Study the water hammer phenomena it's causes and solutions

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SUMMARY:

This research study Water hammer phenomena as a challenge for engineers all times, so we study the water hammer theoretically and particularly at the project latitude and apply software of pipe system analysis of operation and management of water systems because it is associated with systems that cannot be exactly defined due to the size and length of the water distribution system with the profile or the lack of definition of the system components such as valves or pumps. We need for a more practical approach while research continues to provide better descriptions of the physics of water hammer and for useful computational solutions including the way to reduced or prevent water hammer at pipe system like using of surge tank which has ٢٨ $m^٣$ divided to two tanks ١٤ $m^٣$, and initial air champers of ٥$m^٣$.

١,١ Introduction

fluctuations caused by a sudden increase or decrease in flow velocity mean there's problem called water hammer .

These pressure fluctuations can be severe enough to rupture a water main.

Potential water hammer problems should be considered when pipeline design is evaluated, and a thorough surge analysis for water hammer should be undertaken, in many instances, to avoid costly malfunctions in a distribution system. Every major system design change or operation change—such as the demand for higher flow rates—should include consideration of potential water hammer problems. (١)

This phenomenon and its significance to both the design and operation of water systems is not widely understood, as evidenced by the number and frequency of failures caused by water hammer.

١,٢ water hammer.

Water hammer (or hydraulic shock) is the sudden change in the mass flow rate and velocity of water due to increase in pressure of water in the pipe , which occurs in a water system when there is a sudden change of direction or velocity of the water. When a rapidly closed valve suddenly stops water flowing in a pipeline, pressure energy is transferred to the valve and pipe wall. Shock waves are set up within the system. Pressure waves travel backward until encountering the next solid obstacle, then forward, then back again. (٢)

The pressure wave's velocity is equal to the speed of the sound; therefore it "bangs" as it travels back and forth, until dissipated by friction losses. Anyone who has lived in an older castle is familiar with the "bang" that resounds through the pipes when a faucet is suddenly closed. This is an effect of water hammer(hydraulic shock) . A less severe form of hammer is called surge, a slow motion mass oscillation of water caused by internal pressure fluctuations in the system. This can be pictured as a slower "wave" of pressure building within the system. Both water hammer and surge are referred to as transient pressures. If not controlled, they both yield the same results: damage to pipes, fittings, and valves, causing leaks and shortening the life of the system. Neither the pipe nor the water will compress to absorb the shock. (٢),so that the water hammer caused by the uncompress ability of any liquid or water passing through the pipe system .

١,٣The scope of this research :

In this study we have to analyze the hydraulic flow inside the pipeline network system and indicate the positive& negative pressure waves inside pipeline system and compare the same by the permissible values of the network elements, if the encountered pressures inside the pipelines within the design pressures of the network element, in this case pressures are safe and no protection system is required, but if pressures are beyond the design magnitude so protecting the network is a must. Also, the proper size of adequate surge tank for protecting the whole system and detailed description for this tank will be represented.

١,٤The Causes of Water Hammer

A water pipes system’s operating conditions are almost at un steady state. Pressures and flows change continually as pumps start and stop, demand fluctuates, and tank levels change. In addition to these normal events, unforeseen events, such as power outages and equipment malfunctions, can sharply change the operating conditions of a system. Any change in liquid flow rate, regardless of the rate or magnitude of change,

requires that the liquid be accelerated or decelerated from its initial flow velocity. deep changes in flow rate require high forces that are seen as large pressures, which caused **water hammer**. Entrained air or temperature changes of the water also can cause excess pressure in the water lines. Air trapped in the line will compress and will causes extra pressure on the water. Temperature changes will actually cause the water to expand or contract, also affecting pressure. The maximum pressures experienced in a piping system are frequently the result of vapor column separation, which is caused by the formation of void packets of vapor when pressure drops so low that the liquid boils or vaporizes. Damaging pressures can occur when these cavities collapse. (٣)

The hammer are caused by many varies. There are four common causes that typically induce large changes in pressure in the pipe system :

١.Pump startup can induce the rapid collapse of a void space that exists downstream from a starting pump. This generates high pressures especially in the long pipes .

٢.Pump power failure or cut off the electricity can create a rapid change in flow, which causes a pressure upsurge on the suction side and a pressure down surge on the discharge side. The down surge is usually the main problem. The pressure on the discharge side reaches vapor pressure, resulting in vapor column separation.

Figure ١- Lustrations of Water Hammer

٣.Valve opening and closing is a principle to safe pipeline operation. Closing a valve at the downstream end of a pipeline creates a pressure wave that moves toward the reservoir. Closing a valve in less time than it takes for the pressure surge to travel to the end of the pipeline and back is called “sudden valve closure.” Sudden valve closure will change velocity quickly and can result in a pressure surge. The pressure surge resulting from a sudden valve opening is usually not as excessive.

٤.Improper operation or incorporation of surge protection devices can do more harm than good things . An example is over sizing the surge relief valve or improperly selecting the vacuum breaker-air relief valve. Another example is to try to incorporate some means of preventing water hammer when it may not be a problem.

١,٥ Practical Solutions

The surge pressure must be incorporated with the operating pressure in the design of the pipe. The recommendations and requirements regarding allowances for surge pressure are given in the American Water Works (AWWA) standards and manuals for water supply practice, and vary depending on the type of pipe used. There are some tools to reduce the result of water hammer:

١,٥,١ The Valves

Water hammer often will be damages in centrifugal pumps caused by water hammer phenomenon when electrical power fails or cut off. In this case, the best form of prevention is to have automatically-controlled valves, which close slowly. (These valves do the job without electricity or batteries. The direction of the flow controls them.) Closing the valve slowly can modify the rise in the pressure when the down surge wave—resulting from the valve closing—returns from the reservoir. Entrained air or temperature changes of the water can be controlled by pressure relief valves, which are set to open with excess pressure in the line and then closed when pressure drops. Relief valves are commonly used in pump stations to control pressure surges and to protect the pump station. These valves can be an effective method of controlling transients. However, they must be properly sized and selected to perform the job for which they are intended without causing side effects. If pressure may drop at high points, an air and vacuum relief valve should be used. All downhill runs where pressure may fall very low should be protected with vacuum relief valves.

Vacuum breaker-air release valves, if properly sized and selected, can be the least expensive means of protecting a piping system. A vacuum breaker valve should be large enough to admit sufficient quantities of air during a down surge so that the pressure in the pipeline does not drop too low. However, it should not be so large that it contains an unnecessarily large volume of air, because this air will have to be vented slowly, increasing the downtime of the system. The sizing of air release valves is, as mentioned, critical.

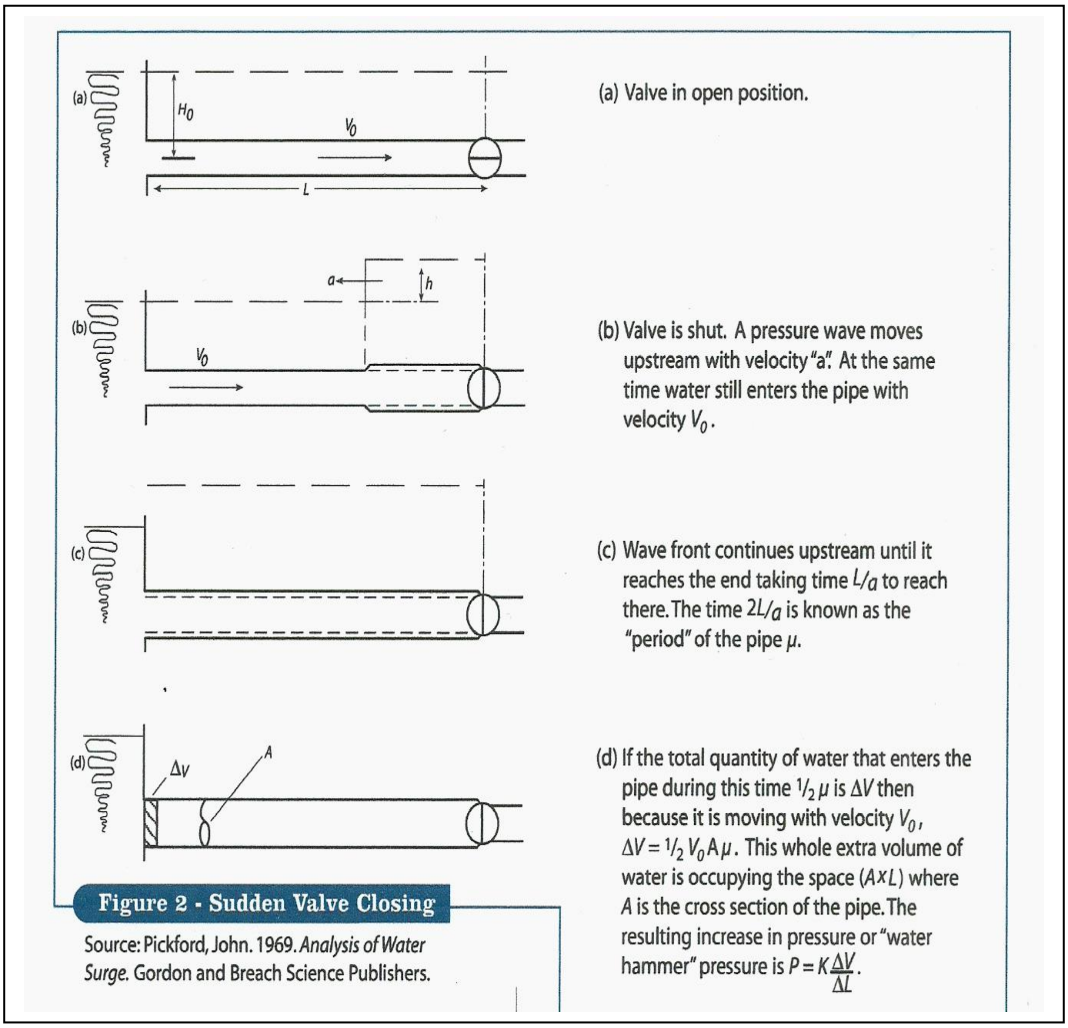


Figure 2 - Sudden Valve Closing

Source: Pickford, John. 1969. *Analysis of Water Surge.* Gordon and Breach Science Publishers.

١. ٥,٢ Pump

We can usually avoided the pump starting problems by increasing the flow slowly to collapse or flush out the voids gently. so, to keep pipeline velocities low a simple means of reducing hydraulic surge pressure. This not only results in lower surge pressures, but results in lower drive power and, thus, maximum operating economy.

١. ٥,٣ Surge Tank:

The surge can be relieved In long pipelines, with a tank of water directly connected to the pipeline called a "surge tank." When surge is encountered, the tank will act to relieve the pressure,

and can store excess liquid, giving the flow alternative storage better than that provided by expansion of the pipe wall and compression of the fluid. Surge tanks can serve for both positive and negative pressure fluctuations. These surge tanks can be used to supply fluid to the system during a down surge, to preventing or minimizing vapor separation column. also, surge tanks may be costly surge control device.

١. ٥،٤ Air Chamber

where water hammer is encountered frequently air chambers are installed in this areas, and are typically seen behind sink and tub
fixtures. Shaped like thin, upside-down bottles with a small orifice connection to the pipe, they are air-filled. The air compresses to
absorb the shock, protecting the supporting and piping system .(٣)

٢. Practical side

٢،١ Introduction:

In this research a method to avoid or prevent the water hammer by an continuous control of the valve closing process. For this purpose, the valve is supplied with a brake system that acts onto the rotation axis of the valve flap. The brake cylinder of the applied hydraulic disk brake is connected to the pipeline just upstream the valve, so that the fluid pressure may activate the brake. By this means the closing is interrupted when the pressure of the fluid increases due to the water hammer. The pressure peak is limited to a maximum pressure given by the user. The described system does not need any external energy source. Furthermore, it adapts to changes of the pipe system parameters, such as varying pipeline length (e.g. liquid supplied from tanks with a different distance from the valve), fluid velocity or physical properties of the fluid. These are major advantages compared to traditional damping systems, which delay valve closing in a fixed manner.

٢،٢ Also we found that:

Depending upon the technical and legal standards of piping operation it is often impossible to delay the closing process of an emergency stop valve in chemical industry or a safety fast-acting valve in power stations. Fast acting flap valves are often applied for a quick safety shut-down of pipelines for dangerous liquids. Without sufficient safety measures, the fast deceleration of the liquid results in high pressure pulses upstream the valve, thus kinetic energy is changed into potential energy [١]. This may cause considerable damages to the pipeline and the support structures. This effect is called water hammer. Due to liquid inertia in the pipe sections downstream the valve the pressure decreases, and vapour bubbles are formed near the valve. As a result of fast recondensation of vapour bubbles, the liquid being transported is stopped rapidly at closed valve. This pressure surge is referred to as cavitational hammer.

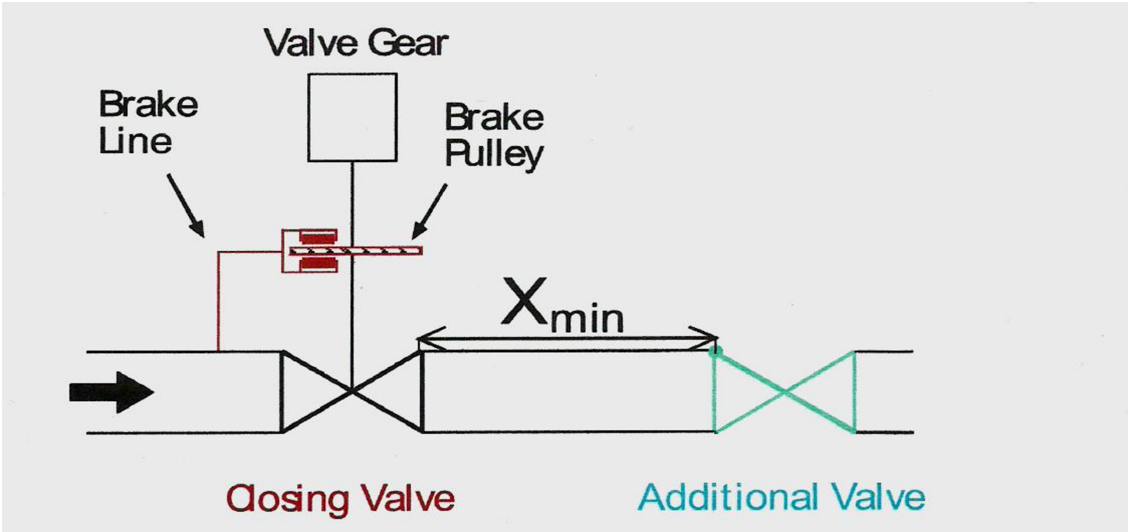
٢,٣How to avoiding the Water and Cavitational Hammers:

The best method and simple way to prevent water hammer is to close or open the valves slowly. The question whether a valve closes slowly enough can be easily calculated by the use of fluid transient software. The minimum closing time depends on the pipe length upstream the valve to the next point where pressure is fixed (i.e. vessel). At this point the high pressure wave is reflected as a low pressure wave. These waves may annihilate each other [١]. Beside that one has to take into account that there are different valve characteristics so that pressure increase due to closing process occurs at different valve positions. In practice, ٣ -١٠ times the minimum closing time is needed to avoid high water hammer pressure peaks. Another ability is to use air vessels, surge shafts or bladder accumulators, which are installed upstream the shut-off valve. Extending the valve gear with a surge damper (often used by swing check valves) or a programmable positioned leads to the deceleration of the closing process, often in the last third of the valve opening. There are also another solutions, which are based upon measurements and subsequent control of the valve [٢].

٢,٤ New Methods to treatments the water hammer:

By using of an “ABS-Armature” as Prevention way:

A passive safety system is enhanced, a so-called “ABS-Armature”, which can be used into the already existing shut-off valve. This hydraulic brake consists of the brake line, brake shoes and brake disc. It is connected with the valve gear and the valve rotation axis (fig. ١). The brake system is immediately activated when the pipe pressure upstream the acting valve rises during the closure process, so closure is interrupted. When the pressure be law, the closing process proceed until completely closed.



٢,٥ The result discussion:

In fig. ٢ the experimental results achieved at the pilot plant of Fraunhofer UMSICHT are represented. They show time-history of pressure, valve position and force with and without “ABS-Armature”. This test facility consists of two pipelines of ٥٠ and ١٠٠ mm inner diameter with an approximate length of ٢٣٠ m [٣،٤]. Fig. ٢ illustrates that the ABS-Armature is independent of the steady state stream and the pressure surges are limited to the maximum pressure allowed, which can be controlled mechanically in advance (in this example to about ٥-١٥ bar). The closing processes is happen optimized.

Figure ٢: Pressure-Time history for fast closing of water pipeline without / with ABS

As represented in fig. ٣ the ABS-Armature damps the effective force on the pipe restraints so that exceeding maximum loads do not occur.

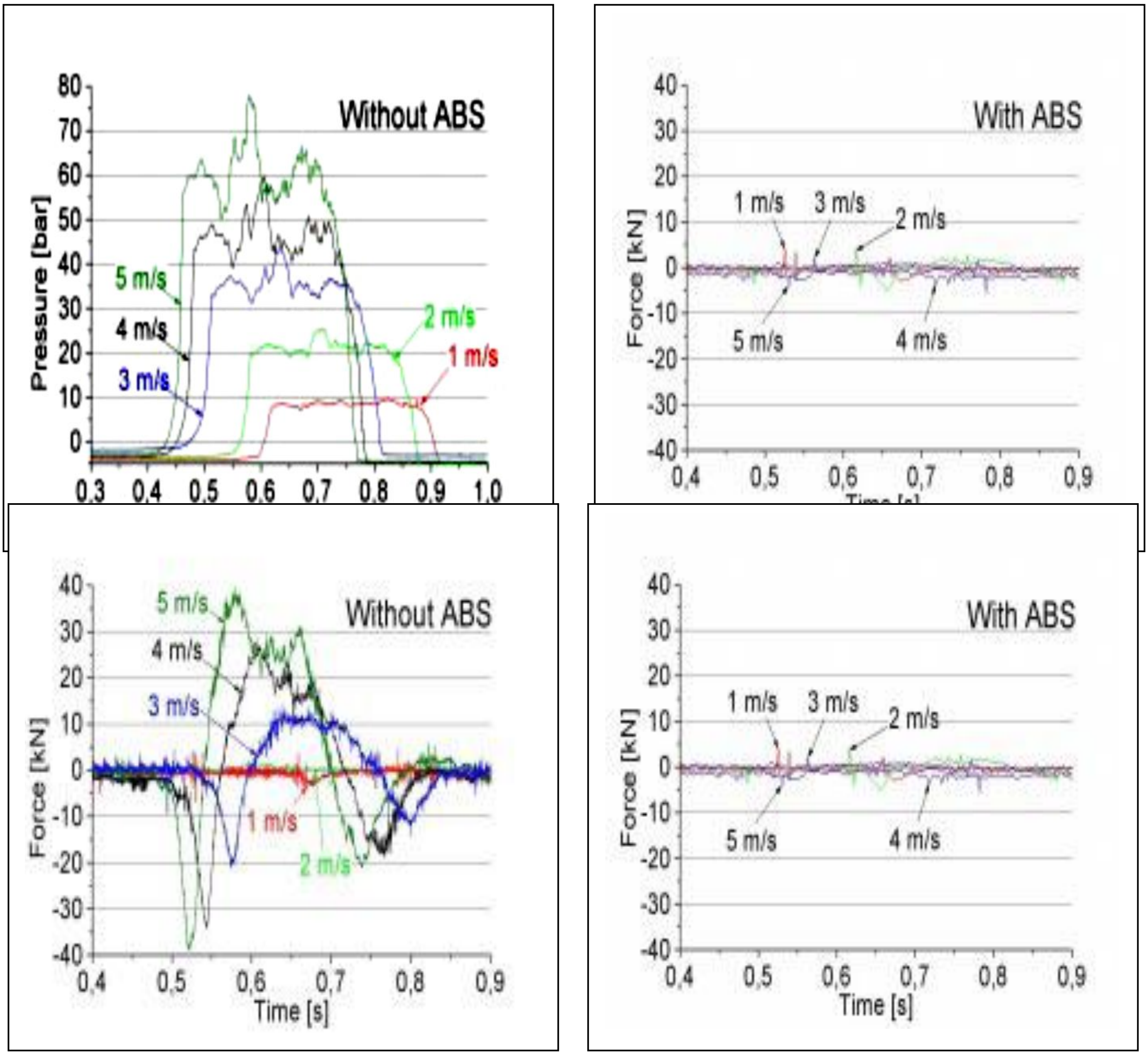
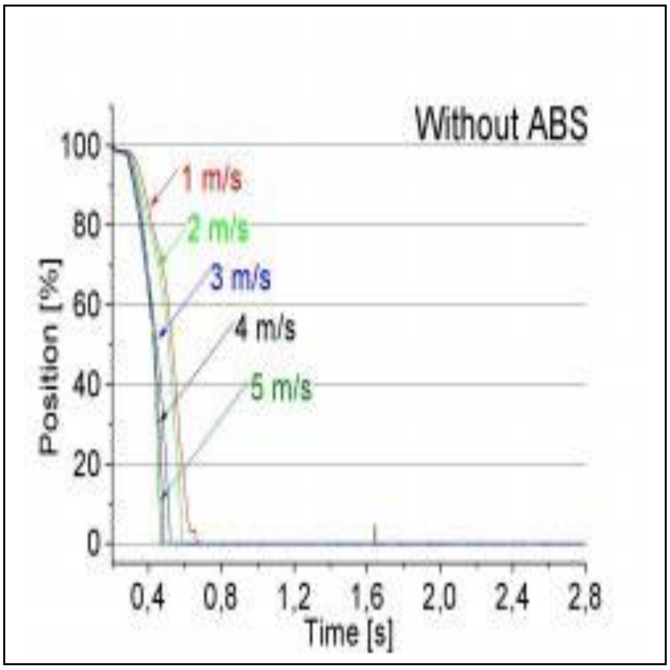


Figure ٣: Force-Time-history for fast closing of water pipeline with without ABS

Fig. ٤ illustrates the closing time of the valve. In comparison to the approximately linear undamped fast closing the hydraulic braking system results in a graded closure. The closing process adapts to the changes of boundary conditions e.g. liquid velocity and to changes of the switching state of the plant, e.g. to changes of the pipe length upstream the valve.



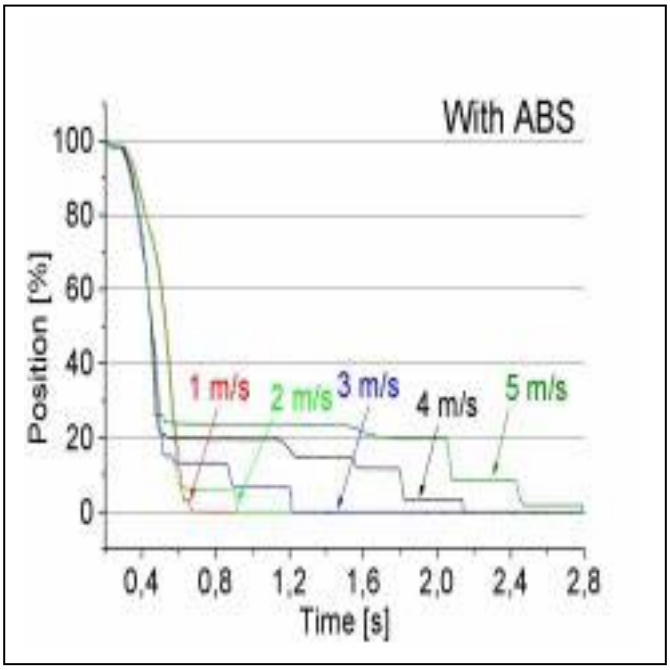


Figure ٤: Valve position-Time-history for fast closing of water pipeline without /with ABS

٢,٦The prevention of Cavitational Hammer:

An innovative pipe work modification to prevent high cavitations hammer is furthermore presented. First the maximum length of a vapour bubble downstream a closing valve must be estimated. An additional valve is arranged at the calculated position (see x min in fig. ١). When the main valve closes, the cavitations bubble is isolated between the two valves. It can be slowly re-filled up with the transported liquid by small holes in the additional valve (could be a clapper check valve), or by re-opening the main valve slowly.

٢,٧ New Methods Combination :

By summation both new methods it is possible to avoid pressure surges in both upstream and downstream sections of pipe systems that contain fast

closing valves. Water hammer is strongly reduced while cavitations hammer due to vapour bubble collapse is totally avoided. The pressure and valve position time history is
represented in figure ٥. It can be seen that the cavitational hammer is totally avoided due to the application of additional check valve. The vapour bubble cannot collapse. The valve closing process performed is always the fastest without the risk of pipe damage. Both methods in combination as well as each for itself, are passive safety systems for any pipe system.

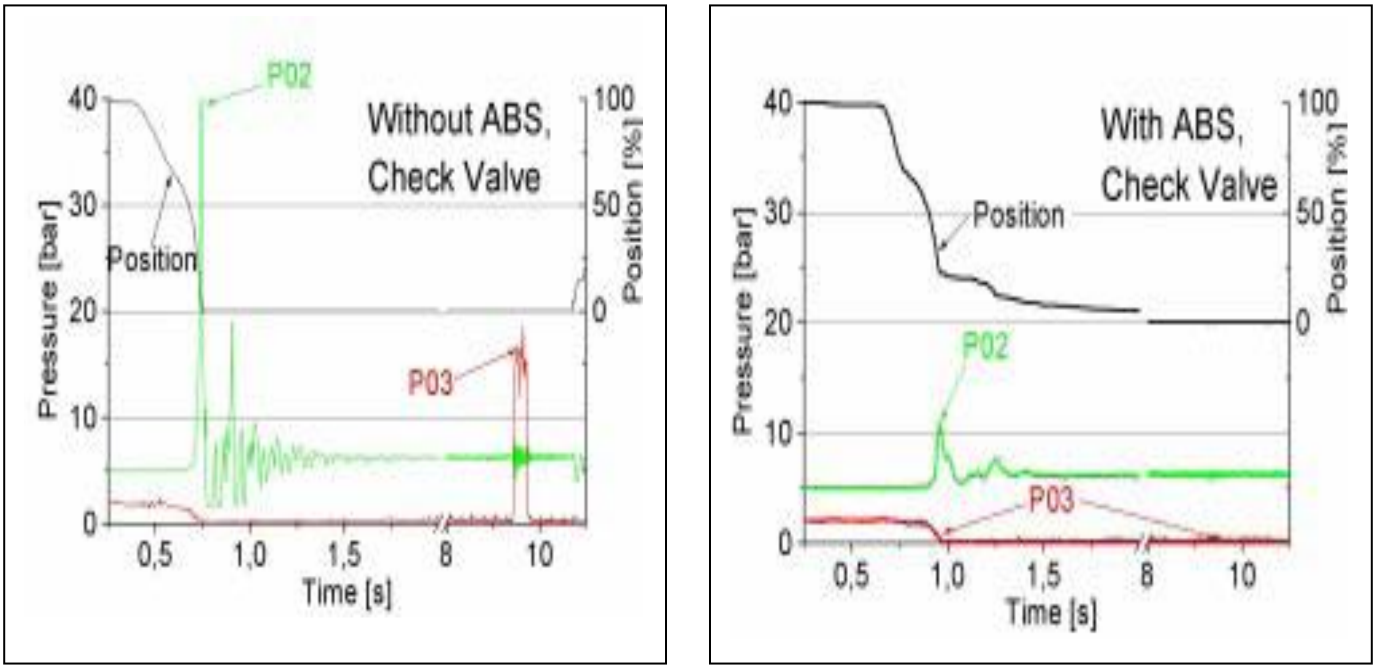


Figure ٥: Pressure and valve position time history upstream (P٠٢) and downstream (P٠٣) the closing valve without / with ABS and swing check valve

٣. Programming analysis for the water Hammer

Software analysis of the water hammer

٣.٠ INTRODUCTION

This chapter presents results from transient analysis study (Surge Analysis of the water hammer) on water pumping station and piping system (in Badra –In

Iraq) pumping station #٥. This study based on technical data of piping system provided by the contractor (AlRaneen & AlMafghra Co.) and any deviation or change out the given data may affect the output results and subsequently affect actual measures in site.

٣.١ SOFTWARE In-Use

The study was performed by using the latest version of the popular software Surge developed at University of Kentucky, USA. This is the most widely used software program in the world and has advanced graphical interface to handle transient analysis of large complex pipe line systems. More than ٢٠٠٠ packages in circulation worldwide, and the program has been successfully used for protecting thousands of pipeline systems (transmission main and distribution networks) over the last ٣٥ years.

٣,٢ DATA SUMMARY

Physical and hydraulic characteristics of the devices used in the pipe network are detailed as follows.

Pipe material: Ductile Iron

Pipe length ٧٥٠٠m

Pipe diameters: ٥٠٠ mm

Pipe thickness: Approx. ٩mm

Wave speed: ١١٣٥ m/s

Transmitted fluid: Potable Water

Applied Equation: Hazen William

Pipe Roughness: (C: ١٤٠)

Pumps

Number of pumps: ٣ working +١ standby

Rated discharge per pump: ٥٠٠ m٣/h aprrox. (١٤٠٠ L/s)

Rated pump head: ٨٠ m

Pump and Motor Inertia: ٤٦,٠٩ N-m٢ (estimated)

Pump rated speed: ١٥٠٠ rpm

Pump efficiency: ٧٠- ٨٠٪

End Point

Main transmission pipeline ended to storage reservoir higher than pump elevation by ٣٢ m and ٧,٥km faraway from pump room.

٣,٣ Analysis data fordesign model :

The study has simulated the pipe network system with all elements as per given technical information provided by the contractor as well as oral communication.

Fig. ١ indicates the parameters used on the surge analysis. (Figure ٢) showing the arrangement of pumping station. We have considered that pipeline profile going upward and straight from pump room to end point. Also, we assumed the end point is water reservoir with minimum water depth ٠,٥ meter.

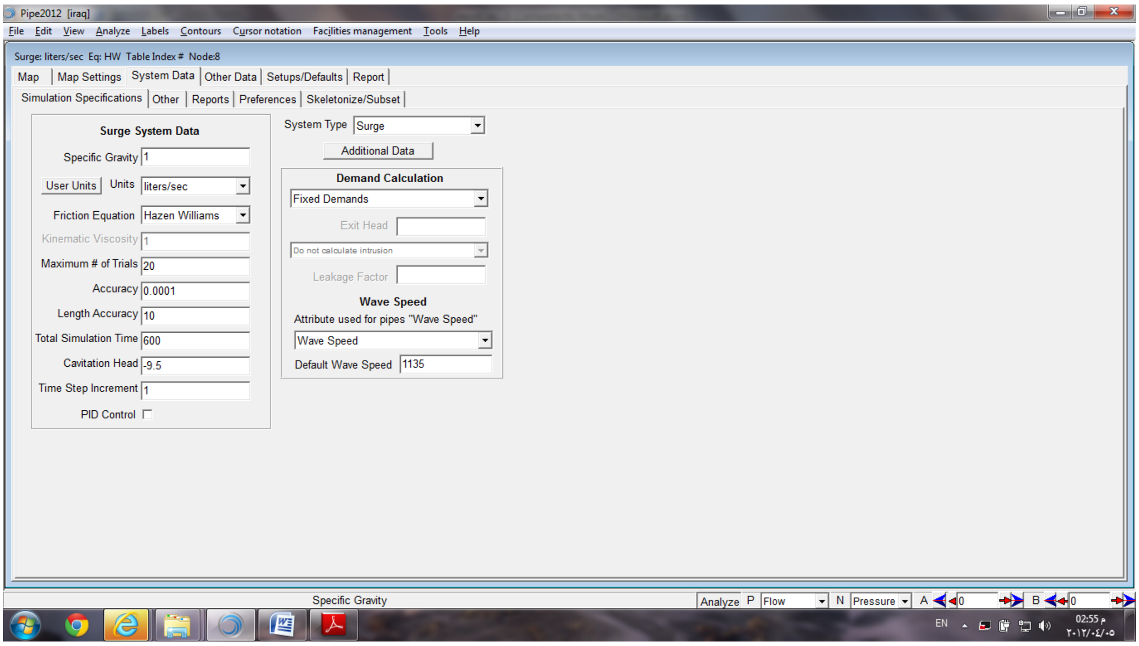


Fig. ١ parameters used on surge analysis

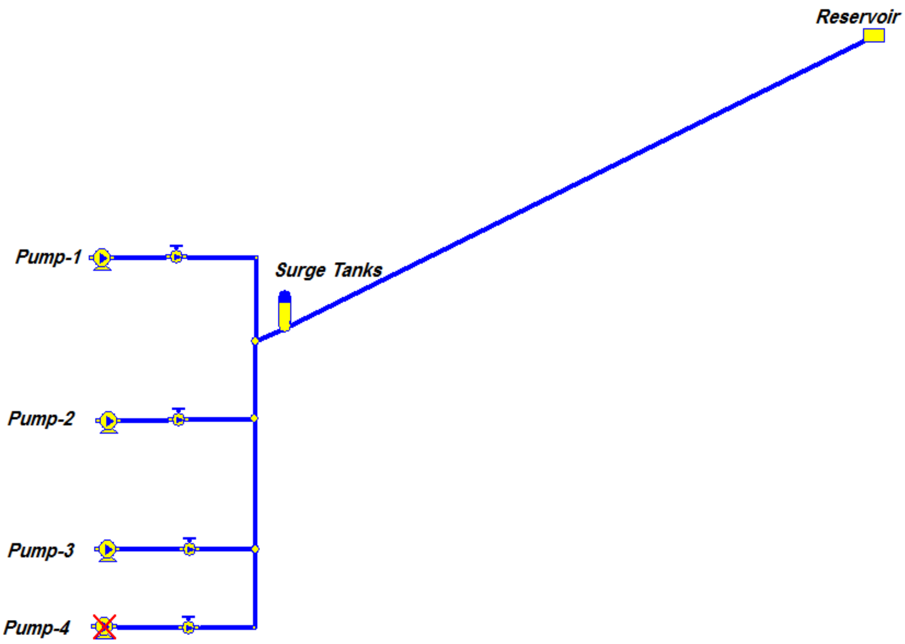


Fig. ٢ pumping station arrangement

٣,٤ Analysis of study state :

A hydraulic model basic was created by using practical information and the pipeline system data supplying by the customer into the Pipe ٢٠١٢ program which is a graphical interface for the Surge ٢٠١٢ transient analysis software. Steady state analysis was performed considering the pump characteristic data and pipeline information. Figure ٣ showing steady state hydraulic grade line (HGL) for the system when ٣ pump running at the normal speed. Below is the pump data as per steady state run.

Pump Name	Flow Rate l/s	Pump Head m
Pump-١	١٤٠,٠	٨٠,٦
Pump-٢	١٤٠,٠	٨٠,٦
Pump-٣	١٤٠,٠	٨٠,٦

٣,٥Transient model programming runs :(SURGE ANALYSIS)

The transient analysis for this pipeline system was carried out without any protection to assess the potential for high/low transient pressures following a pump trip.

It was considered that the worst case scenario would be the power failure situation wherein all the operating pumps get tripped at the same time. Figure ٤ showing pressure envelope following pump trip during a ٨٠٠ seconds transient simulation without any surge protection system.

The green dotted line indicates the maximum pressure and the red line indicates the minimum pressure during a ٨٠٠ seconds simulation and the blue line indicates pipeline profile. As seen from Figure ٤ very high pressure is created and able to damage the system it is almost ٦٨٨,٦٠m, also encountered negative pressures reaches to cavitations head in long portion of the transmission main. Figure ٥ illustrates pressures variation at one of tripped pumps. As evident from these figures the highest positive and negative.

pressures are beyond permissible pressures of the pipeline system and call protection system to suppress these pressure waves to design values. ٢٨ m٣ closed surge tank, compressor type is suitable and sufficient to suppress pressure waves to design values. Figure ٦ showing pressure envelope following pumps trip after adding closed surge tank, the max. pressure ١٤٦,٧٠m and min. pressure is +١,٤٠m, and both are occurring inside pump room. Figure ٧ illustrates pressures variation at one of tripped pumps after adding protecting surge tank. Also Fig. ٨ & ٩ showing variation of pressure& air volume inside surge tank during the transient time ٨٠٠sec after pump trip.

٣,٦ Additional states

Here're Additional transient cases based on pump operating cases with surge prevention system.

a. Three pumps are running while two pumps at rest , Fig. ١٠ showing the pressure envelope when two pumps tripped and one pump still in operating, the pressures of the maximum and minimum values are accepted.

b. Three pumps are running while one pump at rest , Fig. ١١ showing the pressure state when one pump stop and the other ٢ pumps in operating case , the pressures of maximum and minimum values are accepted.

٣,٧ Surge tank dimension and design :

The total required surge tank volume is about ٢٨ m٣, it is prefer to select two tanks each with a volume of around ١٤ m٣. Since the volume is relatively high , we may choose a horizontal pressure tank. The tank might have a diameter anywhere between٢,٠ – ٢,٥meter and length between ٤,٤ and ٣,٠
Example : if the diameter (D) is about ٢,٣ m then length (L) is ٣,٤ m

٤.the result and discussion

٤.١. Introduction:

Because of high positive and negative pressures created while all pumps tripped simultaneously so surge protection system is important to alleviate pressure waves at transient state. ٢٨ m٣ Closed surge tank is capable of protecting this piping system against high& low pressures, and has good advantage to retain long life for the equipment better than other protection elements. NRV(non-return valve) characteristics at the pump discharge has a significant bearing on the modeling results. In particular, how quickly the NRV closes following a flow reversal in the pipeline is an important parameter that may affect the maximum pressure in the pipeline during a transient event
Since surge pressure might reach ١٤٦.٧, thereby it is wise to select valves and fittings near the pumping station to be PN ١٦

٤,٢ Conclusion :

To maintain the positive& negative pressure waves in pipe network system within accepted values, we recommend the following considerations :

- Installation of ٢x١٤m٣ closed surge tanks near to lifting station with outlet/inlet nozzle ٣٠٠mm, and initial air volume ٥ m٣ for each one.

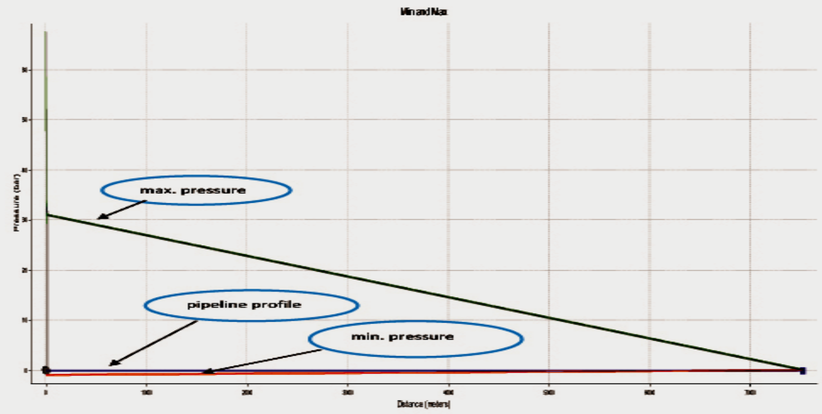


Fig. 4 min. & max. pressures along the pipeline when pumps tripped-without surge protection system.

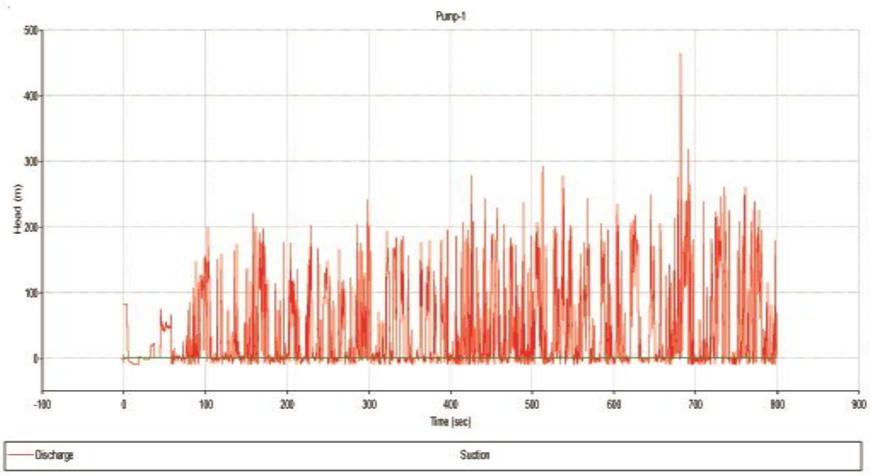


Fig. 5 pressure variation at tripped pump-without surge protection system.

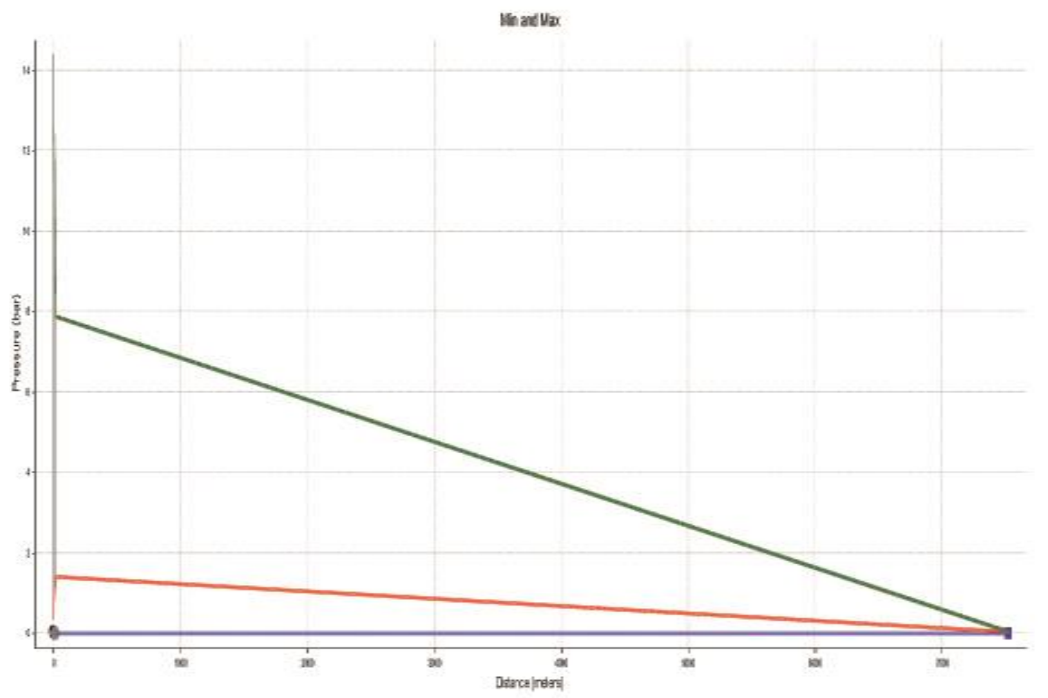


Fig. 6 min. & max. pressures along pipeline when 3pumps tripped-with protection

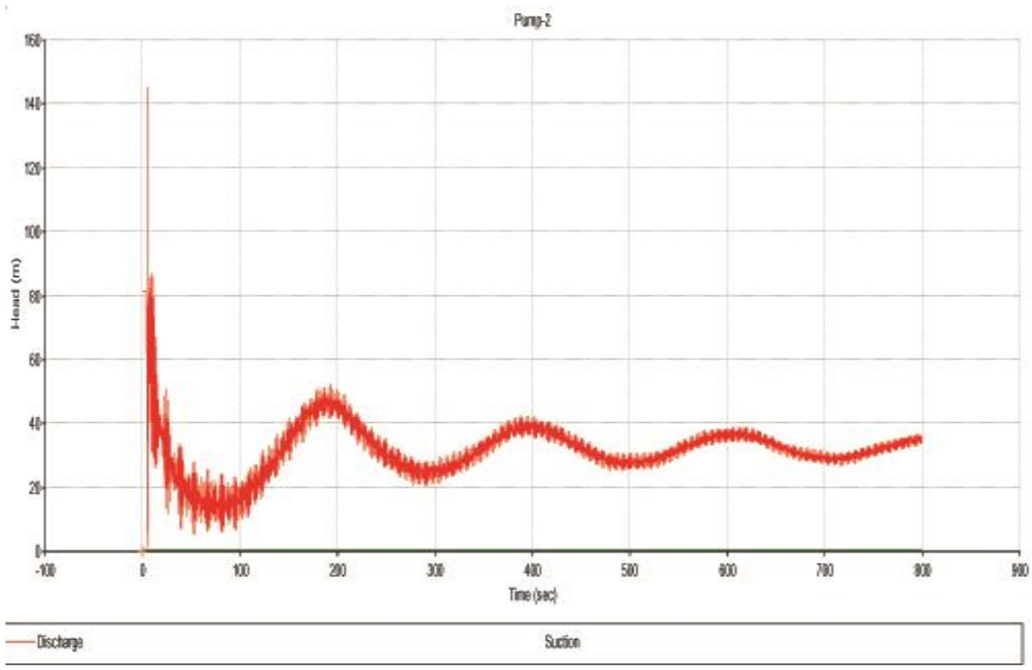


Fig. 7 pressure variation at one of tripped pumps-with surge protection system.

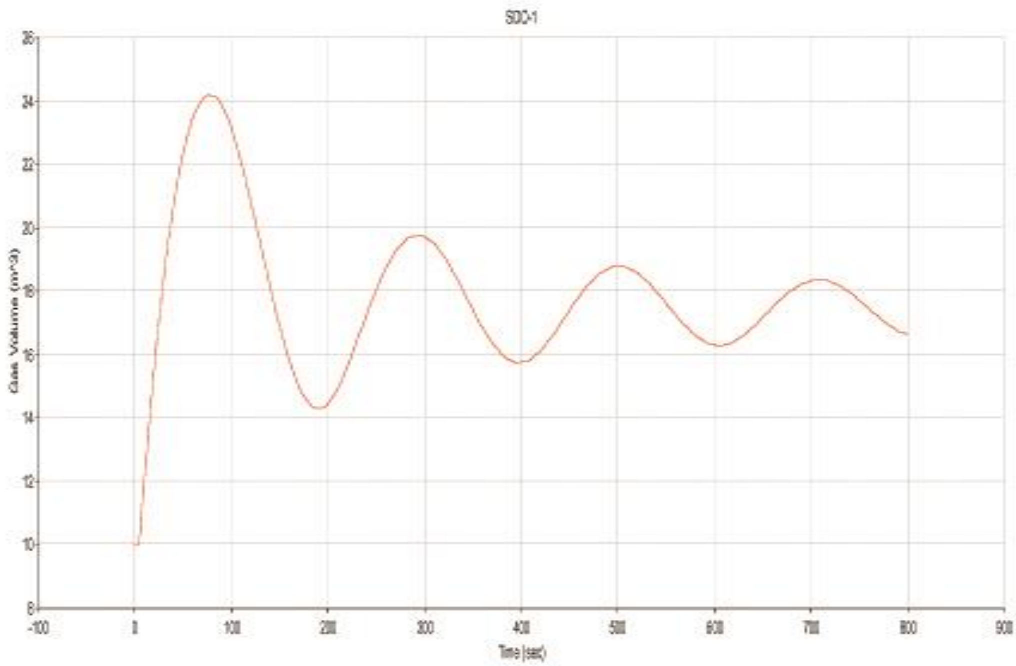


Fig. 9 air volume variation inside surge tank during 800sec transient time.

Fig. 8 pressure variation inside surge tank during 800sec transient time.

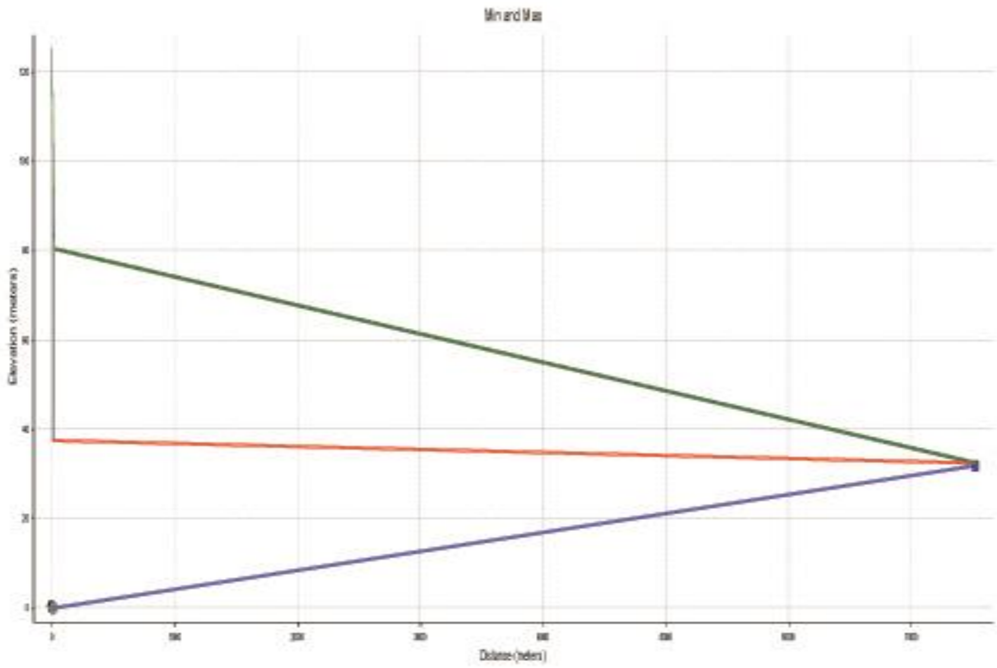


Fig. 10 max. & min. pressure when two pumps tripped from 3 running pumps-with protection system.

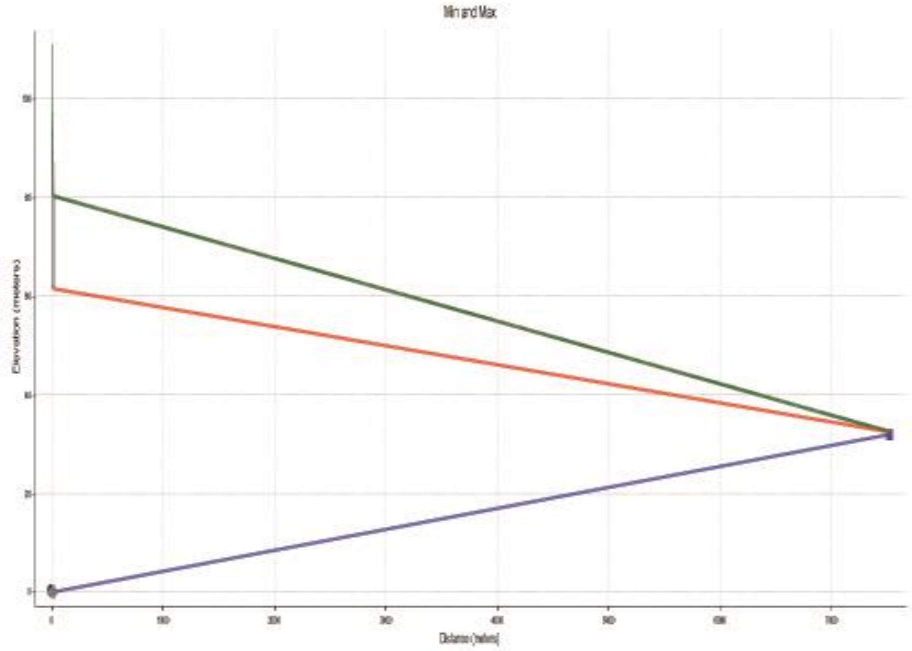


Fig. 11 max.& min. pressure when one pump tripped from 3 running pumps-with protection system

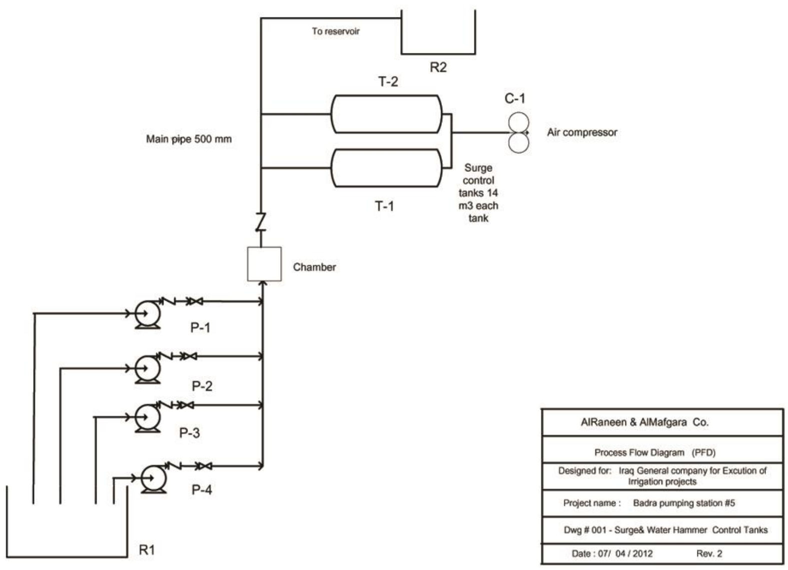


Fig ١٢ Surge& Water Hammer Control Tanks

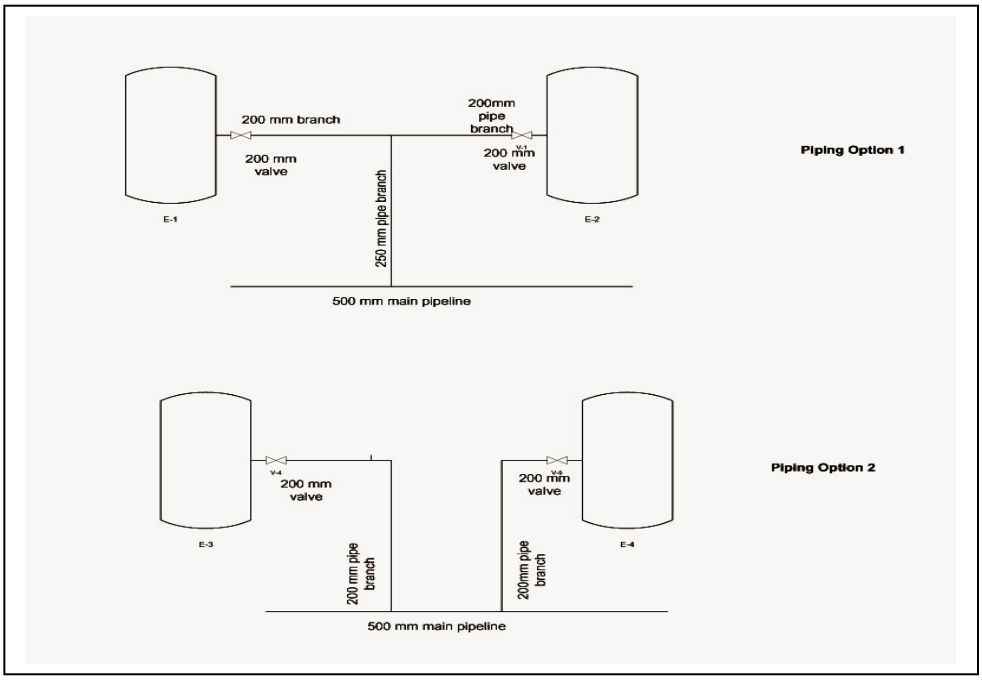
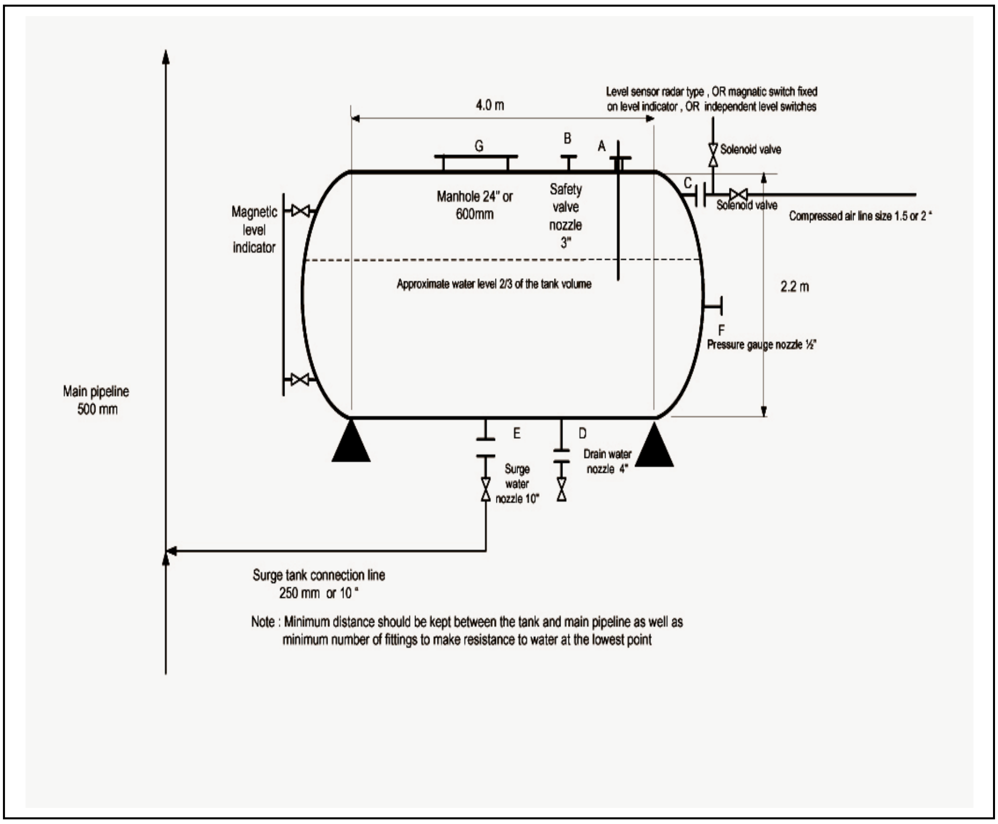


Fig ١٣ piping options



Appendix ١ pictures of the project after fully completed

Appendix ٢ The references

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