# Effects of Using Different Valves Types on Water Hammer Transients

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*Abstract* — **In general the severity of transient associated with water hammer depends upon the rate of change of the flow conditions, for example the rate of valve closure or opening determines for any pipeline the magnitude of the resulting transient. A well understood analysis of transient propagation may allow potentially suppression transients. However, this is not always possible for the range of reasons and in this case it may be necessary to incorporate surge control or suppression devices. In this paper, detailed study of three different valve types of commonly used are included to determine the best functional valve. In this computational investigation, method of characteristics has been implemented with appropriate B.C. to study the effect of using different valves. The three different valve types have been investigated subjected to a different closing time. It has been found that the globe valve is the proper valve to be used at slow closure process while butterfly valve is better in fast closure process in the view of minimizing the water hammer peak pressure.**

*Index Terms:* **water hammer, water transient, valve closing, different valves, closing time.**

## I. INTRODUCTION

The phenomenon of water hammer is generally poorly understood in the water industry. This is due to the difficulty in carrying out a comprehensive analysis, which considers all the system components and their interaction. It is not uncommon for designers to simply add a nominal pressure increase to allow for water hammer. This approach can be too conservative and unnecessarily costly and in some cases there have been system failures due to inadequate water hammer protection being provided.

Water hammer due to valve closure (for example) can cause pressures over the steady state values, while valve opening can cause seriously low pressures, possibly creating the flowing liquid vaporizes inside the pipe.[1]

Different valve types are available and it is used widely in the hydraulic systems without (sometimes) prober guide for choosing. Normally dynamic Characteristics of Valves given by manufacturer are to assist the design professional in predicting valves movements and behavior without dashpots and other specialized hydraulic controls.

It is not intended to provide all of the information necessary for selecting a valve but rather to explain in engineering terms the cause of valve hammer and the inherent closing characteristics of various valves that contribute to this phenomenon. [2,3].

With this knowledge, the design professional can predict before start-up the systems the system behavior and if the valve problems may occur and the degree of damages. Other design issues such as head loss and cost are equally important factors and should be considered in making the final valve selection.[4]

A new methodology will be explained to generate valve response data and predict valve behavior in any application. This is a tall order, but it is hoped that this methodology will be a good starting point so that when it is combined with field experience, a proven valve selection methodology can be adopted in the water and wastewater industries.

## II. NOMENCLATURE

Latin symbols

| | |
|---|---|
| $a$ | water hammer wave speed, m/s |
| $L$ | pipe length, m |
| $E$ | modulus of elasticity, N/m2 |
| $H$ | source head, mw |
| $K$ | Bulk's modulus, N/m2 |
| $P$ | pressure head, m |
| $t$ | time, sec |
| $T_c$ | Valve closing time, sec |
| $V$ | flow velocity, m/s |
| $V_{op}$ | Valve opening |

## III. WATER HAMMER MODEL

In this investigation the water hammer transient in piping systems is computationally investigated by the method of characteristics, [5]. The equations governing the fluid flow transient in the drive pipe are derived based on the dynamic equilibrium during the transient. The system of equations constitutes of two hyperbolic partial differential equations of first order [6]. The method of characteristics was used to transform the two equations into ordinary differential equations. The characteristic values were calculated and the corresponding characteristic functions were solved numerically over the characteristic grid. The pipe downstream end boundary condition constitutes an algebraic second order equation, while the upstream boundary condition is of constant reservoir head. The examine system compromise of two

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tanks connected with a fixed pipe diameter and at the end of the pipe just next to the downstream reservoir the system equipped with a valve.

## IV. GOVERNING EQUATIONS

As in [6, 7] the following two-equation model for fluid variables: *P*, pressure *V*, fluid flow velocity.

$$\frac{\partial P}{\partial t} + K^{'}\frac{\partial V}{\partial x} = 0 \qquad (1)$$

$$\frac{\partial V}{\partial t} + \frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\tau_w}{A}\frac{\pi D}{\rho} = 0 \qquad (2)$$

Where: the wall shear stress is:

$$\tau_w = \frac{f}{4}\rho\frac{V^2}{2} \qquad (3)$$

And the modified bulk modulus is:

$$K^{'} = \frac{K}{1 + \left[\left(\frac{K}{E}\right)\left(\frac{D}{t}\right)\right]\left(1 - \nu^2\right)} \qquad (4)$$

The two partial differential equations (1, 2) are transformed along the characteristics to an ordinary differential equation as[8]:

$$\left.\begin{aligned} &\pm\frac{1}{\rho a}\frac{dp}{dt} + \frac{dV}{dt} + \frac{fV|V|}{2D} = 0 \\ &\frac{dx}{dt} = \pm a \end{aligned}\right\} \qquad (5)$$

Where *+ve* sign for the positive characteristics and *–ve* sign for the negative characteristics and *a* is water hammer wave speed

$$a = \sqrt{\frac{K^{'}}{\rho}} \qquad (6)$$

The upstream boundary condition is given by:

$$P_t = P + \rho\frac{V^2}{2} \qquad (7)$$

The downstream boundary condition is given by the valve oscillatory part superimposed on linear motion, which describe the valve opening ratio $V_{op}$ at any given time t.

$$V_{op} = \left(1 - \frac{t}{T_c}\right) \qquad (8)$$

The valve discharge coefficient as a function of valve opening, $V_{op}$ , has been best fitted from the manufacturer data [9]. And it is found that:

For globe valve an exponential function has been used as:

$$C_d(t) = a \times b^{\left(c^{Vop}\right)} - a \times b \qquad (9)$$

In which the best fit constants are;
***a = 0.5226260928, b = 0.01652205336, and c = 0.9706719746***

For butterfly valve a third order polynomials used as:

$$C_d(t) = aV_{op} + bV_{op}^{\ 2} + cV_{op}^{\ 3} \qquad (10)$$

In which the best fit constants are; ***a = 0.004289002366, b = 2.478851533 x 10$^{-5}$, and c = 1.057440809 x 10$^{-7}$***

For cone valve a third order polynomials used as:

$$C_d = a \times V_{opening} + b \times \left(V_{opening}\right)^2 + c \times \left(V_{opening}\right)^3 \qquad (11)$$

In which the best fit constants are; ***a=0.001370852844, b=6.496018731 x 10$^{-5}$ and c=2.144143958 x 10$^{-7}$***

The valve head loss across the valve is used as:

$$h_{lv} = \frac{1}{C_d^{\ 2}} \qquad (12)$$

The valve head loss along with the ***+ve*** characteristics are used to determine the instantaneous pressure and flow rate at the valve boundary.

## V. INPUTDATA

Pipe parameters used in this investigation:

Upstream reservoir head= 100 m, downstream reservoir head= 10 m, pipe diameter = 2 m , Length of pipeline = 100 m, friction factor = 0.02, wave speed, a = 1000 m/sec. valves type: butterfly valve, globe valve, cone valve.

In the pre-described system the time required to the wave reflection for a valve can be found as per the following [9]

$$T = \frac{2L}{a} = \frac{2x100}{1000} = 0.2\sec$$

Where *T* equal the time required for each cycle

The proposed times for valve closure at this study of the valve behavior are as per the following:

A. Fast closure: It is proposed to study the system in this case at a value closing time of 0.17 second required to perform complete closure procedure , i.e. before the reflection of the wave of water hammer from the reservoir reach the valve, almost just before the wave reflection
B. Slow closure: It is proposed to study the system in this case at a value closing time of 0.80 second required to perform complete closure procedure, which is 4 times the time required for wave reflection
C. Very Slow closure: It is proposed to study the system in this case at a value closing time of 2.50 second required to perform complete closure, which is about 12.5 times the time required for wave reflection

## VI. RESULTS AND DISCUSSIONS

Figure (1, 5 and 9) display the effects of sudden closing valve for all types of valves, the maximum pressure rise up to (2176) meter of water is attained at the valve location. It can be seen that the same wave are repeated with the same wave shape with a rate of damping due to the existence of both viscous damping and entrance dissipative boundary condition. As a result, the system is undergoing oscillatory pressure wave form. As the pressure wave progresses back and forth between the reservoir and valve a full water hammer is developed.

Figure 2 displays the time history of pressure at the valve location when butterfly valve is used as a control valve. During fast closure, the pressure trace could be divided into two parts. The first part during the closing time is named as the transient pressure and the second part begins just after the valve closing period and is named oscillatory pressure. The transient part attains peak value almost just before the end of closing stroke. The oscillatory part attains cyclic peaks with a single water hammer wave frequency. The attenuation of the oscillatory part is in part due to the dissipative viscous friction and the other contribution to the dissipative boundary condition when the flow reverses to the reservoir. It can be seen that the peak value of the transient is equal to (2161) meter water and the oscillatory part reaches (2068) meter with a decreasing rate (damping) due to energy dissipation of order (0.11).

For butterfly valve, Figure 3 displays the time history of pressure at the valve location during the slow closure. It can be noticed that the graph has a sharp end edges at the peak values. It can be noticed also from the figure that the pressure in the two parts is clean from any high harmonics. The transient part attains peak value almost just before the end of closure process. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. It can be seen that the peak value of the transient is equal to (912) meter of water and the oscillatory part reach (895) meter of water with a decreasing rate due to energy dissipation of order (0.04)

Figure 4 displays the time history of pressure at the valve when butterfly valve is used as a control valve for a very slow closure. In this case the transient part has a smooth curvature at the peak values and the oscillatory part has sharp edged peaks. This difference in shape is due to the slow closure time process. It is seen also from the figure that the pressure in the oscillatory part is clean from any high harmonics, while transient part attains peak value almost just before the end of closing process. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. It can be noticed that the peak value of the transient is equal to (240) meter of water and the oscillatory part reach (210) with a decreasing rate due to energy dissipation of order (0.003)

Figure 6 displays the time history of pressure, when the globe valve is used as a control valve for fast closure. It is seen from the figure that the pressure in the two parts is clean from any high harmonics. The transient part attains peak value almost just before the end of closing process. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. It is recorded that the peak value of the transient is of order (1426) meter of water and the oscillatory part reach (1379) meter with a decreasing rate due to energy dissipation of order (0.067)

Figure 7 displays the time history of pressure at slow closure of the global valve. It is seen from the figure that the pressure in the two parts is clean from any high harmonics. The transient part attains peak value almost just before the end of closing. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. It is clear from the figure that the peak value of the transient are equal to (629) meter and the oscillatory part reach (455) meter with a decreasing rate (damping) due to energy dissipation equal to (0.01515).

Figure 8 displays the time history of pressure at the globe valve during very slow closure. It is seen from the figure that the pressure in the oscillatory part is clean from any high harmonics, while transient part attains peak value almost just before the end of closing. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. It can be seen that the peak value of the transient is equal to (221) meter and the oscillatory part reach (118) meter with a decreasing rate due to energy dissipation of order (0.0002), and it can be noticed that there is a large difference between oscillatory and transient pressure due to the slow closure of valve which causes a pressure head equalization with the pressure at the downstream reservoir head.

By studying the cone valve shown in Figure (10) for fast closing process it is seen that the pressure in the two parts is clean from any high harmonics. The transient part attains peak value almost just before the end of closing. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. It can be seen that the peak value of the transient is of order (2030) meter water and the oscillatory part reaches (1948) meter with a decreasing rate due to energy dissipation equal to (0.1).

On the other hand for the same valve during slow closure figure 11 shows that the pressure in the oscillatory part is clean from any high harmonics, while in the transient part has a high value attained almost just before the end of closing process. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. The attenuation of the oscillatory part is in part due to the dissipative viscous friction and the other contribution to the dissipative boundary condition when the flow reverses to the reservoir. It can be seen that the peak value of the transient is of order (829) meter of water and the oscillatory part reach (551) meter with a decreasing rate due to energy dissipation equal to (0.02)

Finally Figure 12 displays the time history of pressure for cone valve during very slow closure process. It is seen from the figure that the pressure in the oscillatory part is clean from any high harmonics and its value is reduced to a significant value. The transient part attains peak value almost just before the end of closing. The oscillatory part attains a cyclic peak with the single water hammer wave frequency. The peak value of the transient is of order (271) meter and the oscillatory part reaches (126) meter of water with a decreasing rate due to energy dissipation equal to (0.0003)

Extensive transient stability studies on the pipe valve system is shown in Table 1 provided above with a conventional fast, slow and very slow valve closing scheme. The effects of different valve closing times of the conventional globe, cone and butterfly valving scheme have been studied in detail. The following times of closing have been considered in studying the given system, {$T_c$ = 0.17s; 0.80s and 2.50s}. In general, the fast closing process for all valves types produces full water hammer pressure. That is the pressure magnitude of order that of sudden ($T_c$=0) closing process. However, when the conventional slow valving scheme with the above valve actuation times is used, the system becomes more stable, and it has good results when the system has a very slow valving which is very difficult to be applied at real for long pipe system. This Detailed studies indicate that the closing time $T_c$ influences the pressure peaks significantly. Therefore, it is very desirable to study the system component for any hydraulic system and to design it in order to increase the $T_c$ to as slow as possible.

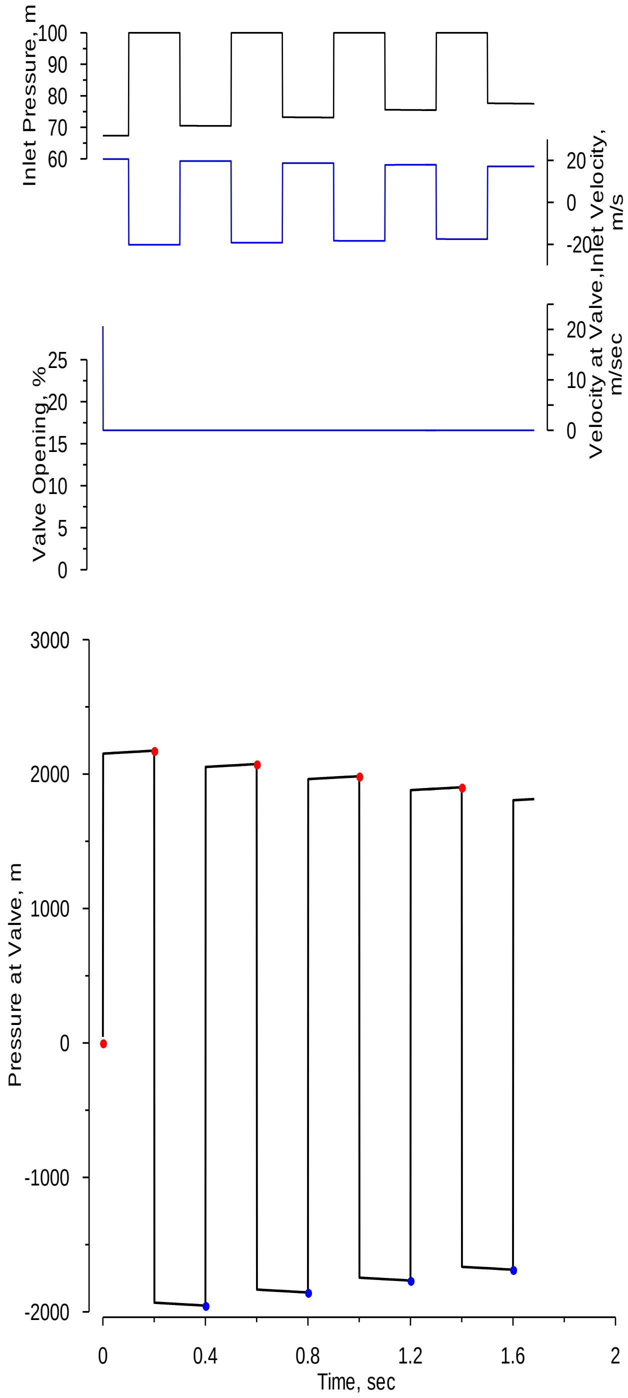

Figure 1. Pressure Transient for Butterfly Valve at Sudden Closure

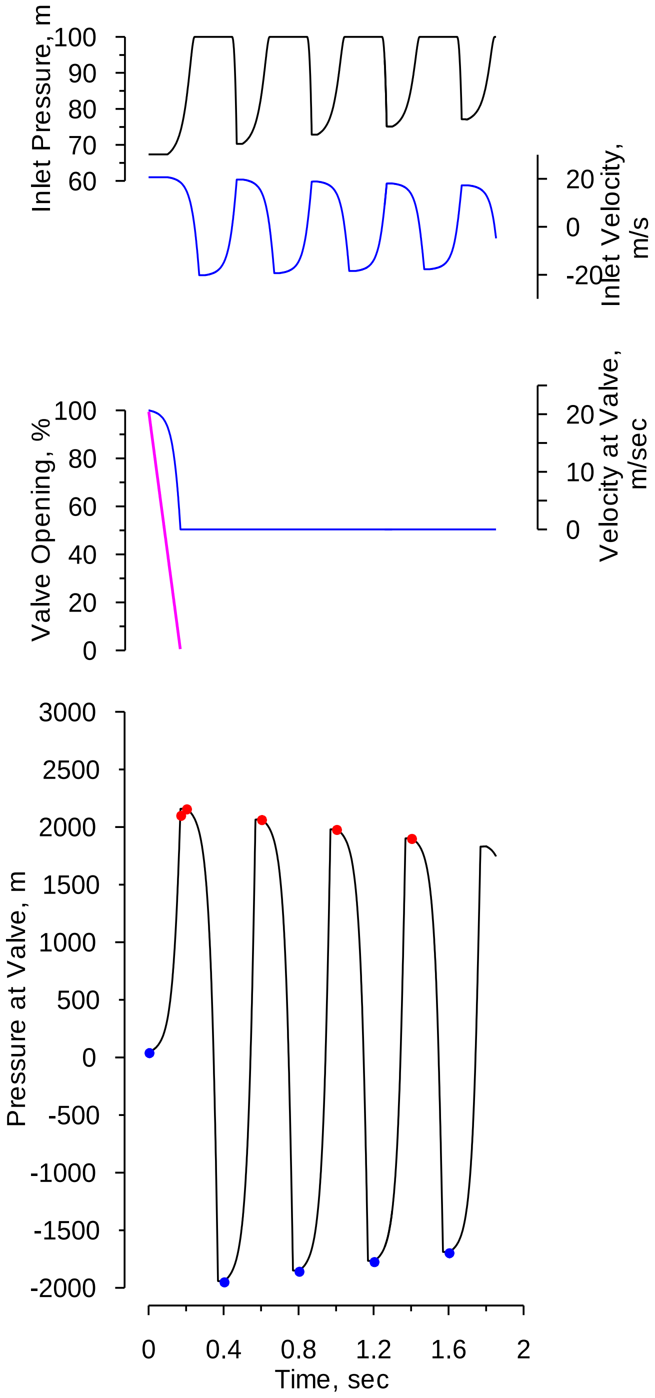

Figure. 2 Pressure Transient for Butterfly Valve at Fast Closure

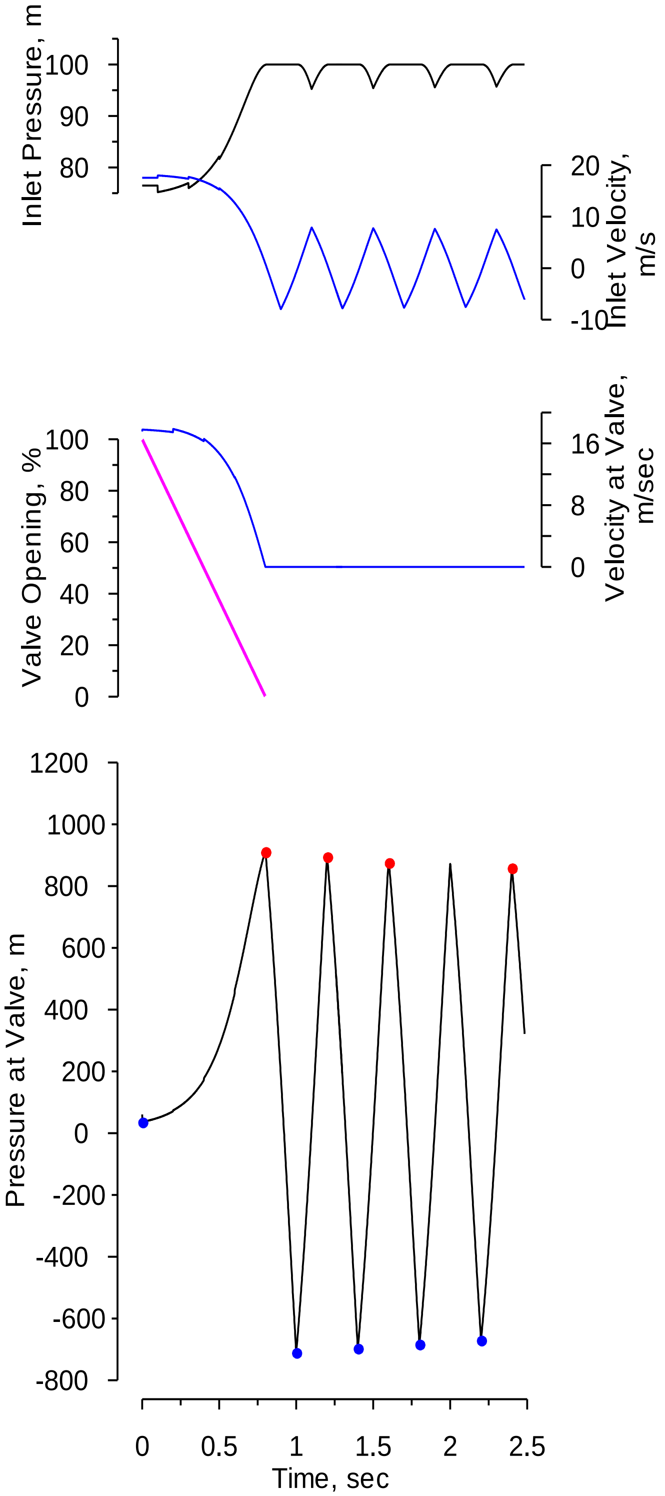

Figure 3. Pressure Transient for Butterfly Valve at Slow Closure

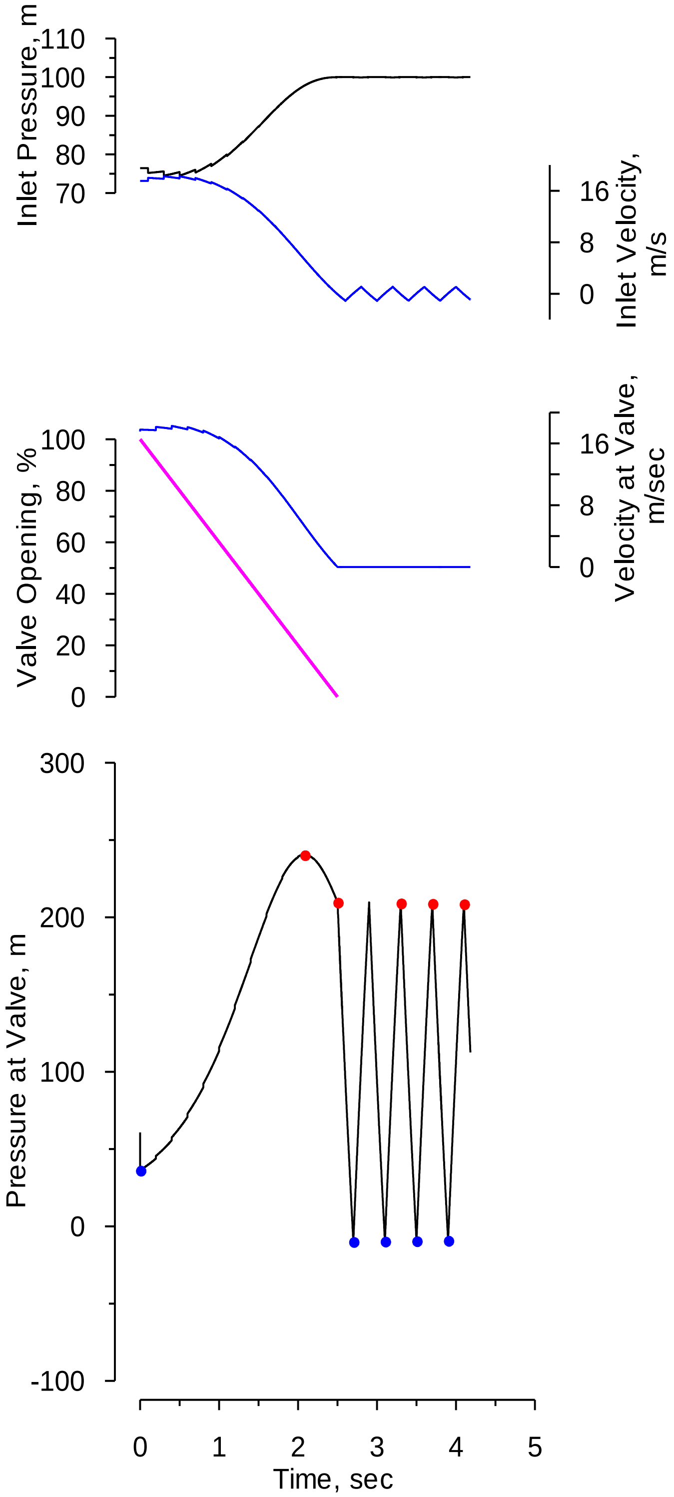

Figure 4. Pressure Transient for Butterfly Valve at Very Slow Closure

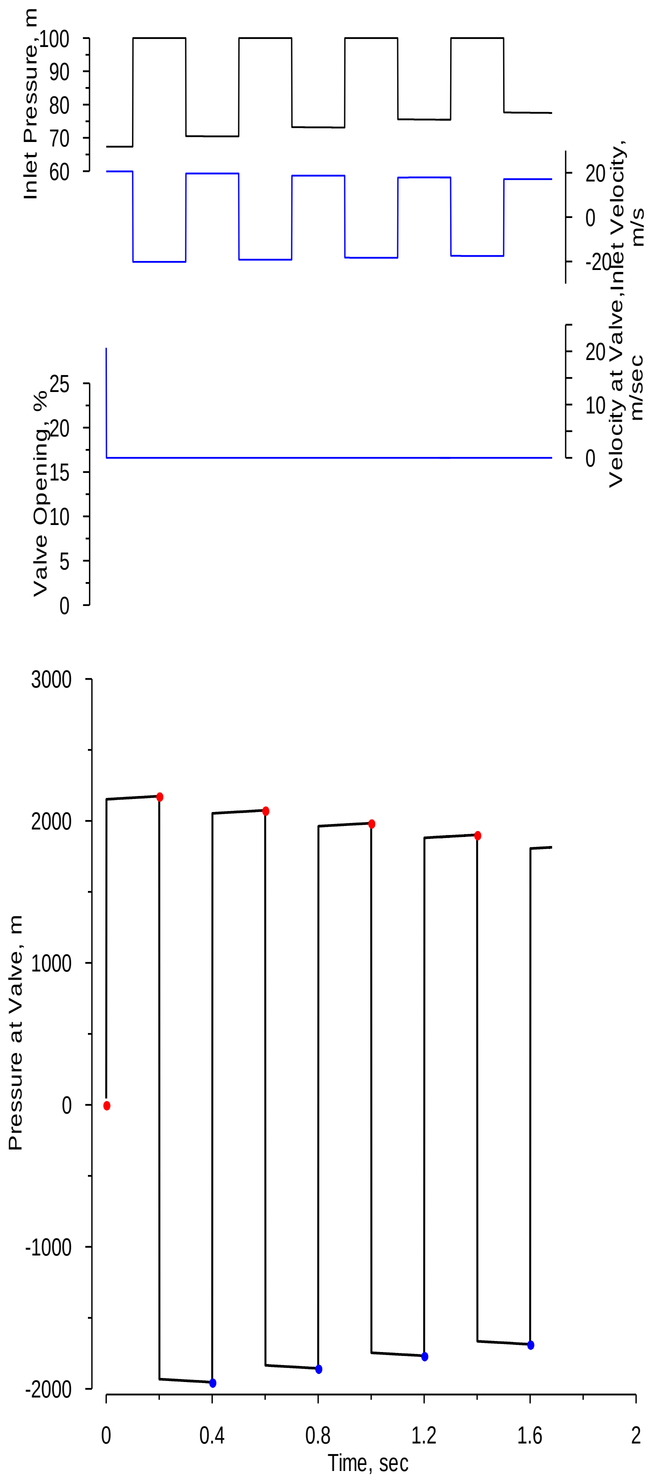

Figure 5. Pressure Transient for Globe Valve at Sudden Closure

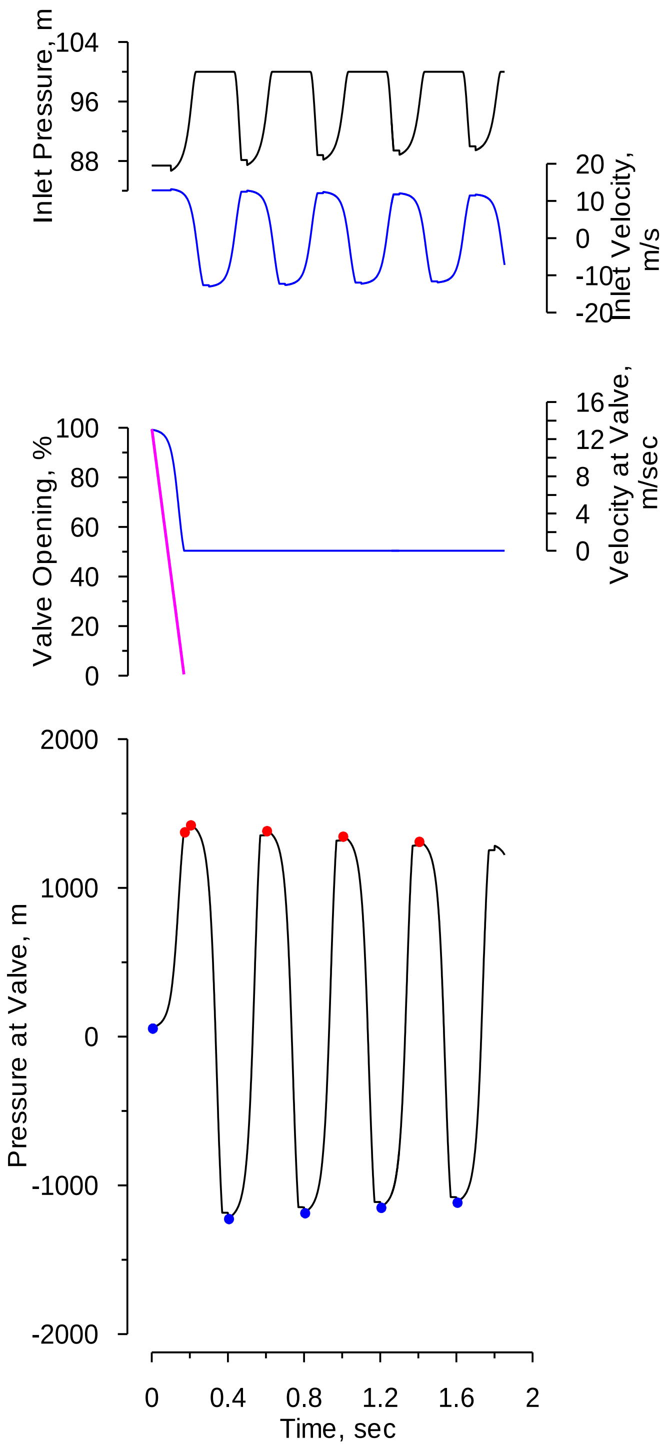

Figure 6. Pressure Transient for Globe Valve at Fast Closure

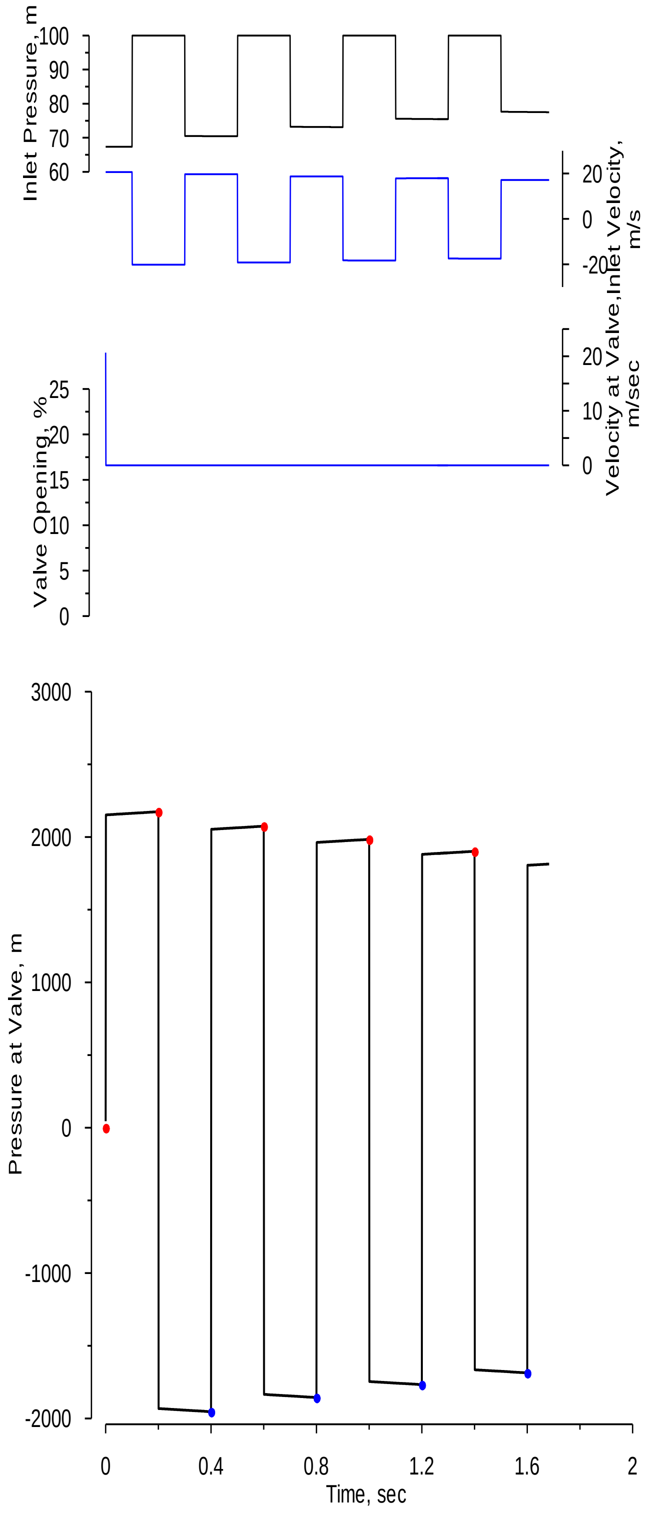

Figure 9. Pressure Transient for Cone Valve At Sudden Closure

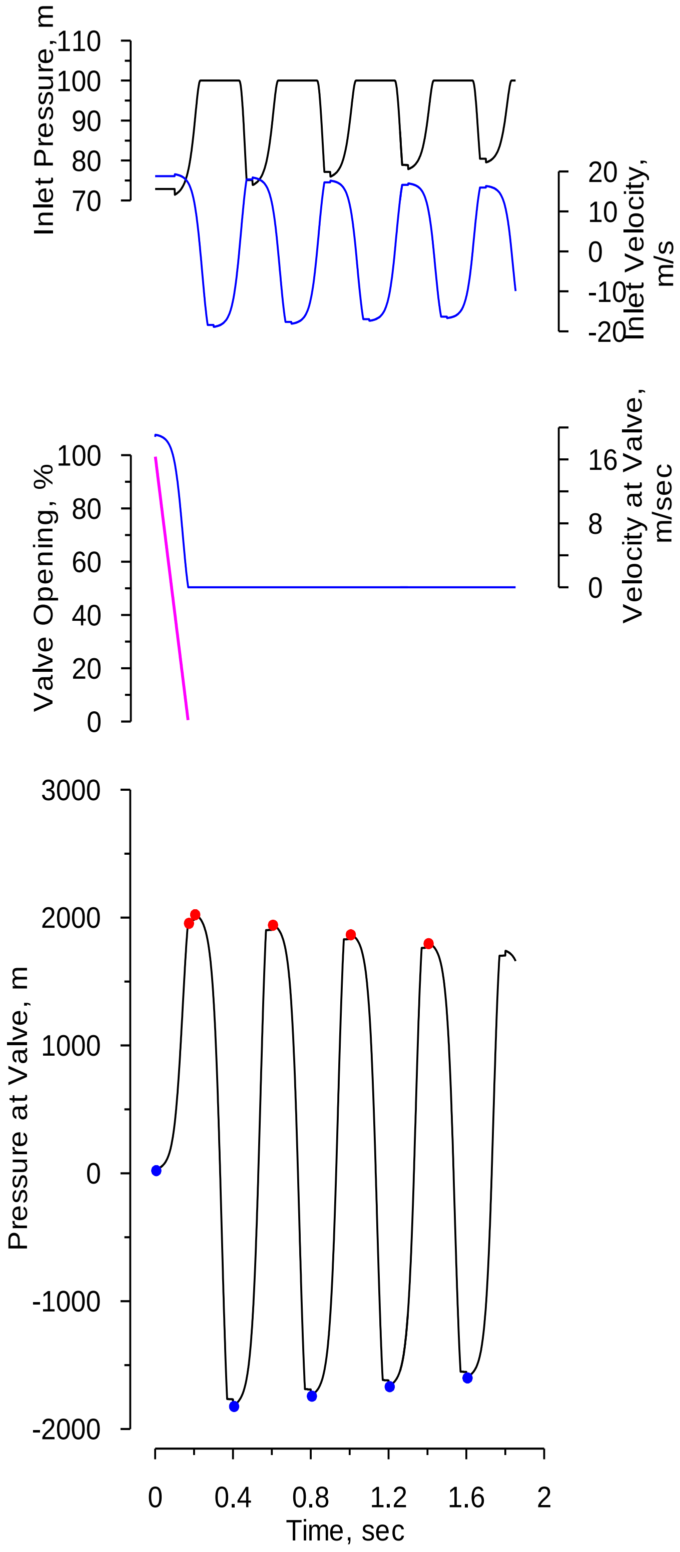

Figure 10. Pressure Transient for Cone Valve at Fast Closure

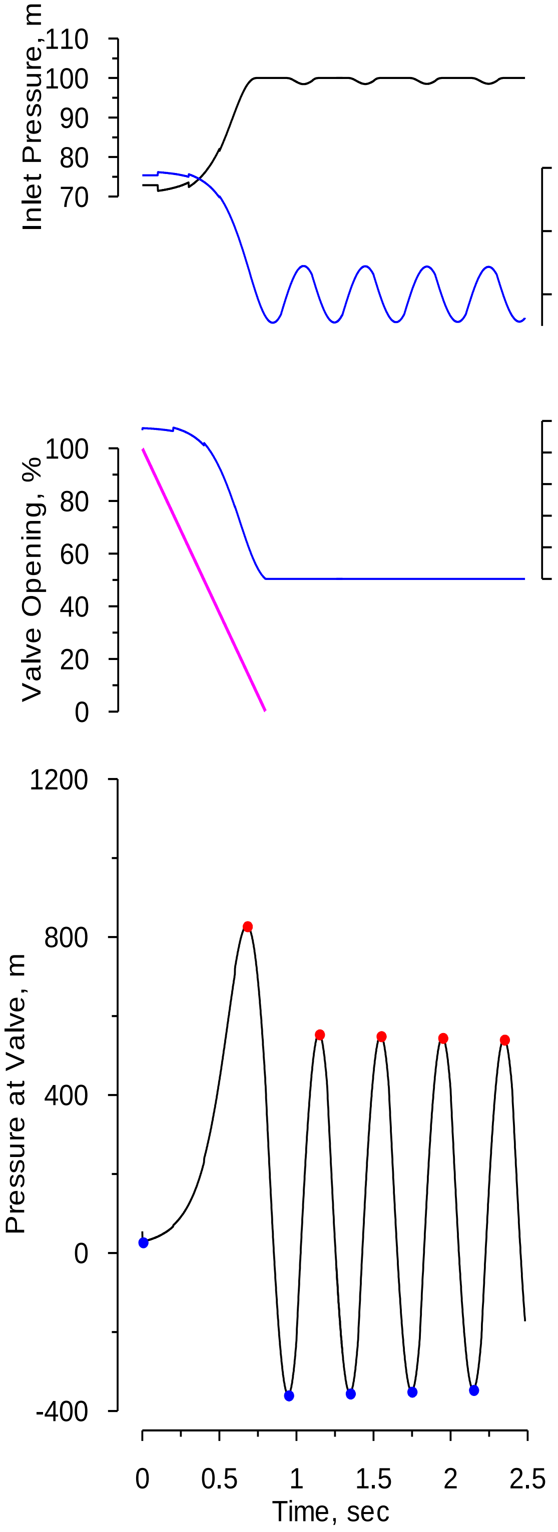

Figure 11. Pressure Transient for Cone Valve at Slow Closure

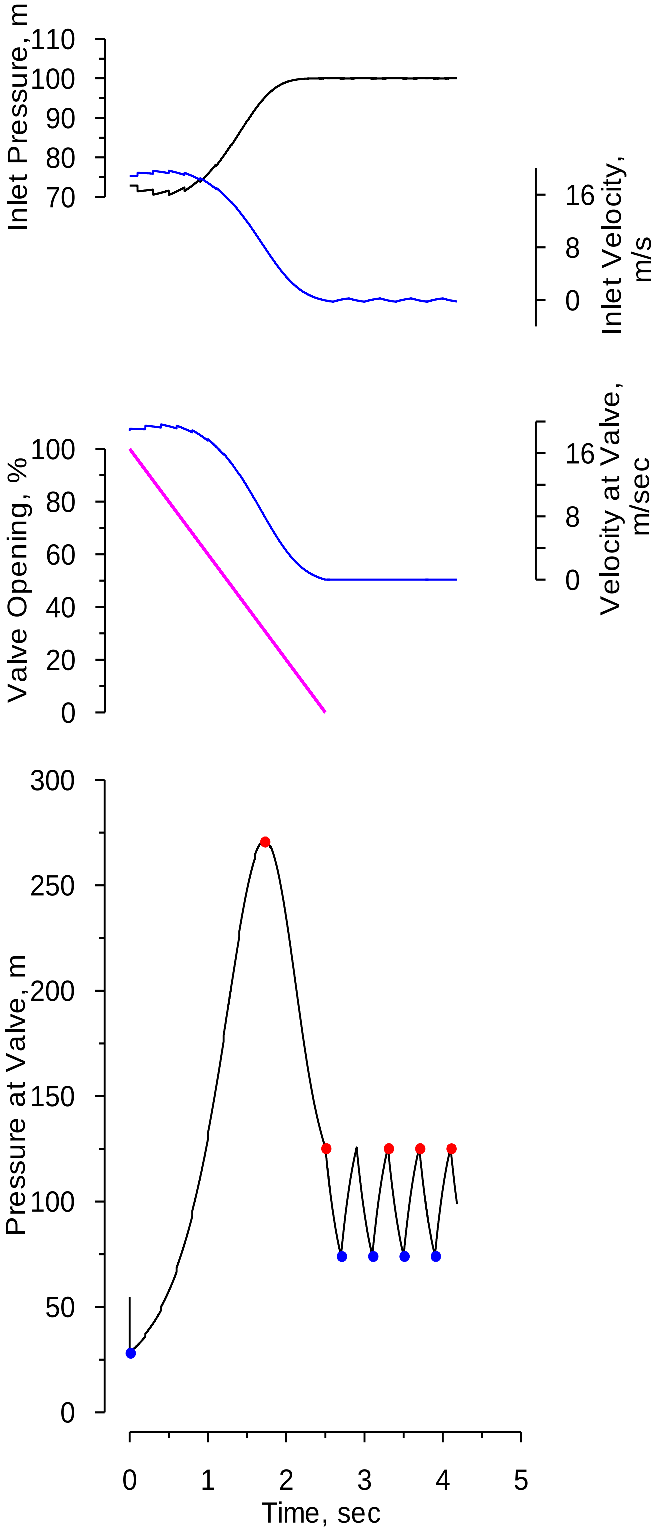

Figure 12. Pressure Transient for Cone Valve at Very Slow Closure

As it is seen, closure time of the valve is an important issue in the valve operation, and it has been investigated for different values with timing, as it is known from previous works that as the closure time decrease the attained transient peak increase.

TABLE 1. Effects of Different Valves on the System at Different Operation Condition

| **Valve type** | **Closing Process** | **Transient Pressure** | **Oscillatory Pressure** | **Rate of Damping** |
|---|---|---|---|---|
| Butterfly valve | Fast closing | 2161 | 2068 | 0.11 |
| | Slow closing | 912 | 895 | 0.04 |
| | V. Slow closing | 240 | 210 | 0.003 |
| Globe valve | Fast closing | 1426 | 1379 | 0.06749 |
| | Slow closing | 629 | 455 | 0.01515 |
| | V. Slow closing | 221 | 118 | 0.0002 |
| Cone valve | Fast closing | 2030 | 1948 | 0.1 |
| | Slow closing | 829 | 551 | 0.02 |
| | V. Slow closing | 271 | 126 | 0.0003 |

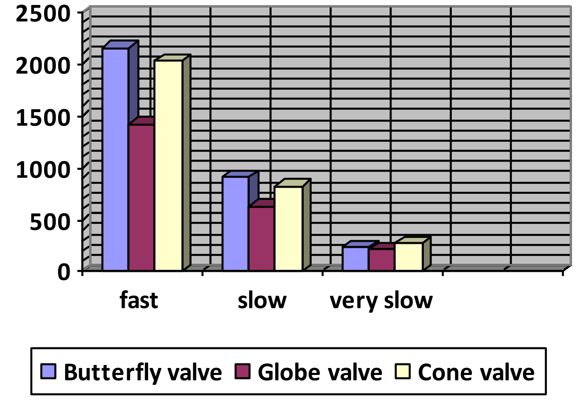

Figure 13.Comparison Results for Different Valves at the Different Operation Condition

## VII. CONCLUSIONS AND RECOMMENDATIONS

The results show that the best flow control during all closure closer can be obtained by using the globe valve while the cone valve shows a good results in slow closing as well for the butterfly valves, on the other hand, the good results can be obtained in very slow control.

Based on the results it can be suggested that for the slow operation of valve in a pipeline it is recommended to use the globe valves and cone valves because it gave the proper behavior with minimum pressure rise during water hammer phenomena. While in the fast closures process of valves which is the most common case in industry due to long pipeline in service it is proposed to use the globe valves, for example, in the real situation and in the application with a long pipe length, there is less potential for rapid flow reversal and the closure process will be relatively fast type. On the other hand, a short system pipeline feeding elevated water tank will experience an extremely rapid flow reversal and the valve closure process will be relatively slow type.

It is recommended for further work to study the effects of the dynamic characteristics of each practical valves during flow control process to find if the designers need to incorporate mechanical of valves with a suppression system of vibration for moving parts . This feature with the valve control protocol will contribute and control much more the water hammer suppression.

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## BIOGRAPHIES

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