

# Surge Tank Analysis for Water Hammer Remedy for Long Distance Pipeline

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## Abstract

Various protection methods can be used for protecting the pipeline system from the impact of water hammer. Which includes the use of special materials for supporting the pipeline and the installation of special devices such as surge tanks, relief valves, and air chambers. In this study, to protect the pipeline system and reduce the effect of water hammer, surge tank has been used. Governing equations of transient flow with and without surge tank is numerically simulated using MATLAB software. Sensitivity analysis was investigated using several variables such as pipe diameter, wave's velocity and friction factor. Method of characteristics (MOC) was implemented in this study. It was found that the diameter and friction factor of pipe have a significant impact on the results of transient flow and surge tank compared to the effect of wave's velocity. It has been reached that the capacities of surge tanks at diameter (1m), are (1475m<sup>3</sup>) at first, second and fourth stages, (1360m<sup>3</sup>) at third and fifth stages and (570m<sup>3</sup>) at sixth stage. And at diameter (1.2m), the capacities are (1700m<sup>3</sup>), (1530m<sup>3</sup>) and (1475m<sup>3</sup>) at first, second and third stages respectively. But at diameter (1.4m), the capacities are (1590m<sup>3</sup>) at first and second stages. For all values of wave's velocity, the capacities of surge tanks are (1760m<sup>3</sup>), (1530m<sup>3</sup>) and (1420m<sup>3</sup>) at first, second and third stages respectively. But the capacities of surge tanks at friction factor (0.007) are (1810m<sup>3</sup>), (1585m<sup>3</sup>) and (1245m<sup>3</sup>) at first, second and third stages respectively. However, for the capacity of surge tanks at the friction factor (0.008), it was mentioned when the surge tanks capacity of the diameter (1.2m) was mentioned. And when the friction factor is (0.009), the capacities are (1460m<sup>3</sup>) at first stage, (1415m<sup>3</sup>) at second and third stages and (570m<sup>3</sup>) at fourth stage.

**Keywords:** Pipeline, Transient flow, Water hammer remedy, Surge tank, MATLAB.

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## 1.Introduction

Surge tanks can be used to alleviate both low and high pressures. And these devices can work as a temporary storage devices of excess liquids that have been converted from the main flow. This conversion permits a much more gradual change in velocity in the pipeline and a significant reduction in the magnitude of transient pressure waves. To prevent excessive deceleration and low pressures, surge tanks can also provide liquid to the pipeline [1]. However, the success of surge tank depends largely on the designer/operator experience and the pipeline system properties [2, 3]. Designing a surge tank for a pipeline system is an important issue in the field of fluid engineering. Surge tank installed close to the end valve for the reservoir pipeline valve system [4, 5]. It is located so that the normal water level elevation is equal to the hydraulic grade line elevation. During valve closure, the surge tank substitutes the pump and by gravity feeds the system with water or the surge tank accommodate the excess water. This controls the magnitude of the high pressure transient generated as a result of valve closure [1]. Pipeline systems can suffer either a fatigue failure from repeated surges or catastrophic failure from a surge event [6]. Traditionally, the method of characteristics (MOC) was widely used to simulate the transients in a pressurized pipeline system generated by valve actions [4, 5].

Lee (1998) [7] modeled the impact of air entrainment in a pipeline system equipped with an air chamber that was also simulated on the platform of transient analysis. Kim (2010) [6] used the method of characteristics and the impulse response method to simulate the pressure variation in pipeline systems equipped with a surge tank. The simulation results showed good agreement only in the condition of an identical computational interval between pipeline elements and that of the surge tank connector. Jalut and Ikhnefeir (2010) [8] simulated the transient flow in pipes by taking Omar Almokhtar Reservoir and Omar Almokhtar Grand Reservoir hydraulic system as a case study and installed air vessels to protect the pipeline system from the risk of water hammer by using WANDA software.

Akpan, et al. (2015) [9] predicted the pressure surge for different flow conditions in two different pipeline systems using WANDA Transient simulation software. Computer models were setup in WANDA Transient for two different systems namely; the Graze experiment (miniature system) and a simple main water riser system based on some initial laboratory data and system parameters. The simulation results showed there is moderately accurate to approximate the air conduct in air vessel used for water pipeline protection systems.

In the present study, the governing equations numerically solved using MATLAB software. Fluctuations of pressure were investigated by changing the pipe diameter, wave's velocity and friction factor, and compared between protected and unprotected system. Sensitivity analysis of the numerical model was implemented for thorough understanding the effectiveness of surge tanks for pipeline systems.

Method of characteristics is the commonly used method because of its simplicity and superior performance in comparison with other methods. Its thrust lies in its ability to convert the two partial differential equations (PDEs) of momentum (Euler) and continuity of unsteady flow in pipe systems into four ordinary differential equations that are solved numerically using finite difference techniques [1]. These equations are:

$$\frac{\partial V}{\partial t} + \frac{1}{\rho} \frac{\partial p}{\partial s} + g \frac{dz}{ds} + \frac{f}{2D} V|V| = 0 \quad (1)$$

$$a^2 \frac{\partial V}{\partial s} + \frac{1}{\rho} \frac{\partial p}{\partial t} = 0 \quad (2)$$

The equations express the flow and head for small time steps ( $\Delta t$ ) at numerous locations along the pipe sections. Calculations during the transient analysis must begin with a known initial steady state and boundary conditions. In other words, flow and head at time ( $t = 0$ ) will be known along with flows and/or head at the boundaries at all times. To find the initial conditions at time zero, energy or Bernoulli equation will be used. A head loss due to pipe friction can be calculated by using Darcy-Weisbach formula.

Now, with method of characteristics and finite difference numerical solution, the equations for interior values of ( $V_p$ ) and ( $H_p$ ) is [1]:

$$V_{Pi} = \frac{1}{2} \left[ (V_{i-1} + V_{i+1}) + \frac{g}{a} (H_{i-1} - H_{i+1}) - \frac{f \Delta t}{2D} (V_{i-1}|V_{i-1}| + V_{i+1}|V_{i+1}|) \right] \quad (3)$$

$$H_{Pi} = \frac{1}{2} \left[ (H_{i-1} + H_{i+1}) + \frac{a}{g} (V_{i-1} - V_{i+1}) - \frac{a f \Delta t}{g 2D} (V_{i-1}|V_{i-1}| - V_{i+1}|V_{i+1}|) \right] \quad (4)$$

## 2.1 Boundary Conditions

The boundary conditions used to determine the ( $H$ ) and ( $V$ ) values at the ends of the pipe. These conditions are:

### 2.1.1 Reservoir Boundary Condition (upstream end of pipe)

Where a pipe exits from a reservoir, the head ( $H$ ) assumes the value corresponding to the head of the reservoir water surface. The ( $H$ ) is constant, if the water surface elevation is constant in time. If the reservoir water surface elevation changes with time, so too does ( $H$ ), if the local pipe entrance loss is neglected. This is represented in equation form as:

$$H_{P1} = H_0 \quad (5)$$

The expression for velocity is:

$$V_{P1} = V_2 + \frac{g}{a} (H_0 - H_2) - \frac{f \Delta t}{2D} V_2 |V_2| \quad (6)$$

### 2.1.2 Velocity Boundary Condition (downstream end of pipe)

Assume a valve is closed, so that the velocity decreased linearly from ( $V_0$ ) to zero in ( $T_c$ ) seconds. The velocity behavior is:

$$V_{PN+1} = V_0 \left( 1 - \frac{t}{T_c} \right) \quad , \quad 0 \leq t \leq T_c \quad (7)$$

$$V_{PN+1} = 0 \quad , \quad t > T_c$$

The equation for ( $H_p$ ) is:

$$H_{PN+1} = H_N - \frac{a}{g} (V_{PN+1} - V_N) - \frac{a f \Delta t}{g 2D} V_N |V_N| \quad (8)$$

For any value of ( $V_{PN+1}$ ) including zero.

## 2.2 Representation of surge tank

The height of the surge tank is governed by the highest possible water level that can be expected during operation.

$$S = V \sqrt{\frac{AL}{Atg}} \quad (9)$$

The maximum elevation within a cylindrical surge tank can be found by solve equation 9.

### 3. Case Study

The beginning of the project from the region is called (Five Bridges) to (Wadi abi-Naft) (within the villages of Clans Neda) in the outskirts of Mandali city in Diyala Governorate, Iraq, for distance (54 Km) as shown in Figure 1.

The city's population in 2010 is estimated as (29765 capita). This number is taken from the Statistics Division in Diyala Governorate. Design lifetime of the project is (25 year) from 2016 until 2041, with average population growth is (3%) per year. Then the population in (2041) will be (57447 capita). On assumption that the rate of per capita consumption of water per day is (300 liters) according to the Iraqi Ministry of Planning. So, the total consumption rate for population is (0.2m<sup>3</sup>/sec).

As for agricultural land that will be irrigated in this project, the estimated area of about (37234 acres), according to the information that was obtained from the Water Resources Department in Diyala Governorate. The necessary amount of discharge of farmland is (3.2 m<sup>3</sup>/sec). Therefore, the total discharge for domestic and agricultural purposes is (3.5 m<sup>3</sup>/sec).

Circular unplasticized polyvinyl chloride (PVC-U) pipeline will be used in the design of the pipeline path depending on DIN 8062 specifications for (2009) [10].



Figure (1) The pipeline transport path

### 4. Results and Discussion

The effect of surge tank on a system including a pipe within variable diameter, friction factor

and wave's variable velocity, would be assessed. For this purpose, a code in MATLAB language was written in which the parameters are allowed to be replaced as shown in Figure 2. This code was applied on a published case study (Gubashi and Kubba, in (2010)) [11] and the results were quite satisfactory as shown in Figure 3.

The equations of method of characteristics were solved. The fluctuation of pressure with and without remedy is calculated in 4 statuses (pipe's full length, pipe's 3/4 length, pipe's 2/4 length and pipe's 1/4 length).

In this study, diameters of the pipes that were used are (1m), (1.2m) and (1.4m). The steady state calculations showed that in case of diameter (1m), the pipeline needs six pumping stations, while the pipeline needs three pumping stations when diameter of pipe is (1.2m) and two pumping stations when diameter of pipe is (1.4m).

To remedy the water hammer and high pressure fluctuations in case of valve closure, surge tanks will be used. According to equation 9 the size of surge tanks can be calculated along the pipeline. The calculations showed that the first, second and fourth stages need surge tanks their capacity equals (1475 m<sup>3</sup>), but the third and fifth stages need Surge tanks their capacity equals (1360 m<sup>3</sup>) and sixth stage needs (570m<sup>3</sup>) when the pipe diameter is (1m). The results of the calculations and behavior of pressure fluctuations for first pumping station for protected and unprotected system are shown in Figure 4.

According to Figure 4 showed that the maximum pressure head will decrease by amount (32.38%) when using surge tanks as a remedy from water hammer at downstream of the first stage.

When the diameter of pipe is (1.2m), then, the capacity of surge tanks in first stage is (1700m<sup>3</sup>), in second stage is (1530m<sup>3</sup>) and in third stage is (1475m<sup>3</sup>) which calculated by using equation 9. The locations and elevations of pumping stations and surge tanks can be shown in Figure 5. Additionally, the results of the calculations and behavior of pressure fluctuations for first pumping station for protected and unprotected system are shown in Figure 6. Figure 6 showed that the maximum pressure head will decrease by amount (32.63%) when using surge tanks as a remedy from the risk of water hammer at the end of the first stage.

The capacities of surge tanks in pipe with diameter (1.4m), that will be used to remedy the water hammer and high pressure fluctuations, are (1590 m<sup>3</sup>) at first and second stages which calculated by using equation 9. The results of the calculations and behavior of pressure fluctuations for first pumping station for

protected and unprotected system are shown in Figure 7.

The maximum pressure head at downstream end of the first stage will decrease by amount (30.71%) when using surge tanks as a remedy from water hammer as shown in Figure 7. All the locations of surge tanks are located of distance 0.75 from the end of each stage.

From above, when increasing the diameter of the pipe, the size and number of surge tanks would be decreased. So the total cost of the establishment would be affected.

Now, the wave's velocity is variable and other parameters are constant. The values of wave's velocity are (250m/sec), (300m/sec), (350m/sec) and (400m/sec). The constant parameters are: diameter of pipe is (1200mm), friction factor (0.008) and the valve closure's time is (10sec). The steady state calculations are showed that the pipeline system need three pumping stations.

The surge tanks will be used to remedy the water hammer and high pressure fluctuations by using equation 9 to calculate the size of surge tanks along the pipeline. The calculations showed that the first stage needs surge tanks their capacity equals (1760 m<sup>3</sup>), second stage needs (1530m<sup>3</sup>) and third stage needs (1420m<sup>3</sup>) for all values of wave's velocity. The results of the calculations and behavior of pressure fluctuations for first pumping station for protected and unprotected system are shown in Figures 6, 8, 9 and 10.

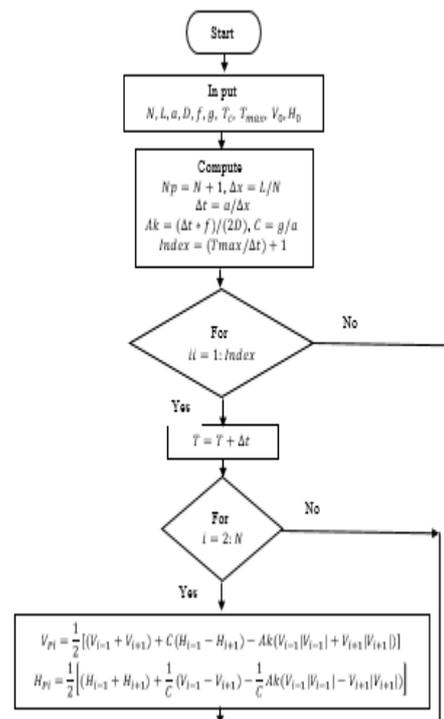
The maximum pressure head at downstream end of the first stage will decrease by amount (36.85%) when the wave's velocity is (250 m/sec), (32.63%) when the wave's velocity is (300 m/sec), (30.25%) when the wave's velocity is (350 m/sec) and (27.66%) when the wave's velocity is (400 m/sec) when using surge tanks as a remedy from water hammer as shown in Figures 6, 8, 9 and 10. All the locations of surge tanks are located of distance 0.75 from the end of each stage.

Now, the friction factor is variable and other parameters are constant. The values of friction factor are (0.007), (0.008) and (0.009). The constant parameters are: diameter of pipe is (1200m), allowable working pressure is (70m), wave's velocity is (300m/sec) and the time required for valve closure is (10sec). The steady state calculations showed that the transport path needs three pumping stations when the values of friction factor are (0.007) and (0.008), but needs four pumping stations when friction factor is (0.009). Surge tanks has been used along the pipeline to remedy the water hammer and high pressure fluctuations. The calculations showed that the first stage needs surge tank its capacity equals (1810 m<sup>3</sup>), second stage needs (1585m<sup>3</sup>) and third stage needs (1245m<sup>3</sup>) when the friction factor is (0.007). The results of the

calculations and behavior of pressure fluctuations for first pumping station for protected and unprotected system are shown in Figure 11. According to Figure 11, the maximum pressure head will decrease by amount (32.21%) when using surge tanks as a remedy from water hammer phenomenon at end of the first stage.

The calculations of friction factor is (0.008) are mentioned earlier and can be shown in Figure 6. Finally when the friction factor is (0.009), the capacity of surge tanks along the pipeline is (1640 m<sup>3</sup>) at first stage, (1415 m<sup>3</sup>) at second and third stages and (570 m<sup>3</sup>) at fourth stage. The maximum pressure head at downstream end of the first stage will decrease by amount (34.08%) when using surge tanks as a remedy from water hammer as shown in Figure 12. All the locations of surge tanks are located of distance 0.75 from the end of each stage.

From above, when increasing the friction factor of the pipe, the size of surge tanks would be decreased. So the total cost of the establishment would be affected.



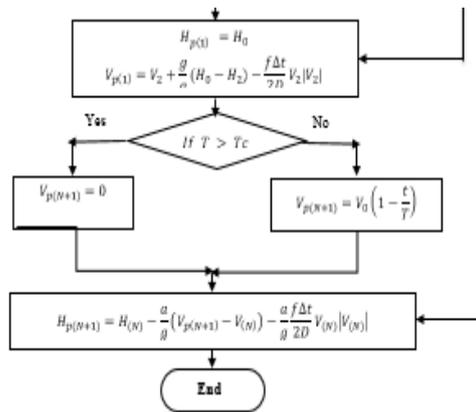


Figure 2: Flow Chart for Valve Closure

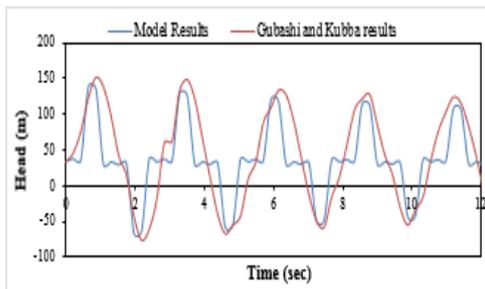


Figure 3: Water hammer simulation results

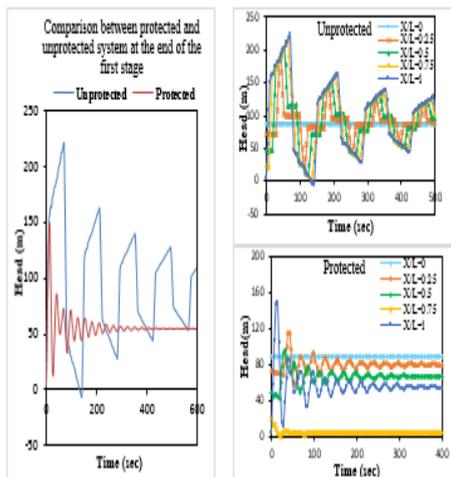


Figure 4: Pressure fluctuations at first stage ( $D=1\text{m}$ ,  $f=0.0077$ ,  $a=325\text{m/sec}$ )

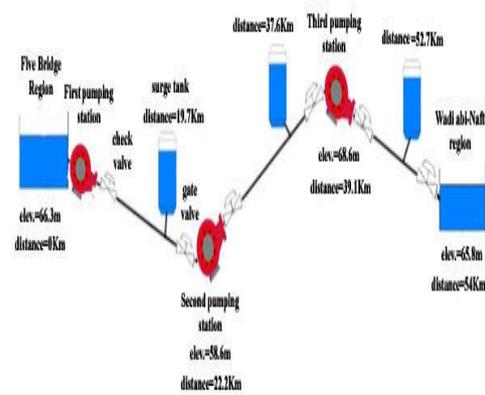


Figure 5: Locations and elevations of pumping stations and surge tanks

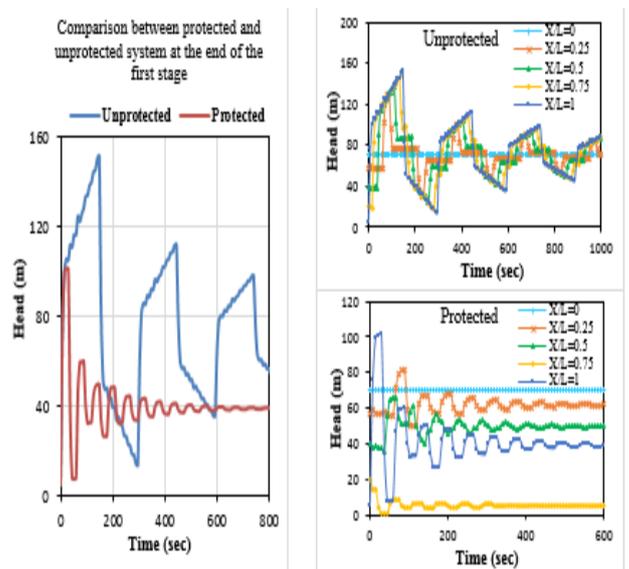


Figure 6: Pressure fluctuations at first stage ( $D=1.2\text{m}$ ,  $f=0.008$ ,  $a=300\text{m/sec}$ )

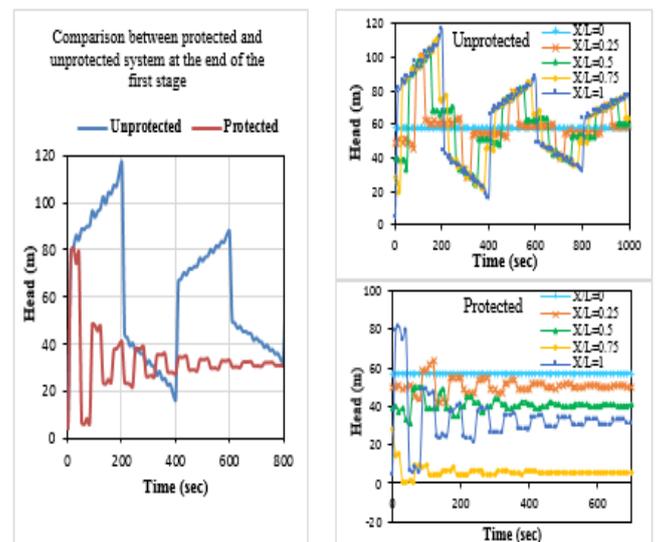
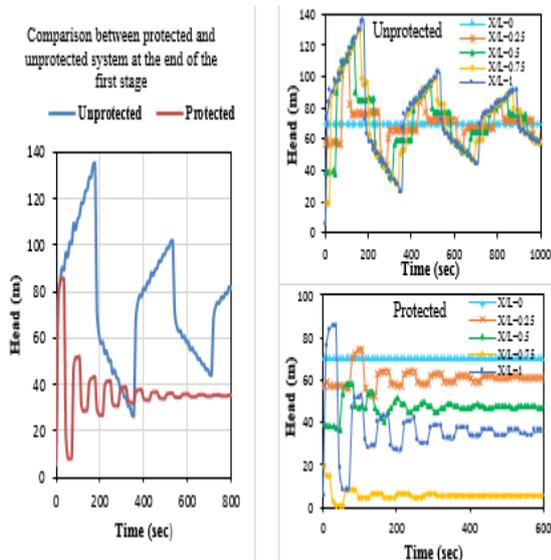
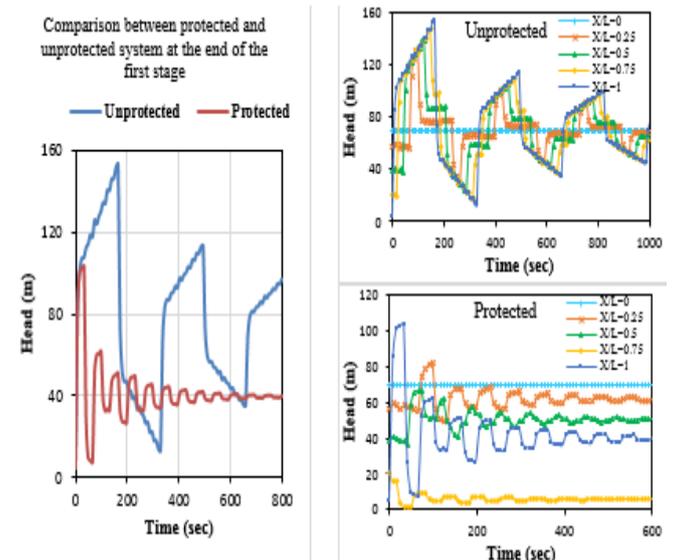


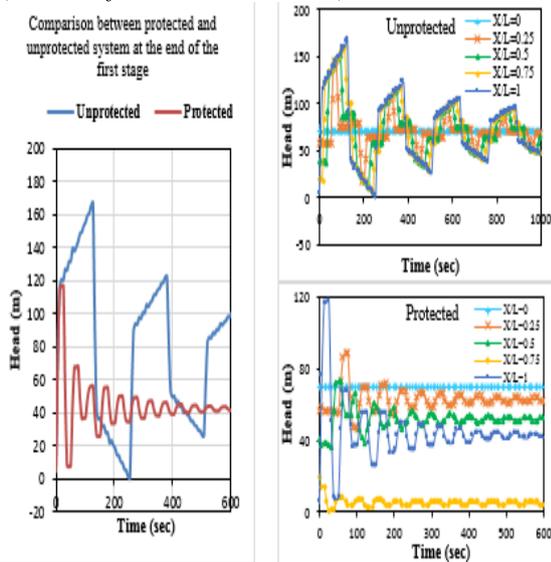
Figure 7: Pressure fluctuations at first stage ( $D=1.4\text{m}$ ,  $f=0.009$ ,  $a=275\text{m/sec}$ )



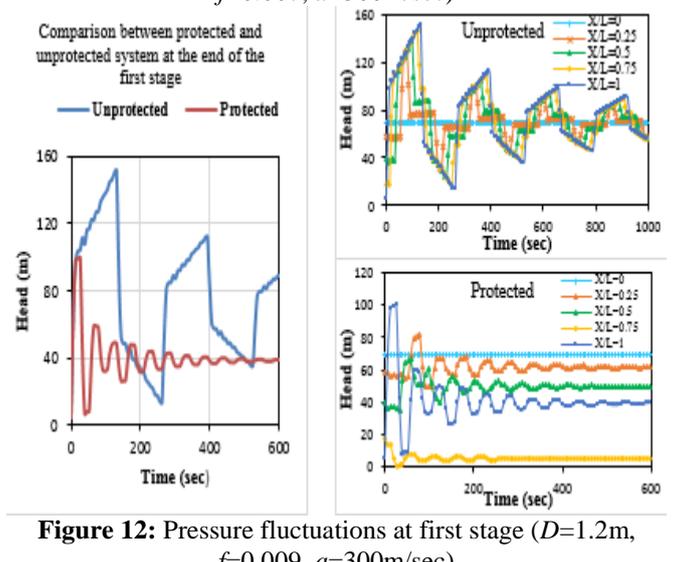
**Figure 8:** Pressure fluctuations at first stage ( $D=1.2m, f=0.008, a=250m/sec$ )



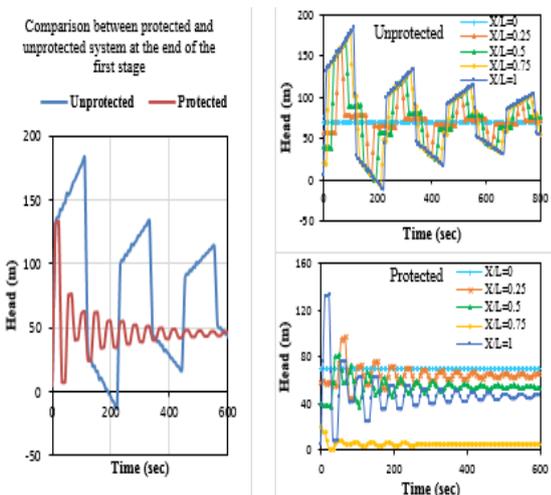
**Figure 11:** Pressure fluctuations at first stage ( $D=1.2m, f=0.007, a=300m/sec$ )



**Figure 9:** Pressure fluctuations at first stage ( $D=1.2m, f=0.008, a=350m/sec$ )



**Figure 12:** Pressure fluctuations at first stage ( $D=1.2m, f=0.009, a=300m/sec$ )



**Figure 10:** Pressure fluctuations at first stage ( $D=1.2m, f=0.008, a=400m/sec$ )

## 5. Conclusions

This study showed the effectiveness of surge tanks for controlling the pressure values along the pipeline. The volume of surge tanks have been changed from one stage to another, it was found that the volume of surge tank increased when increased the length of pipeline. When increasing the diameter of the pipe, the size and number of surge tanks would be decreased and the pressure fluctuations would be small. The increment of the wave's velocity would be decreased the pressure fluctuations. And finally, the increment of friction factor decrease the size of surge tanks and decrease the pressure fluctuations and energy dissipation would occur much rapidly.

## Notations

$a$	Wave celerity ( $m/sec$ )
$L$	Length of pipe work ( $m$ )
$D$	Inner diameter of pipe work ( $m$ )
$f$	Darcy-Weisbach coefficient
$p$	Pressure of water in pipes ( $Pa$ )
$V$	velocity of water in pipes ( $m/sec$ )
$H$	Pressure head of water in pipes ( $m$ )
$g$	Acceleration due to gravity ( $m/s^2$ )
$z$	Elevation head or potential energy ( $m$ )
$t$	Time interval ( $sec$ )
$T_c$	Time of valve closure ( $sec$ )
$\Delta t$	Time steps
$A$	Area of pipe ( $m^2$ )
$S$	Maximum elevation within a cylindrical surge tank ( $m$ )
$At$	Area of the surge tank ( $m^2$ )

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