operation of a water system and avoid water hammer

1.5 Apparatus

- To understand equipment we need to learn some basic definitions.
- Water hammer: A large force generated by sudden increase in flow speed
- Friction: Force of resistance between two layers is called friction
- Static friction: Friction before start of motion.
- Dynamic friction: friction after start of motion. It is less than static friction.
- Viscosity: Friction between layers of fluid is viscosity. Denser material more viscous it gets.
- Density: mass per unit volume of fluid. Its unit is Kg/m^3 . Density of water is 1000kg/m^3 .
- Young's Modulus: it is defined as Ratio of stress/ strain. It has same unit as pressure.
- Pressure: Force per unit area. Its unit is newton per meter.
- Gravity: Force of attraction applied by earth.
- Fluid: gas or liquids which can flow are Fluids
- Fluid mechanics: It is study of mechanics of fluids.

- Transducer: a device to measure pressure upstream and downstream.
- Water tanks: it is a water storage device in apparatus to generate pressure and control water flow.
- Valve: opens and closes suddenly to generate pressure.



Figure 2: Water Hammer Set up

Product spec	Model number Product code	Supplier	Website	Quantity	price	Total price
100mx15mm polyethylene	9110PUS0008	McNAIRS	https://www.mcnairs.co.uk/item/35424/BathroomPlumbing/Barrier-Pipe-Coil-White-100mx15mm.html	1	£137.93/inc VAT	£137.93/inc VAT
electric valve to stop flow instantly	L182 Water Solenoid Valve	DMS metering solutions	https://www.dmsltd.com/p_113_1182-water-solenoid-valve?pvid=463&gclid=EAlaQobChMI38ii0sPI2QIVSrvtCh1t-QUVEAQYBSABEGKUCvD_BwE	1	£64.39All prices include VAT (where applicable).	£64.39All prices include VAT (where applicable).
Electronic pressure transducer	100361	automation24	https://www.automation24.co.uk/pressure-sensor-ifm-electronic-pi2797?previewPriceListId=1&refID=adwords_shopping_UK&gclid=EAlaQobChMIjPrr6Mv12QIVpbftCh11VgvBEAYyAyABEgI_d_BwE	1	£463.26	£463.26
A Bypass valve	DU144A1001	Amazon	https://www.amazon.co.uk/Honeywell-DU144A1001-Straight-Automatic-Bypass/dp/B00BJ74QNA	1	£33.10	£33.10
Pressure Gauge	MAT1F10B18	RS Components	https://uk.rs-online.com/web/p/products/1365159/?grossPrice=Y&cm_mmc=UK-PLA-DS3A-_google-_PLA_UK_EN_Test_And_Measurement_-_Pressure_Measurement%7CAnalogue_Positive_Pressure_Gauges_-_PRODUCT+GROUP&matchtype=&gclid=EAlaQobChMI3cqzpc7I2QIVzbDtCh2OggfEAYYAiABEgLu3fD_BwE&gclidsrc=aw.ds	1	£6.92	£6.92
Motor water supply	FW1215	Whale Watermaster FW1215 Automatic Pressure Pump 12L 12V 3 Bar	https://www.google.co.uk/search?q=motor+supply+water+3+bar+auto&source=lnms&tbm=shop&sa=X&ved=0ahUKEwjTyvOKkPnZAhVKOMAKHXt9Ag4QAUICigB&biw=1920&bih=985#spd=11693593983875774731&spf=1521487936437	1	£84.95	£84.95
Two channel Oscilloscope	Rigol DS1052E	Rigol	https://www.testers.co.uk/brands/siglent	1	£271.20	£271.20

Table 1: Apparatus TQ TE 88 Experiment

Chapter 2: Literature Review

2.1 Literature review:

Turbulence in pipe can induce large pressure, forces and large velocities in piping system. After effects of such turbulence can results in to failure of mechanical device such as pumps, compressors and turbines etc. It can stop flow of valve, which may results in pipe breaking, and back flow of waste. It is not common now days because of basic prevention systems people are applying without knowledge. Back in days it caused joints and column separations, which results into catastrophes like oil pipeline leakage, underwater, oil spills etc. So, turbulence (water hammer) can cause causalities and health risk to surroundings. In order to avoid these problems in future everything must be tested and simulated with help of software like Matlab, maple and ANSYS. Each software has their own graphic user interface which in simulating results exact as the system exist in real life.

This phenomena is inevitable in highlands and remote location where overhead storage is located far away and results in low static pressure. It can cause shut down & start up without authorized commands and entire structure can go into unexpected flow of fluids. Equipment failure and human loss can be occurred at these stages. It can also create a small earth quake which may cause land sliding in hills and snowy areas. (Don J. Wood and Srinivasa Lingireddy, 2015)

These turbulent effects are distortions in the system caused by change in operation from low steady state to high steady state. Pressurized waves are generated which travel through the structure. Speed of the fluid can rise up to sonic speed (speed of sound). As these waves are

generated and flowed through the pipe in the shape of a turbulent wave, it causes the effect of water hammer & turbulence.

(Chou, et al., 2015) Lang Chau studied the effect of change in valve size of piping system. Piping system as we know is one of the causes of water hammer. The valve specification and selection are to be studied with care as they can create turbulent or laminar flow. They influence complete system. In terms of back flow, valves should close fast, so they don't allow waste fluids to get back into the system and should not be so fast that it stops the flow of fluids creating turbulence. As turbulences increase, pressurized waves are induced in the system which takes time to calm it down. The Pressure generated in water hammer corresponds to the opening and closing of the valve. With the help of valve opening and closing time, we can drive a relation among water hammer, valve size and opening and closing time. Lang in 2015 has performed this experiment and given us relations so we can focus on other factors like downstream and upstream pressure etc.

Chao Xu developed a one-dimensional system from nonlinear hyperbolic system of PDEs. The problems for him and his companion were mitigating water hammer during the valve closure. His work is different from previous mention as the previous case was developed using apparatus of water hammer, which is about the mathematical model of systems. He used constraints and numerical condition of the water hammer apparatus and resolved the hyperbolic partial differential equation in first order ODE system and applied the boundary conditions to this case. He first explained what water hammer is, as a surge in water creates a large pressurized wave, which makes a large bang, sound. "We apply the control parameterization method to obtain an

approximate optimal parameter selection problem that can be solved using nonlinear optimization techniques, such as Sequential Quadratic Programming (SQP)". (Tehuan Chen, 2015)

Transient flow is defined as flow above 1400 and below 2400. Transient flow is studied by Manel Dalleli and his companions. They developed a numerical method and derived solutions for it. The Case was based on a very long inclined pipe. Water hammer phenomenon is generated in inclined pipeline. The results are obtained with help the of hook's law and one-dimensional flow in cylindrical pipe. Effects of gravity were quite visible in the case of downstream. With the help of numerical method, a safety factor was derived for system and applied, to avoid further risks and dangers. Also a surge pipe was introduced into the system to remove un-wanted air bubbles. This system was complex as they have to consider a head loss that is obtained by the large length of the pipe. These heads and other instantaneous heads created by sudden closure of valve are compared and taken in to the study. With the help of heads, gravity, pipe length and flow rate results are obtained such as pipe thickness which is required to avoid water hammer. (Azari, 2016)

As discussed earlier, Energy production certainty and interruptions are crucial in tiny hydropower plants (SHP) operative. Therefore, style studies of SHPs particularly target safe and reliable operations. Steady operation of a SHP is the safest state for it, as there's no modification in its hydraulic variables like discharge and pressure head within the system. However, if the turbine flow changes throughout the hydropower generation, a disturbance can occur and cause an unexpected modification within the state of the system. (Azari, 2016)

The water hammer caused disturbance that modify the rotary engine speed, is monitored by the governor action that tries to keep the rotary engine at a synchronous speed by adjusting the

wicket gates during a Francis kind turbines or by a modification within the position of jet device and shutting up gap of needle valves in Peloton turbines. All of those immediate actions cause the changes in turbine flow and different flow parameters lead to formation of water hammer pressures within the penstock. Tiny hydropower plants square measure terribly liable to effects of water hammer since they're usually equipped with tiny inertia turbines and long penstocks. Specific protecting measures square measure usually used for shielding mechanical instrumentation and also the penstock from harmful effects of water hammer. Contrary to measures applied in giant pipelines and electricity power plants, these instruments square measure tiny and of low-cost. Pressure relief valves and safety membranes that square measure employed in tiny hydropower plants square measure safe and economic. Also, it's acceptable to use fly wheels for the security of mechanical instrumentation in hydro technical engineering, associate degree unsteady flow is commonly encountered in pipelines, whereby the variations of flow (and consequently of water speed) cause the conversion of K.E. of water into different forms of energy (A Bergant, 2006). However, as a result of water and different liquids square measure solely slightly compressible, a little flow imbalance will manufacture giant pressure changes and thereby permits a substantial amount of energy to be hold on. Speedy changes in water speed will cause the bang development, which may harm pipelines and different hydro technical instrumentation. The foremost frequent causes of bang square measure is the unexpected closing (or opening) of a valve, and also the unexpected switch off (or switch on) of a pump. The modeling of the unsteady occurrences in pressure systems is that the basis

for achieving the safe operation of a water system, and it's the foremost difficult part of the rational style of such a system.

To avoid the incident of bang, pipelines are principally protected by introducing associate degree air vessel. The most important function of the air vessel is to impede the modification of speed, thus avoiding abrupt changes in the speed of water flow. Nevertheless, one of the foremost and critical queries to be answered is, how speedy is the rapid and haphazard?

That is however the work of an analyst to apprehend whether or not softness effects are necessary and what errors may be introduced by employing a rigid water column model. Towards the start of the nineteenth century, the event began of models that delineated the variations of speed and of pressure caused by bang, and lots of programs were created to alter the oscillation of water mass and/or of bang to be simulated. Supported comparison of activity results, of unsteady flow within a pipeline between the PPV Ravnik pump station and the VS Veliko Brdo reservoir, on the one hand, and individual numeric calculations, on the opposite hand, it's claimed that in real water systems synchronic bang and the oscillation of water mass occur. During this approach, we have a tendency to show that in numerical analysis full equations of unsteady water flow in pipes is ought to be used, which makes it terribly advantageous to require associate degree energy approach in describing pressure systems. Therefore the expansion of information of the physical facet of reality cannot think to be an additive method. The fundamental shape of this data changes from time to time.

All of these immediate actions causes turbine flow (above 2400) which results in different flow parameters and lead to the formation of water hammer. The Water hammer causes high

pressures within the penstock (identified by large bang sound). The Small neck of pipe with the long length can cause turbulence. Certain protective measures are used for shielding and protecting mechanical instrumentation and also the penstock from harmful effects of the water hammer. (A Keramat, 2012)

On the Contrary applying square measure is easy because of its size and cost. These measures are applied in giant pipelines and electricity power plants. Pressure relief valves and safety ducts and laminar flow that square measure employs in tiny hydropower plants. The Square measure are each safe and economic and can be designed easily. In hydro mechanical and technical engineering degree associate with unsteady flow is some time encountered in pipelines, hereby the variations of flow (laminar to turbulent) and consequently of water speed causes the conversion of kinetic energy of water into different forms of energy like potential energy, breaking and sound energy. However, as a result water and different liquids (fluids) passing through square measure can become slightly compressible, a little flow imbalance and turbulence will generate great pressure and velocity changes and thereby permits a substantial amount of energy to be hold in to square measure. Regulator should be installed to maintain certain pressure in pipeline, Control fluid velocity and flow rate according to pipe factor of safety to keep hammering effect controlled and lowered. Use of valve which have slow closing speed like in toilet pressure and pipe diameter has close relation and Use of high young's modulus pipeline. Random and haphazard changes in water speed will cause the bang (large colliding noise) developmental structure, which may harm pipelines and hydro technical & mechanical parts and instrumentation in case. The foremost frequent causes of bang where square measure

are present is the unexpected closing (or opening) of a valve, and also the unexpected switch off (or switch on) of a pump (create transient flow from start). The mathematical and physical modeling of the unsteady flow occurrences in pressure systems and structure is the basis for achieving the safe operation of a water system and avoid water hammer, and it's the foremost and ultimate difficulty of such old and outdated system.

If the main issue is vapor condensation (conversion of water into liquid state from gaseous state), it's referred to as condensed particle iatrogenic bang. The destructive results of the condensation iatrogenic water hammer is extremely valuable and sturdy. As we know, the incidents occurred in Yankee caused significant losses. Therefore to mitigate the harmful effects, a great attention and significant contribution has been paid by the scientists and flow engineers. Theoretical analysis of this cavity collapse development is not possible because we don't know amount of fluid which has break down during flow and converted into gas. And what amount will be converted back to liquid after reaction during flow of fluid. Therefore, solely simulation calculations and experiments will be done. However, experimental researches are qualitative and, moreover, rather dangerous (can't be apply is all factors are not considered). Most existing and helpful simulation algorithms are supported and explained by Vapor Bubble Note Purpose Model and One-Dimensional Model. Typically speaking, they're rather coarse (generic). So, results obtained from these algorithms require a lot of correct numerical simulation algorithmic rules and regulations. We also need to know what things are required for engineering applications. All of those rapid and haphazard actions cause changes in turbine flow and different

flow parameters like valve and pump to lead to formation of water hammer pressures within the penstock.

Therefore, it's necessary for us to analyze the critical valve-closing speed for Hydraulic management Valve (HCV). Researches about theoretical system and engineering applications for eruption and protection of pipeline fluid delivery area are progressively improved. However it's still a troublesome downside in mines system due to the limited mine area at present, the theories and ways of eruption and its means of protection have become additionally mature.

To summarize the researches regarding this downside area unit in the following 3 aspects:

1. Hydraulic transient modeling,
2. The calculations
3. And protection ways of eruption. For the future recommendation of project.

2.2 Hydraulic Transient Modeling:

For the analysis on hydraulic transient, from the mathematical derivation of the eighteenth century to the graphical analysis of the mid-20th century and to the present laptop digital simulation, scholars have already made lots of analysis results.

The major achievements have gotten the connection between multiphase and multicomponent transient flow equations, water hammer equations, and also the management equations, like Joukowsky equation. Supporting the transient flow simulation theory, Colombo et al. planned AN aqueducts fault detection technology; Lee et al. planned the pipe network leak and deterioration over time detection technology by the time domain reflectometry (TDR), Arbon et al. Proposed pipeline corrosion and blockage detection technology, Gong et al. planned a detection

technology for pipe friction, wall thickness, velocity, position, and also the length of the pipes, and Ferrante et al. conferred a leak detection technique with coupling riffle analysis and a Lagrangian model techniques.

Meniconi et al. conferred a pipe system diagnosis technique with the little amplitude sharp pressure waves.

2.3 Calculation:

The calculation ways of Hydraulic Transient for Water Hammer. The Main purpose is to develop a generic model which can be applied anywhere on any system. Results obtain by my method will consider every factor discussed in literature review, so with help of my mathematical model all castes trophies of old time must not be repeated.

The calculation ways of hydraulic transient for water hammer embrace Arithmetic technique, Graphic technique, and Numerical technique.

- (i) Arithmetic technique: Before the Thirties, the hydraulic transient calculation of eruption used Allievi equations mostly. Allievi equations are often known as Arithmetic method that is employed to unravel the issues of eruption with easy boundary conditions. Its workload is incredibly large.
- (ii) Graphic Method: Graphic technique is developed in 30s to 1960s. then forth area unit committed to develop this method. The Boundary conditions and also the method of eruption fluctuation area unit are expressed through coordinate graphics of H and V according to this method.

Due to the graphics, it's easy and intuitive method for the hydraulic transient calculation of eruption. However, the accuracy isn't high as the result of this technique is restricted by scheming means and assumptions.

- (iii) Numerical technique: From 1960s, some numerical ways appeared which were assisted by computers, like Characteristic (MOC), Wave Characteristic technique (WCM), implicit technique, and Finite component technique (FEM). The WCM can solve eruption issues of advanced piping systems and boundary conditions. It is the most common technique due to the high accuracy and computation. The Implicit Method divides pipeline into many segments and solves equations of the whole pipeline system simultaneously in every phase. The advantage of Implicit Method is often delineated in an exceeding approach because an extended phase is selected and also the range of calculations is reduced. However, there is longer time required for calculations of massive and complex pipeline network system. FEM with flexibility is used in pipe network system which has advanced boundary conditions. However, it has a limitation in finding hydraulic transient issues like Eruption Protection. Hindrance and dominant means for eruption area unit researched with the event of their theory and calculation. Wylie has researched many protecting devices for eruption, such as air valves, check valves, pressure tank, and surge tank. Lee and man of affairs mentioned the performances of air valves in eruption protection. However, these researches haven't given a quantitative calculation for the problem of eruption protection. This paper is provides an eruption protection technique based on speed

adjustment of HCV to subsume the matter of valve-closing eruption in mine system.

A mathematic model of eruption fluctuations is founded based mostly on MOC per the hydraulic transient. Then, boundary conditions of eruption dominant for mine system area unit are determined and a simplex model is established. Finally, the improvement adjustment strategy is solved with simulation and experiment.

CHAPTER 3: Aims, Objectives & Methodology

3.1 Aims and Objective:

Water hammer effect is main cause of failure of plants. As we know the plants take a lot of resources to build and work. We need to stop wasting large resource when resource are

becoming low and non-renewable. Water hammer is not a thing, which cannot be avoided. There are many cases where water hammer is avoided with help of proper inspection.

My purpose is to develop a generic model which can be applied anywhere on any system. Results obtained by my method will consider every factor discussed in literature review so with the help of my mathematical model all castes trophies of old time must not be repeated.

With help of this dissertation we will develop a mathematical model, which can help stop these causes of destruction of pipelines. And comparing result with real life problems we will see what can be done differently for that system to avoid it in future.

3.2 Methodology

Different sets of experiments were performed using different sets of scenarios. Few were on Matlab and few were of real life problem.

To completely understand problem we need a few concepts about the basic principle of Fluid mechanics like:

3.2.1 Continuity equation:

$$A^2 \frac{\partial Q}{\partial x} + g A + \frac{\partial H}{\partial t} = 0$$

According to continuity equation we can understand the concept of flow rate of fluid easily and why it causes water hammer. When flow area of pipe gets reduced or in some cases water creates

oxygen bubbles and those get stuck in elbow, at an angle or at narrow ends of pipe to cause water hammer.

3.2.2 Momentum equation:

$$\frac{\partial Q}{\partial t} + qA \frac{\partial H}{\partial x} + FQ|Q|/2DA = 0$$

Momentum equation tells that more flow causes more momentum. Momentum is also directly proportional to force generated. As velocity increase at narrow ends, it can generate large momentums.

3.2.3 Simulation model:

In constructing equation of simulation model we first need to understand about the following factors:

1. Pipe length
2. Inner diameter of pipe
3. Thickness of pipe wall
4. Young's modulus
5. Head
6. Flow rate
7. Density of water
8. Density of fluid
9. Kinematic velocity
10. Temperature
11. Pressure upstream

12. Pressure downstream
13. Adiabatic component of air
14. Duration of valve closing
15. Some important factors:

3.2.4 Pipe length:

Pipe length is an important factor. What kind of effect will it have when increased? What kind of effect will it have when we decreased? As pipe length increases flow becomes more streamlined from turbulent. As the length decreases we need to increase its strength to withstand turbulent flow pressure.

3.2.5 Inner Diameter of pipe:

Pipe's inner diameter is an important factor. What kind of effect will it have when increased or decreased? As pipe diameter increases there is more room for fluid so flow per unit area will decrease resulting in safer working of apparatus and increase flow is streamlined from turbulent. As diameter decreases we need to increase its strength to withstand turbulent flow pressure, as more pressure will act on the walls.

3.2.6 Thickness of pipe:

Pipe thickness is an important factor. What kind of effect will it have when increased or decreased? As pipe thickness increases cross-section area of pipe will increase either it increases outer radius or inner radius if inner radius remains same, increase can move to withstand turbulent flow pressure.

3.2.7 Young's modulus:

Young's modulus is an important factor. What kind of effect will it have when increased or decreased? As YM increases there is more capacity and strength of fluid to withstand turbulent flow. With its help we can increase inner diameter, which results in flow per unit area to decrease resulting in safer working of apparatus and increased and streamlined flow from turbulent.

3.2.8 Sim hydraulics solution:

It was developed by matlab to study effects such as fluid flow and friction etc. we need to develop schematic blocks on matlab and provide them with proper equations to replicate results. The following report of water hammer flow simulations uses one differential method for solving ordinary one-dimensional differential equations describing dynamics. The first is Matlab-Simulink-SimHydraulics, which is a commercial software developed to solve the dynamics of general hydraulic systems. It defines them with block elements. The experimental measurements were performed on a simple test stand consisting of a flexible tube of polyethylene. Water hammer has piping system which provides strong damping between two reservoirs. When we quickly close the valve, it causes water hammer. The physical properties of the elastic parameters of liquids and pipes are taken into account in both simulations. The problem of study for him and his companion was mitigating water hammer during valve closure. His work is different from previous mention as the previous case was developed using apparatus of water hammer and this is about mathematical model of system. He used constraint and numerical condition of water hammer apparatus and resolved hyperbolic partial differential equation in first order ode system and applied boundary conditions to this case. He first explained what is water hammer as surge in

water creates large pressurized wave which make large bang sound. We need to add every factor discussed earlier in matlab to gain exact results

1. Pipe length
2. Inner diameter of pipe
3. Thickness of pipe wall
4. Young's modulus
5. Head
6. Flow rate
7. Density of water
8. Density of fluid
9. Kinematic velocity
10. Temperature
11. Pressure upstream
12. Pressure downstream
13. Adiabatic component of air
14. Duration of valve closing

We need to consider addition real life factors like friction and account it in equations to get close to real life results. Pipe is divided in small segments and resistive factors are added fluid inertia friction and air bubbles. These things cause damping factors for more accurate result.

Pipe elastic property is defined hook's law and "static pressure coefficient" that means pressure and diameters have relation and has unit m/pa. Also from hook's law we can drive

$E = \frac{\Delta \sigma}{\Delta \epsilon}$ = Diameter²/2young's modulus * Change of Diameter.

Damping is a factor which is dependent on time and have relation with elasticity and can be explained by Voight-kelvin model.

$T = B/\text{young's modulus}$

3.2.9 Discretized and Constitutive equation:

Joukoysky's equation:

From this we can calculate velocity at any point. This equation help verify data of flow meter and calibrate it.

$$C = \sqrt{\frac{1}{\rho \left[\frac{1}{K} + \frac{D}{Ee} \right]}}$$

Joukoysky's (Zhukoysky) Equation:

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

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)

3.2.10 Taylor series:

This equation is derived from Taylor series. It is up to second differential and make problem easy to understand.

$$s(x, t + \Delta t) = s(x, t) + \Delta t \frac{\partial s(x, t)}{\partial t} + \frac{\Delta t^2}{2} \frac{\partial^2 s(x, t)}{\partial t^2}$$

3.2.11 Finite Difference method:

These methods were developed to gain equation with help of test data. Based on type of data we can divide this method into four groups.

1. Elliptical FDM
2. Parabolic FDM
3. Hyperbolic FDM
4. General FDM

Solution for above FDM data can be found by these three methods

3.2.12 Centered difference method

This method relay on finds point when both first and last value are given.

$$y''(x_i) = \frac{1}{h^2} [y(x_{i+1}) - 2y(x_i) + y(x_{i-1})]$$

3.2.13 Backward difference method

This method relay on find point when both first and last value are given.

Also helps with centered to find hyperbolic values

$$\nabla_h^n[f](x) = \sum_{i=0}^n (-1)^i \binom{n}{i} f(x - ih),$$

3.2.14 Forward difference method

This method rely on find point when both first and last value are given.

Also helps with centered to find parabolic hyperbolic values

$$f''(x) \approx \frac{\Delta_h^2[f](x)}{h^2} = \frac{f(x+2h) - 2f(x+h) + f(x)}{h^2}.$$

3.2.15 Explicit FDM:

With the help of above equation we can drive 1D equation which can help our system to get simplified.

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

$$i+1 \quad i-1$$

and

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

$$i+1 \quad i-1$$

Chapter 4: Experimental Procedures, Results and Discussions

The system is connected with two tanks using POLYETHYLENE pipe and an overhead is used to stable head in case of over flow.

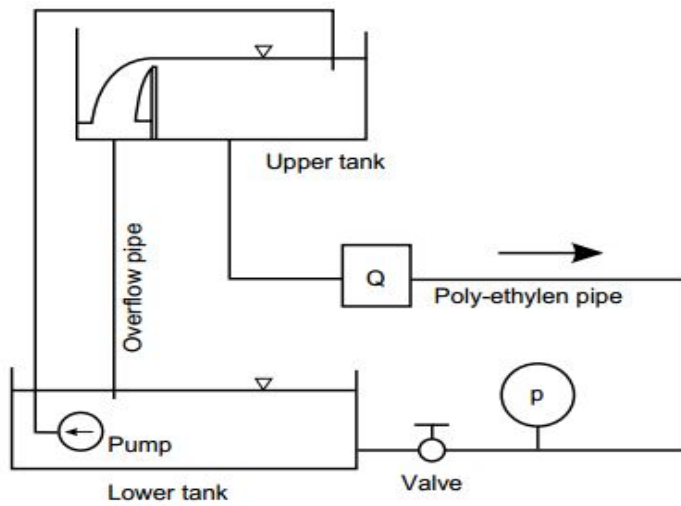


Figure 3 Schematic Diagram of water hammer apparatus

Flow rate initial state was 0.591/s and fast closure of valve was done for water hammering effect of 14.1s. Record of pressure is shown in diagram below.

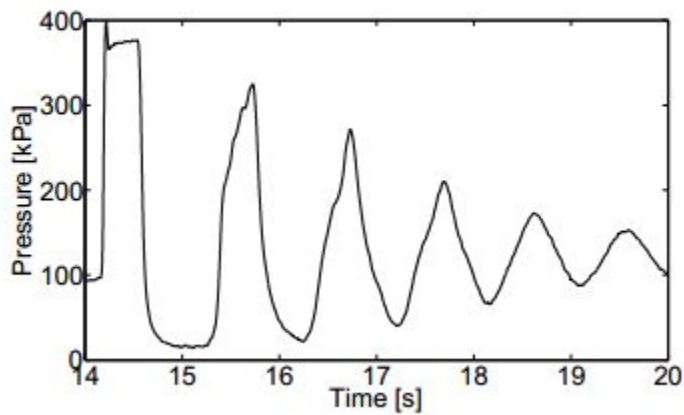


Figure 4 pressure induced graph

As from the image above we can see pressure reaching more than 300 kPa under values of factor shown in table below. Pressure was stable for quite some time and stop at initial state of 80 kPa.

Table b: Factors value

1. pipe length	100
2. Inner diameter of pipe	29
3. Thickness of pipe wall	5
4. Young's modulus	334
5. Head	2.1
6. Flow rate	0.59
7. Density of water	1000
8. Density of fluid	1000
9. Kinematic velocity	10^{-6}
10. Temperature	288
11. Pressure upstream	100
12. Pressure downstream	93
13. Adiabatic component of air	1.4
14. Duration of valve closing	0.08
15. Gas constant	287

For our experiment because of air pressure uncertainty is .25%

4.1 Conditions: 1

Enter diameter of pipe in millimeter: 10

Enter water supply pressure in bar: 36

Enter volumetric flow rate in l/min: 2

The valve closure time is 0.010000 seconds

The time it take for pressure wave to travel back to the entire pipe is 0.157007 seconds

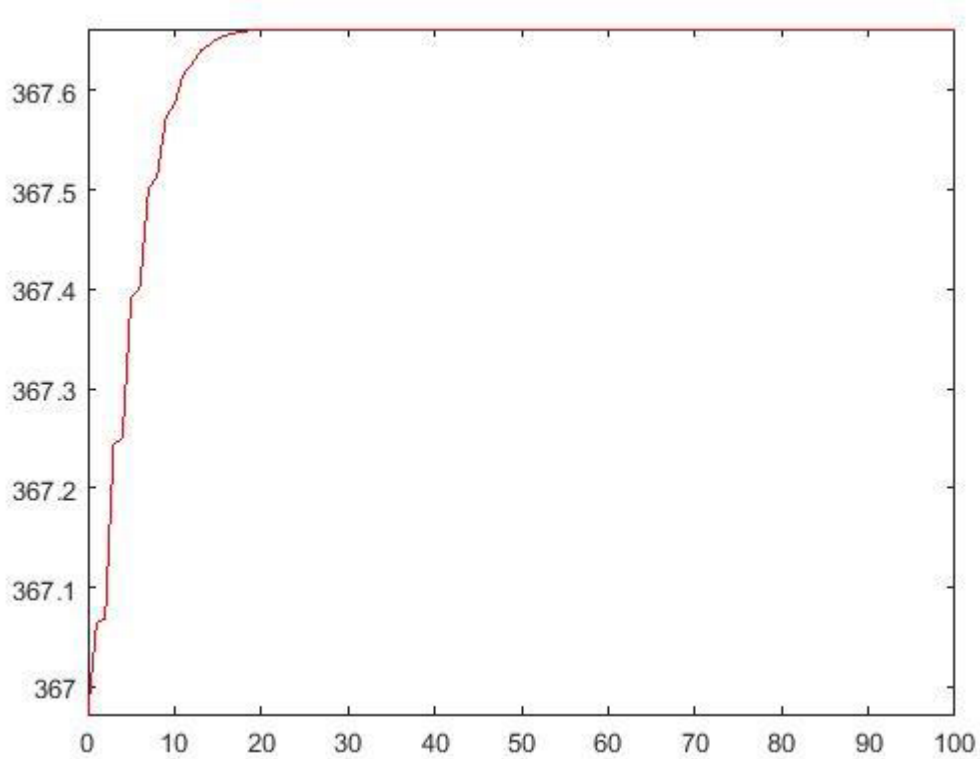


Figure 5 Matlab condition 1

The pressure before valve closure: 36.000000 bar
 The pressure max after valve closure: 36.067622 bar
 The water hammer (pressure difference): 0.067622 bar

4.2 Condition: 2

Enter diameter of pipe in millimeter: 10
 Enter water supply pressure in bar: 36
 Enter volumetric flow rate in l/min: 3
 The valve closure time is 0.010000 seconds

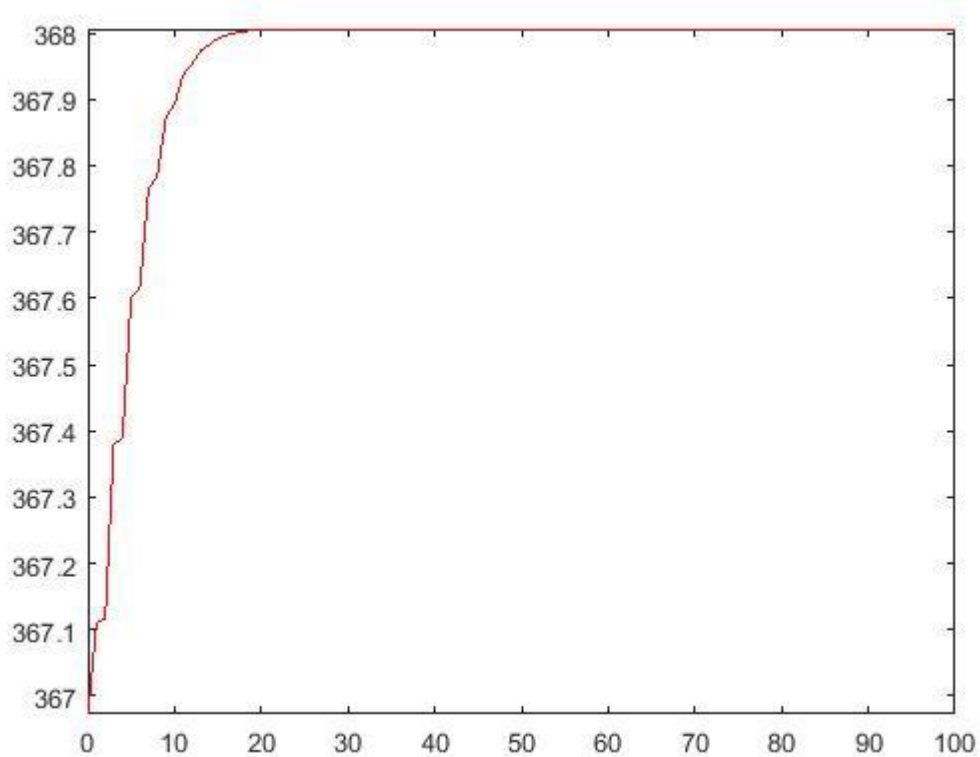


Figure 6: Matlab condition 2

The time it take for pressure wave to travel back to the entire pipe is 0.157007 seconds

The pressure before valve closure: 36.000000 bar

The pressure max after valve closure: 36.101433 bar

The water hammer (pressure difference): 0.101433 bar

4.3 Condition: 3

Enter diameter of pipe in millimeter: 10

Enter water supply pressure in bar: 36

Enter volumetric flow rate in l/min: 4

The valve closure time is 0.010000 seconds

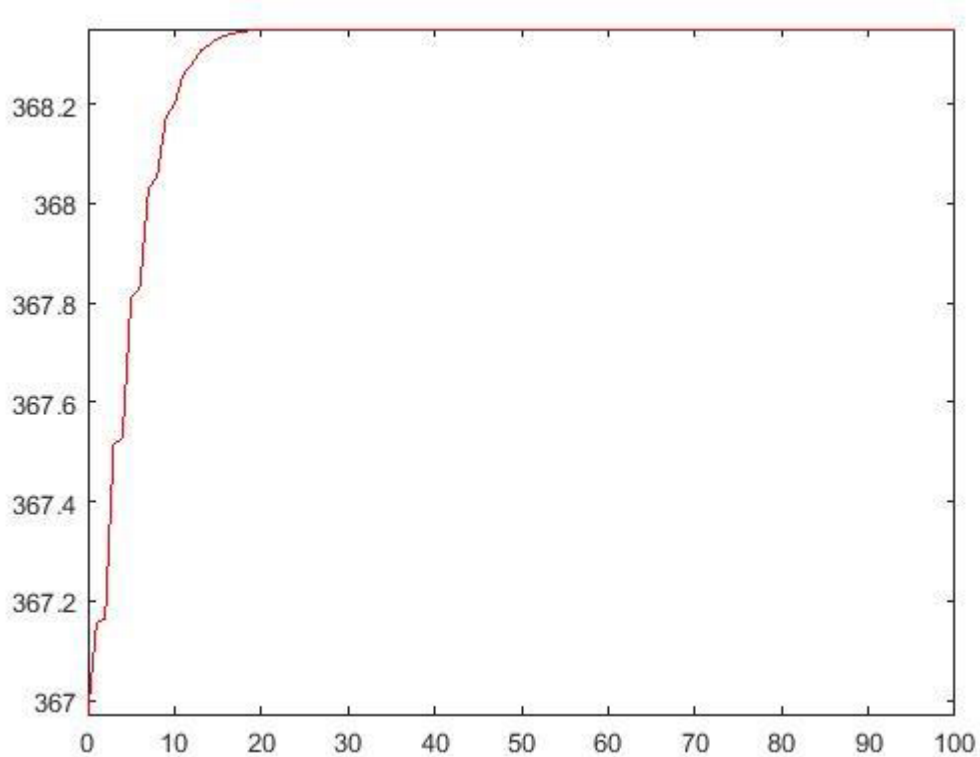


Figure 7: Matlab Condition 3

The time it take for pressure wave to travel back to the entire pipe is 0.157007 seconds

The pressure before valve closure: 36.000000 bar

The pressure max after valve closure: 36.135243 bar

The water hammer (pressure difference): 0.135243 bar

For our experiment because of air pressure uncertainty is .25%

Code

```
clc
clear all
%PARAMETERS
k=1000;%Conversion factor
g=9.81;%gravtational acceleration in m/s^2
L=100;%Length of the pipe in m
D=input('Enter diameter of pipe in millimeter: ');%Diameter of the pipe in m
```

```

D=D*10^-3;
Pr=input('Enter water supply pressure in bar: ');%pressure in bar provided by
water supply
Pr=(Pr*10^5)/(1000*9.81);%convert pressure in meter to get pressure head
Q0=input('Enter volumetric flow rate in l/min: ');%Volumetric flow rate
Q0=k*((Q0/1000)/60);
WT=0.005;%Wall thickness of the pipe in m
% E=3.1e9;%Young Modulus in Pa for PVC
E=1e9;%Young Modulus in Pa for polyethylene
roughness=0.001;%Roughness of the inside pipe wall in m
c='W';
%WATER PROPERTIES
if c=='W'
    Bulk_M=2.15e9;%Bulk Modulus of water
    Visc=1.0035e-6;%kinematic Viscosity m^2/s at 20 degrees C
    density=1000;%density in kg/m^3
    % gaugeP=19620;%Gauge pressure in Pa P = density * g * h where h is the
height of the fluid above the object
    z=Pr;%reservoir height = pressure head
    % z=306;%reservoir height
    Hres=z;%(gaugeP/(density*g))+z;
    % Vb=0.472;
    % Vb=sqrt(4*g);%velocity of water coming out of tank
    A=pi*D^2/4;%Cross sectional area of the pipe
    % Q0=A*Vb%Initial volumetric flow rate in m^3/s
    FV=Q0/A;%Fluid Velocity in m/s
    RN=(FV*D*density)/Visc;%Reynolds Number
end

a=sqrt(1/(density*((1/Bulk_M)+(D/(E*WT)))));%Sonic velocity in m/s
%Reynolds Number must be greater than 4500 for Colebrook-White equation
while RN<4500
    disp('RN not big enough')
    D=input('Redefine D = ')
    Visc=input('Redefine Kinematic Viscosity = ')
    RN=(FV*D*density)/Visc;
end
%Calculation of friction factor based on Colebrook-White equation
dv=10;%Dummy variable
fc=0.0001;%Friction factor
while dv>1
    A=1/sqrt(fc);
    B=-2*log10(roughness/(3.71*D))+(2.51/(RN*sqrt(fc)));
    if abs(A-B)<0.001
        dv=0;
    end
    fc=fc+0.00001;
end
fc;
fc=0;

%GRID SPACING INPUT
h=1;%grid spacing that will be a user input
dT=0.9*h/a;%Time step that will be a user input

```

```

Tclose=0.01;%Valve time closure that will be a user input
SC=(a*dT)/h;
while SC>=1
    disp(['STABILITY CRITERION BROKEN! SC = ' num2str(SC) ' must be <1'])
    dT=input('Re-enter time step = ')
    h=input('Re-enter grid spacing = ')
end

%INITIALISATION OF ROW VECTORS Q & H
TC=(L/h)+1;%Total Number of Nodes
X=[0:h:L];
Q=zeros(1,TC);
H=zeros(1,TC);
NQ=Q;
NH=H;

%INITIAL DOMAIN CONDITIONS
Q=Q+Q0;
for i=1:TC
    H(1,i)=Hres-(i-1)*((fc*L)/(2*g*D*(L/h)*A^2));
end
% H
%BOUNDARY CONDITIONS at RESERVOIR
H(1,1)=Hres;
R=fc/(2*D*A);
Q(1,1)=Q(1,2)+((g*A)/a)*(Hres-H(1,2))-R*dT*Q(1,2)*abs(Q(1,2));

%BOUNDARY CONDITIONS at the VALVE
H(1,TC)=H(1,TC-1)-(a/(g*A))*(Q(1,TC)-Q(1,TC-1))-(a/(g*A))*R*dT*Q(1,TC-1)*abs(Q(1,TC-1));
Q(1,TC)=Q0;

%CALCULATIONS OF Q & H FOR THE DIFFERENT TIME STEPS UNTIL tmax=L/a
t=0;
tmax=L/a;
while t<tmax
    for i=2:TC-1
        Qb=0.5*(Q(1,i+1)-Q(1,i-1));
        NQ(1,i)=0.5*(Q(1,i-1)+Q(1,i+1))-0.5*g*A*(dT/h)*(H(1,i+1)-H(1,i-1))-R*dT*Qb*abs(Qb);
        NH(1,i)=0.5*(H(1,i-1)+H(1,i+1))-0.5*(dT/h)*(a^2/(g*A))*(Q(1,i+1)-Q(1,i-1));
    end
    %RECALCULATION OF BOUNDARY NODES
    %**RESERVOIR**
    NH(1,1)=Hres;
    NQ(1,1)=NQ(1,2)+((g*A)/a)*(Hres-NH(1,2))-R*dT*NQ(1,2)*abs(NQ(1,2));
    %**VALVE**
    NH(1,TC)=NH(1,TC-1)-(a/(g*A))*(NQ(1,TC)-NQ(1,TC-1))-(a/(g*A))*R*dT*NQ(1,TC-1)*abs(NQ(1,TC-1));
    if (t+dT)<Tclose
        NQ(1,TC)=Q0*(1-(t/Tclose));
    else

```

```

        NQ(1,TC)=0;
    end
    %AMEND TIME t AND VECTORS Q & H
    t=t+dT;
    Q=NQ;
    H=NH;

    figure(1)
    plot(X,H,'r')
    yticks(min(H):(max(H)-min(H))/10:max(H))
    axis([0 L min(H) max(H)])
    pause(0.01)

end
% H
% disp('DONE')
Pmin=min(H);
Pmax=max(H);

fprintf('The valve closure time is %f seconds\n',Tclose)
fprintf('The time it take for pressure wave to travel back to the entire pipe
is %f seconds\n',tmax)
Pmin=(Pmin*9.81*1000)/(1e5);
fprintf('The pressure before valve closure: %f bar\n',Pmin)
Pmax=Pmax*9.81*1000/(1e5);
fprintf('The pressure max after valve closure: %f bar\n',Pmax)
DeltaP=Pmax-Pmin;
fprintf('The water hammer (pressure difference): %f bar\n',DeltaP)

```

4.4 Experimental Procedure

Differential manometer is used for each test to measure correct velocity for experimental set up.

Venturi apparatus was used to measure flow rate which resulted in velocity. As to increase flow rate speed of variable gear pump was varied as a test velocity increased. Hindrance and dominant means for eruption area unit researched with the event of their theory and calculation. We have researched many protecting devices for eruption, such as air valves, check valves, pressure tank,

and surge tank. Lee and man of affairs mentioned the performances of air valves in eruption protection. However, these researches haven't given a quantitative calculation for the problem of eruption protection. This paper planned an eruption protection technique based on speed adjustment of HCV to subsume the matter of valve-closing eruption in mine system. All of those rapid and haphazard actions cause changes in turbine flow and different flow parameters like valve and pump to lead to formation of water hammer pressures. The mathematic model of eruption fluctuations is founded based mostly on MOC per the hydraulic transient. To obtain results fast we used higher pressure and high flow rate to depict actual results. in whole experiment pressure was maintained at 20 to 25 psi while material used for this experiment was polyethylene and length was kept to 100.

Valve was quickly opened an few milli seconds later valve was closed abruptly by using visicordor manually. Manual switch was pressed for brief period and release for quick opening and closing. Water traveled a short distance of 1 to 2 feet before flow was ended. A recorder is used to measure these distance. Proper switches were pressed carefully to obtain result.

The following data were determined from the Visi-corder record for each test:

Rate of valve motion

Downstream pressure (incremental)

Time for ware to travel b/w transducer (pressure).

Upstream pressure (incremental)

Based on data obtain from problem experiment was conducted using polyethene. POLYETHYLENE pipe would act and perform according to real life conditions. Using the value of

real life condition it was possible to verify result of simulations. Tests were conducted such that one of the two-pressure transducer fails. Failure wills means transducer was not properly calibrated for such flow. This means pipe will break in real life flow is increased to such degree. We can also see effect of variation in height of pipe the density was probably less than that achieved at other locations around the pipe in compact fill. Crack formation of pipe will display what type of crack will be produced if we don't calibrate our pressure transducer properly. Also we can measure at what pressure pipe was damaged in real life. From the real life experiment we know only about that when pressure was at second phase of downstream when damage of pipe happened.

If as suggested above, the failure was callused by the superposition of two or more positive pressure waves, then conditions of this test were precisely those needed for this to occur. During the other tests, this combination did not occur, at least not until after viscous action had, substantially reduced the peak pressure increments. Many sources of reflections for pressure waves exist in the system in addition to the valve at the downstream end. At the upstream end the test pipe is preceded by an: 8-inch diameter pipe which causes partial reflection.

This means that we have to design our system which can withstand pressure of more than 1000 psi. Since downstream pressure rise up to 400psi.

Hundreds of angles and elbows were existed between this enlargement and the pump in real life experiment. These elbow reflect wave partially and reflection caused by pump-sump during operations. Because of reflection wave were at different velocities and Flow rate resulted in more no. of experiments.

4.5 WATER HAMMER TEST

Factor effecting Water hammer pressure

The time required for the pressure wave to travel between the two pressure transducers

The incremental pressure in the pipe at the position of the downstream pressure transducer

The incremental pressure in the pipe at the position of the upstream transducer

Data giving the rate of valve closure

Three series of water hammer tests were completed, plus a number of preliminary tests necessary for the adjustments to achieve more satisfactory valve closure times. Three of these were, for buried 6-inch POLYETHYLENE pipe. Between the three series of tests on the POLYETHYLENE pipe, the fill was excavated to the level of the bottom of the pipe and then again compacted around and over the pipe to a depth of approximately 1 1/2 feet above the pipe. The fill was not disturbed between the second and third series of tests on the POLYETHYLENE pipe. The first series of tests in each pipe replicated the measurements at each velocity three times before going to the next higher velocity. The last series of tests in each buried pipe also started with 2 fps, but increased the velocity by 1 fps increments for each succeeding test to 4 fps. These 3 tests were then replicated three times.

4.6 Results & Discussion

All pressure in psi

Table c Factors and Results

Volumetric Flow Rate (FPS)	Pipe Diameter	wave velocity	Pressure downstream (n)	Pressure Upstream(n)	Pressure downstream (Max)	Pressure Upstream(max)
2	10	1240	32.2	26.6	36	26.6
2	15	1240	37.9	35.5	44.5	36.6
2	20	1325	37.9	35.5	44.5	36.4
3	10	1240	53	51.5	58.7	50.6
3	15	1240	51.1	47.9	56.8	47.9
3	20	1240	51.1	47.9	56.8	47.9
4	10	1225	68.1	59.5	69.1	59.5
4	15	1210	62.5	63.9	68.1	63.9
4	20	1210	65.3	65.7	70	65.7

4.7Condition: 1

Relation with Downstream (normal)

Response Table for Signal to Noise Ratios

Larger is better

Level	FPS	Time	Velocity
1	31.19	31.57	36.10
2	34.27	32.54	36.66
3	36.38	36.66	32.54
4		36.10	31.57
Delta	5.19	5.09	5.09
Rank	1	2.5	2.5

Response Table for Means

Level	FPS	Time	Velocity
1	36.47	37.90	63.90
2	51.73	43.39	68.10
3	66	68.10	43.39
4		63.90	37.90
Delta	23.93	30.20	30.20
Rank		3	1.5

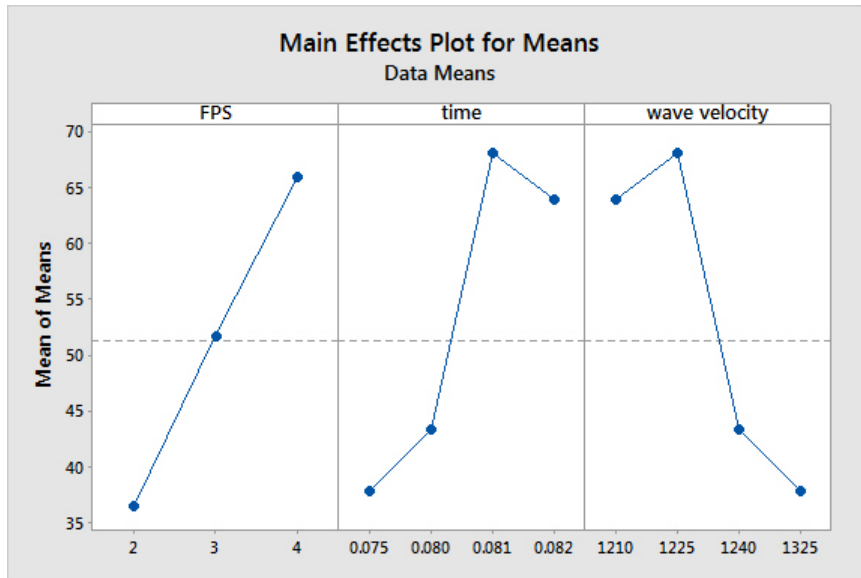


Figure 8 Downstream (normal) S/N

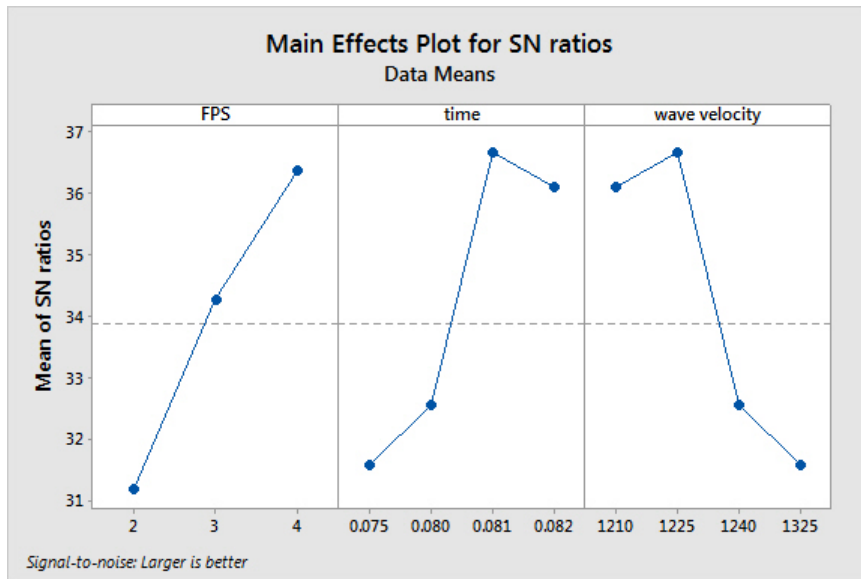


Figure 9 Downstream (normal) Mean

First was flow rate, wave velocity and time of valve opening with comparison to downstream.

Most effective factor for all experiment was Flow rate and wave velocity and valve opening have equal effect on pressure of downstream transducer under normal condition.

4.8 Condition: 2

Relation with upstream (normal)

Response Table for Signal to Noise Ratios

Larger is better

Level	FPS	Time	Velocity
1	30.29	31.00	36.23
2	33.81	31.69	35.49
3	35.86	35.49	31.69
4		36.23	31.00
Delta	5.57	5.22	5.22
Rank	1	2.5	2.5

Response Table for Means

Level	FPS	Time	Velocity
1	33.27	35.50	64.80
2	49.10	40.08	59.50
3	62.15	59.50	40.08
4		64.80	35.50
Delta	28.88	29.30	29.30
Rank	3	1.5	1.5

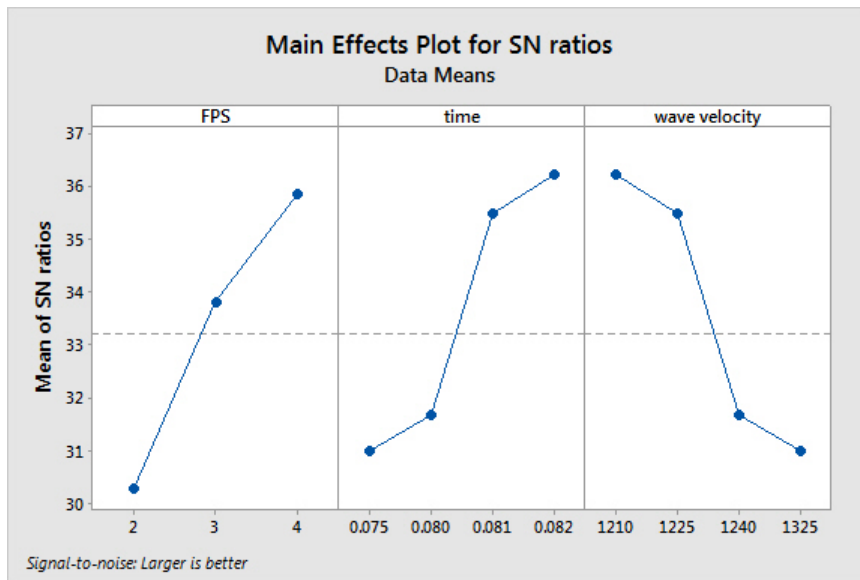


Figure 10 upstream (normal) S/N

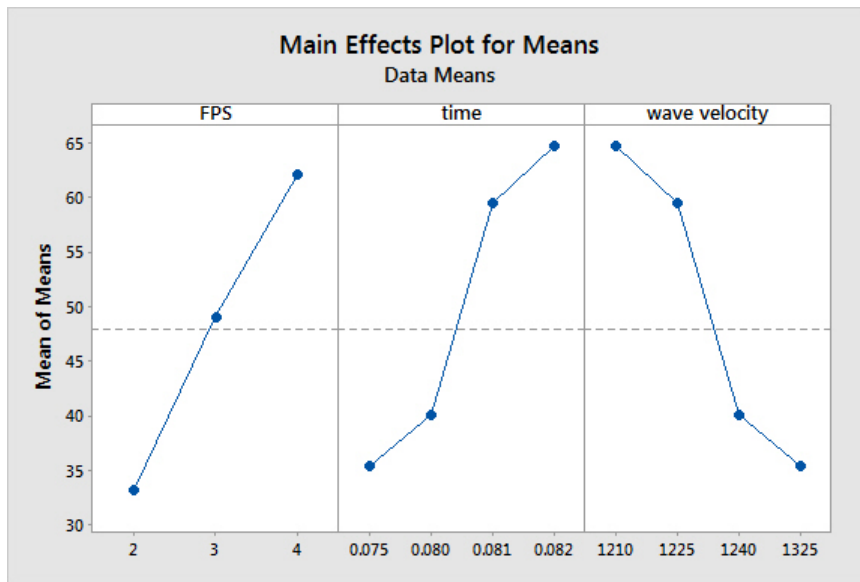


Figure 11: Upstream (normal) mean

Second was flow rate, wave velocity and time of valve opening with comparison to upstream pressure under normal conditions. Most effective factor for all experiment was Flow rate and wave velocity and valve opening have equal effect on pressure of upstream transducer under normal condition.

4.9 Condition: 3

Downstream (max)

Response Table for Signal to Noise Ratios

Larger is better

Level	FPS	Time	Velocity
1	32.46	32.97	36.78
2	33.18	33.56	36.79
3	36.79	36.79	33.56
4		36.78	32.97
Delta	4.33	3.82	3.82
Rank	1	2.5	2.5

Response Table for Means

Level	FPS	Time	Velocity
1	42.38	44.50	69.05
2	57.43	48.84	69.10
3	69.07	69.10	48.84
4		69.05	44.50
Delta	26.70	24.60	24.60
Rank	1	2.5	2.5

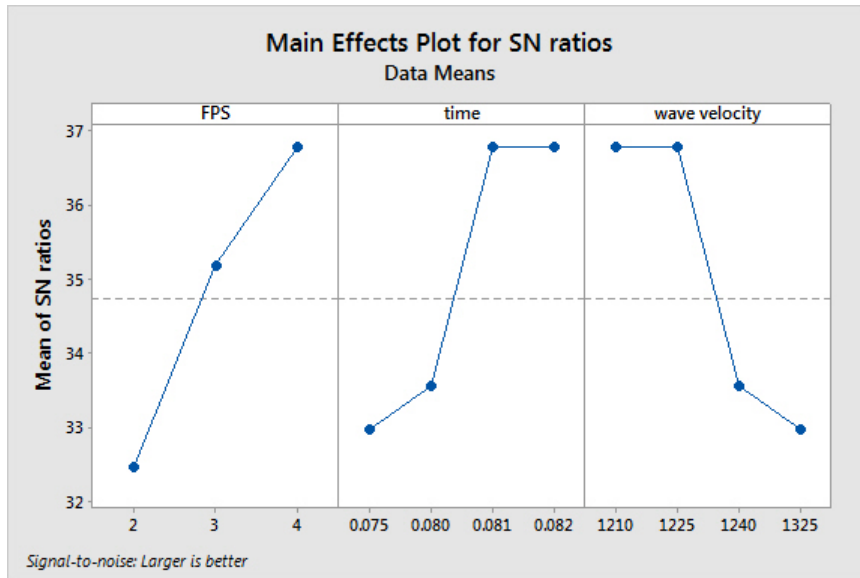


Figure 12:downstream (maximum) S/N

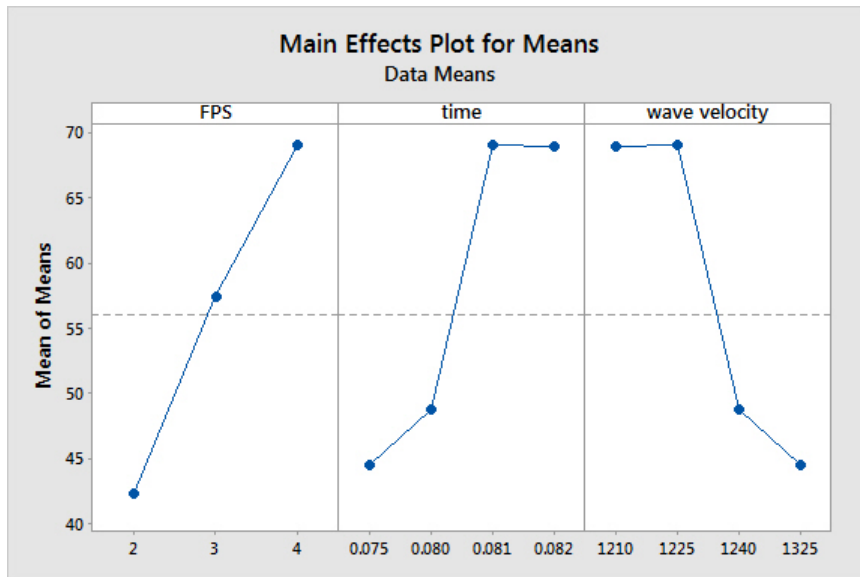


Figure 13:downstream (maximum) Mean

Third was flow rate, wave velocity and time of valve opening with comparison to downstream pressure under normal conditions. Most effective factor for all experiment was Flow rate and

wave velocity and valve opening have equal effect on pressure of downstream transducer under maximum pressure condition.

4.10 Condition: 4

Upstream (max)

Response Table for Signal to Noise Ratios

Larger is better

Level	FPS	Time	Velocity
1	30.44	31.22	36.23
2	33.76	31.71	3.49
3	35.86	35.49	31.71
4		36.23	31.22
Delta	5.42	5.01	5.01
Rank	1	1.5	2.5

Response Table for Means

Level	FPS	Time	Velocity
1	34.00	36.40	64.80
2	48.80	40.20	59.50
3	62.15	59.50	40.08
4		64.80	36.40
Delta	28.15	28.40	28.40
Rank	3	1.5	1.5

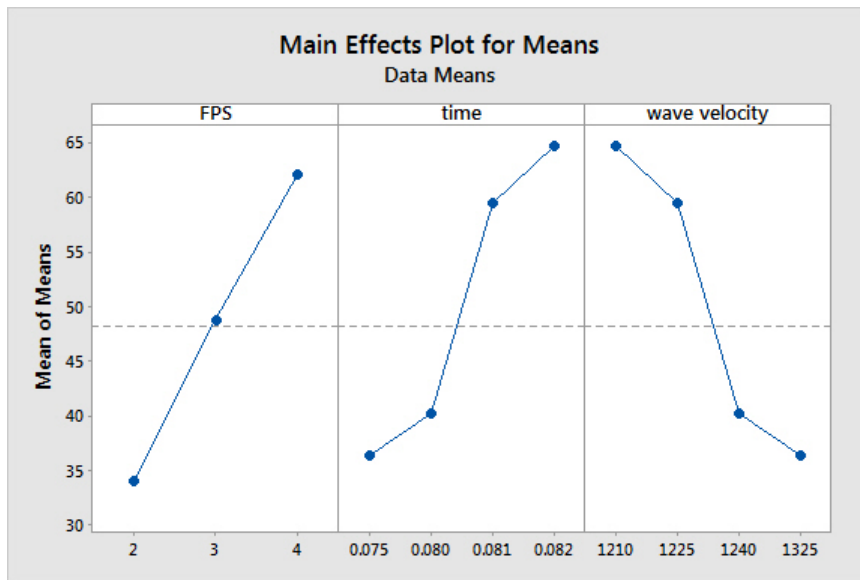


Figure 14: Upstream (maximum) S/N

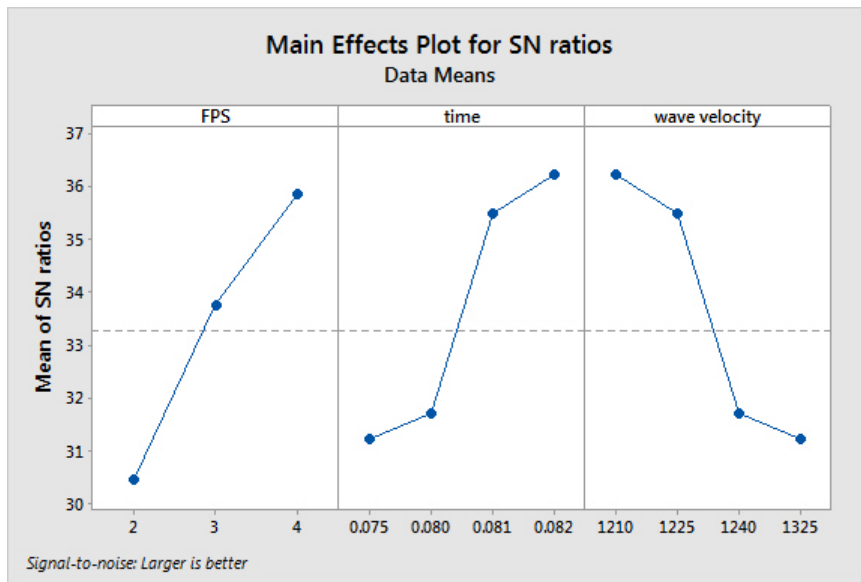


Figure 15: Upstream (maximum) Mean

Forth condition was flow rate, wave velocity and time of valve opening with comparison to upstream pressure under maximum pressure. Most effective factor for all experiment was Flow rate and wave velocity and valve opening have equal effect on pressure of upstream transducer under maximum condition.

4.11 Variation with valve opening.

Level .5 in 3.5 in 4 in

1	*	*	*
2	*	*	*
3	* 24.34	*	
4	24.34	*	*

5		*	*
6		*	24.34
7		*	
Delta	0.00	0.00	0.00
Rank	2	2	2

Response Table for Means

Level	.5 in	3.5 in	4 in
1	32.20	32.20	32.20
2	37.90	37.90	37.90
3	51.73	65.30	53.00
4	65.30	65.30	51.10
5	51.73	51.10	
6	37.90	65.30	
7		65.30	
Delta	33.10	33.10	33.10
Rank	2	2	2

Last condition with valve opening of different value in that case every factor accounted for has same effect.

Chapter 5: Conclusions & Recommendations

5.1 Conclusion:

From studying the main factor in both matlab and real life scenario it clearly visible how much pressure is raised in case of water hammer. This apparatus is quite useful to replicate results of real life problem. The report of water hammer flow simulations uses one differential method for solving ordinary one-dimensional differential equations describing dynamics. The first is Matlab-Simulink -SimHydraulics, which is a commercial software Developed to solve the dynamics of general hydraulic systems. It defines them with block elements.

The experimental measurements were performed on a simple test stand consisting of a flexible tube. Strong damping connects two reservoirs. When we quickly close the valve, it causes water hammer. The Physical properties of the elastic parameters of liquids and pipes are taken into account in both simulations.

Both surges have same values approximately. First was flow rate, wave velocity and time of valve opening with comparison to downstream. Most effective factor for all experiment was Flow rate and wave velocity and valve opening have equal effect on pressure of downstream transducer under normal condition. Second was flow rate, wave velocity and time of valve opening with comparison to upstream pressure under normal conditions. Most effective factor for all experiment was Flow rate and wave velocity and valve opening have equal effect on pressure of upstream transducer under normal condition. Third was flow rate, wave velocity and time of valve opening with comparison to downstream pressure under normal conditions. Most effective factor for all experiment was Flow rate and wave velocity and valve opening have equal effect on

pressure of downstream transducer under maximum pressure condition. Forth condition was flow rate, wave velocity and time of valve opening with comparison to upstream pressure under maximum pressure. Most effective factor for all experiment was Flow rate and wave velocity and valve opening have equal effect on pressure of upstream transducer under maximum condition. Last condition with valve opening of different value in that case every factor accounted for has same effect.

We conclude Matlab and real life problem have same results we add factors like friction air bubbles trapped in pipeline and casting and deigning defects in to consideration. I was able to develop a generic model which can be applied anywhere on any system. Results obtain by my method has consider every factor discussed in literature review so with help of my mathematical model all castes trophies of old time cannot be repeated. We can proudly say I was able to achieve my aims.

5.2 Future Recommendations:

Based on Results and difficulties faced during whole dissertation, these are things I will consider doing in my future research.

- Develop my own GUI (graphic user interface).
- Develop a mathematical model of water hammer apparatus, which can be access on hand held devices.
- Calibrate all me results with more of real life problems
- Cost analysis of projects like pipeline and plants, what cost are added and life is increased.
- Publish my work on high impact journal to help other in same field.

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Appendix 1

Definitions:

Water: It is substance made by combination of hydrogen and oxygen gas. Water is most abundant compound on earth. It is about 70% of whole earth.

Air: it is mixture. It consists of nitrogen oxygen and carbon dioxide mainly.

Friction: Force of resistance between two layers is called friction

Static friction: Friction before start of motion.

Dynamic friction: friction after start of motion. It is less than static friction.

Viscosity: Friction between layers of fluid is viscosity. Denser material more viscous it gets.

Density: mass per unit volume of fluid. Its unit is Kg/m^3 . Density of water is 1000kg/m^3 .

Young's Modulus: it is defined as Ratio of stress/ strain. It has same unit as pressure.

Pressure: Force per unit area. Its unit is newton per meter.

Gravity: Force of attraction applied by earth.

Fluid: gas or liquids, which can flow, are Fluids

Fluid mechanics: It is study of mechanics of fluids.

Transducer: a device to measure pressure upstream and downstream.

Water tanks: it is a water storage device in apparatus to generate pressure.

Material requirements planning: Material requirements planning (MRP) is a computational procedure used to convert the master production schedule for end products into a detailed schedule for raw materials and components used in the end products. The detailed schedule indicates the quantities of each item and when it must be delivered to achieve the master

schedule. Material requirements planning are relatively straightforward in concept. The lead-time for a job is the time that must be allowed to complete the job from start to finish. There are two kinds of lead times in MRP: ordering lead times and manufacturing lead times. Ordering lead-time is the time required from initiation of the purchase requisition to receipt of the item from the vendor. If the item is a raw material stocked by the vendor, the ordering lead-time should be relatively short, perhaps a few weeks. If the item is fabricated, the lead-time may be substantial, perhaps several months.

Automated 100% Inspection: Automation of the inspection process offers a possible way to overcome the problems associated with 100% manual inspection. Automated inspection is defined as automation of one or more steps in the inspection procedure, such as

Quality: Quality is actually a concept whose definition changed with respect to time. The word quality is considered as a very attractive term for both organizations and customers. In new international business trend quality became like a slogan. The term "quality" is often used in different ways depending upon the domain under consideration and have different approaches to achieve quality. But the common parameter used for quality in every field is: **cost, time, customer satisfaction and defects**. The nature of term quality itself imply that according to today business environment continuous attention should be given in order to achieve changing quality standards and attain a best position in internationally competitive market. In any organization quality improvement program are designed and implemented in order to increase profit, production and lower rejected rate and for customer satisfaction. Quality improvement program focused on both external and internal customer. The quality of product can be evaluated with

the help of several dimensions of quality i.e. performance, reliability, durability, serviceability, aesthetics (appearance), features, perceived quality, and conformance to standards.

Annex 1:

Tables

Volumetric Flow Rate (FPS)	Pipe Diameter	wave velocity	Pressure	Pressure	Pressure
			downstream (Max)	Upstream(max)	
2	10	1240	36	26.6	Every change results in increase in pressure.
2	15	1240	44.5	36.6	
2	20	1325	44.5	36.4	
3	10	1240	58.7	50.6	
3	15	1240	56.8	47.9	
3	20	1240	56.8	47.9	
4	10	1225	69.1	59.5	
4	15	1210	68.1	63.9	
4	20	1210	70	65.7	

1.	pipe length	100
2.	Inner diameter of pipe	29
3.	Thickness of pipe wall	5
4.	Young's modulus	334
5.	Head	2.1
6.	Flow rate	0.59
7.	Density of water	1000
8.	Density of fluid	1000
9.	Kinematic velocity	10^{-6}
10.	Temperature	288
11.	Pressure upstream	100
12.	Pressure downstream	93
13.	Adiabatic component of air	1.4
14.	Duration of valve closing	0.08
15.	Gas constant	287

Specification for Stainless Steel Plate and Sheet for General Applications										
SA-240/SA-240M										
(Identical with ASTM Specification A 240/A 240M-04)										
Table 1 Chemical Composition Requirements										
Type	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Chromium	Nickel	Molybdenum	Nitrogen	Copper
316	0.08	2	0.045	0.03	0.75	16.0–18.0	10.0–14.0	2.00–3.00	0.1	...
316L	0.03	2	0.045	0.03	0.75	16.0–18.0	10.0–14.0	2.00–3.00	0.1	...
316H	0.04–0.10	2	0.045	0.03	0.75	16.0–18.0	10.0–14.0	2.00–3.00	...	...

Table 2 Mechanical Test Requirements

Type	Tensile Strength, Min. (MPa)	Yield Strength Min. (MPa)	Elongation in 50 mm, Min., %	Hardness, Max. Brinell
316	515	205	40	217
316L	485	170	40	217
316H	515	205	40	217

Specification for Seamless and Welded Austenitic Stainless Steel Pipes**SA-312/SA-312M**

Identical with ASTM Specification A 312/A 312M

Table 1 Chemical Composition Requirements

Type	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Chromium	Nickel	Molybdenum	Titanium	Columbium
316	0.08	2	0.045	0.03	1	16.0–18.0	11.0–14.0	2.00–3.00	...	...
316L	0.035	2	0.045	0.03	1	16.0–18.0	10.0–14.0	2.00–3.00	...	...
316H	0.04–0.10	2	0.045	0.03	1	16.0–18.0	11.0–14.0	2.00–3.00	...	...

Table 2 Tensile Requirements

Type	Tensile Strength, Min. (MPa)	Yield Strength Min. (MPa)
316	515	205
316L	485	170
316H	515	205

Relation with Downstream (normal)

Response Table for Signal to Noise Ratios

Larger is better

wave

Level FPS time velocity

1 31.19 31.57 36.10

2 34.27 32.54 36.66

3 36.38 36.66 32.54

4 36.10 31.57

Delta 5.19 5.09 5.09

Rank 1 2.5 2.5

Response Table for Means

wave

Level	FPS	time	velocity
1	36.47	37.90	63.90
2	51.73	43.39	68.10
3	66.00	68.10	43.39
4	63.90	37.90	
Delta	29.53	30.20	30.20
Rank	3	1.5	

Condition: 2

Relation with upstream(normal)

Response Table for Signal to Noise Ratios

Larger is better

wave

Level	FPS	time	velocity
-------	-----	------	----------

1	30.29	31.00	36.23
---	-------	-------	-------

2	33.81	31.69	35.49
---	-------	-------	-------

3	35.86	35.49	31.69
---	-------	-------	-------

4	36.23	31.00	
---	-------	-------	--

Delta	5.57	5.22	5.22
-------	------	------	------

Rank	1	2.5	2.5
------	---	-----	-----

Response Table for Means

wave

Level	FPS	time	velocity
1	33.27	35.50	64.80
2	49.10	40.08	59.50
3	62.15	59.50	40.08
4	64.80	35.50	
Delta	28.88	29.30	29.30
Rank	3	1.5	1.5

Condition: 3

Downstream (max)

Response Table for Signal to Noise Ratios

Larger is better

wave

Level	FPS	time	velocity
-------	-----	------	----------

1	32.46	32.97	36.78
---	-------	-------	-------

2	35.18	33.56	36.79
---	-------	-------	-------

3	36.79	36.79	33.56
---	-------	-------	-------

4	36.78	32.97	
---	-------	-------	--

Delta	4.33	3.82	3.82
-------	------	------	------

Rank	1	2.5	2.5
------	---	-----	-----

Response Table for Means

wave

Level	FPS	time	velocity
1	42.38	44.50	69.05
2	57.43	48.84	69.10
3	69.07	69.10	48.84
4	69.05	44.50	
Delta	26.70	24.60	24.60
Rank	1	2.5	2.5

Condition: 4

Upstream (max)

Response Table for Signal to Noise Ratios

Larger is better

wave

Level	FPS	time	velocity
-------	-----	------	----------

1	30.44	31.22	36.23
---	-------	-------	-------

2	33.76	31.71	35.49
---	-------	-------	-------

3	35.86	35.49	31.71
---	-------	-------	-------

4	36.23	31.22	
---	-------	-------	--

Delta	5.42	5.01	5.01
-------	------	------	------

Rank	1	2.5	2.5
------	---	-----	-----

Response Table for Means

wave			
Level	FPS	time	velocity
1	34.00	36.40	64.80
2	48.80	40.20	59.50
3	62.15	59.50	40.20
4	64.80	36.40	
Delta	28.15	28.40	28.40
Rank	3	1.5	1.5

Variation with valve opening.

Level .5 in 3.5 in 4 in

1	*	*	*
2	*	*	*
3	*	24.34	*
4	24.34	*	*
5		*	*
6		*	24.34
7		*	
Delta	0.00	0.00	0.00
Rank	2	2	2

Response Table for Means

Level .5 in 3.5 in 4 in

1 32.20 32.20 32.20

2 37.90 37.90 37.90

3 51.73 65.30 53.00

4 65.30 65.30 51.10

5 51.73 51.10

6 37.90 65.30

7 65.30

Delta 33.10 33.10 33.10

Rank 2 2 2

Code:

```
%% This script calculates and plots graphically the pressure waves
%% occurring in a hydraulic system due to sudden valve closure

clear all;

%%% Initialization

tsim = 0.9;

tc = 0.5;      %valve closure time

resolution = 0.005; %time interval for graphics

tf = tc+0.3;    %final time for analysis

ti = tc-0.01;

time_array = linspace(tc-0.01,tf,3+(tf-tc)/resolution);

Tss = 100e-6;

Nseg = 100;

Lpipe = 25;

Ps_high = 10e5; %% relative to atmosphere

Ps_low = 0*(Ps_high/3); %% relative to atmosphere

sim('pressure_wave_model.slx');

time_vect = simlog.pipe_in.ch_1.pressure.series.time;

dim = length(time_vect);

matrix_pin = zeros(dim,1);
```

```

matrix_pout = zeros(dim,1);

%%% Create matrix with simulation data

for n = 1:Nseg

    name1 = 'simlog.pipe_in.ch_';

    name_pin = strcat(name1, num2str(n), '.pressure.series.values');

    array_pin = eval(name_pin);

    matrix_pin = horzcat(matrix_pin, array_pin);

end

F(length(time_array)) = struct('cdata',[],'colormap',[]);

h = figure(1);

location = [72.5 47.5 0 0];

fps = 2; %frames per second

%%% Create analysis for different time points

for m = 1:length(time_array)

    %%% Definition of time points of interest

    time_point = time_array(m);

    aux = find(time_vect>time_point);

    index = aux(1);

    %%% Acquisition of pressure from matrix

    for k = 1:Nseg

```

```

        pressure_pin(k) = matrix_pin(index, k+1);
    end

    plot(pressure_pin, 'LineWidth', 2);

    grid on;

    den1_title = strcat('Time instant..',num2str(time_point),'sec');

    xlabel('Node index (100 in contact with valve)');

    ylabel('High pressure [Pa]');

    ylim([-5e5 5.5e6]);

    legend(den1_title,'Location','SouthWest');

    drawnow limitrate;

    F(m) = getframe;

    end

    movie(h,F,1,fps,location);

```

Annex 2:

Applicable Codes and Standards

Following codes and standards or equivalent shall be applied during design, construction, material specification, welding, testing and inspection etc.

ASME Standards

ASME Military Code for Class 2 Components (Year 2010)

ASME Section V, Division 1, **Non-destructive Examination**.

ASME Military Code (Year 2010) ASME Section II, **Material Specification**

ANSI NQA 1-2008 **Quality Assurance Program Requirements**.

ANSI B16.34 (Steel Valves, **Flanged, Threaded and Butt Welding End**)

ANSI B 16.25 (Butt Welding End for **Pipes, Valves, Flanges and Fittings**)

MIL-167-1 **Vibration Test**

MIL-22687 **Shock and vibration qualification**

MIL-S-901 D **Shock Test** Shipboard Machinery, Equipment and Systems

ASTM Standards

A 262 Practices for Detecting Susceptibility to **Intergranular Attack in Austenitic Stainless Steels**

A 370 Test Methods and Definitions for **Mechanical Testing** of Steel Products

A 999/A 999M Specification for General Requirements for Alloy and Stainless Steel Pipe

ANSI Standards

B1.20.1 **Pipe Threads, General Purpose**

B36.10 **Welded and Seamless Wrought Steel Pipe**

B36.19 Stainless Steel Pipe

AWS Standards

A5.9 Corrosion-Resisting Chromium and Chromium Nickel Steel **Welding Rods and Electrodes**

Other Standard:

SAE J1086 Practice for **Numbering** Metals and Alloys (UNS)

SNT-TC-1A Personnel Qualification and Certification in **Non-destructive Testing**

Materials Requirements

Acceptance of material shall conform to ASME-III-1 And section II

Welding Requirement

All welding shall be done as per ASME Section IX. In addition, where the depth of repair cavity exceeds 10% of the section thickness, the repair weld shall be radiographed.