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EFFECT OF FRICTION SOURCE IN THE HYDRAULIC TRANSIENT IN A PIPELINE SYSTEM USING METHOD OF CHARACTERISTICS

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ABSTRACT

Numerical modelling is real need to analyze transients, since the system of equations representing the phenomena does not have an analytical solution because of the nonlinear term of friction losses. Consequently, the presents study applies the method of characteristics to determine the pressure change variation along a simple pipeline system resulted from hydraulic transient, along with using two different approaches in approximating of the friction term. The performance of numerical scheme is verified, considered against many scenarios and different parameters in the simple pipeline system. It was found that the two models gives slightly different results in terms of simulating the velocity and the pressure wave velocity in the undertaken scenario of pipe filled system. But follow the same scheme. Also it was approved that the first approach is linear while the second one is not. The effect of wave speed was proven to be a significant influence on the transient state. The study also shows that Flow velocity and pipe frictional coefficient also affects on pressure head proportionally. The computational time interval which gives stable results was proven to be chosen according to Courant stability condition. A MATLAB code has been written and then used in the simulation of test cases.

KEYWORDS: Pipeline, Friction Source, Hydraulic Transient, Tank.

1. INTRODUCTION

Safe and efficient operation of pipeline systems is a challenging hydraulic task Chaudhry, (1979), in which it is difficult to predict or to anticipate the effects of changing the conditions of a pump, valve, tank, or any other hydraulic components. It is also difficult to determine how quickly the operational condition of a pump, valve, tank, or other components can be changed without causing unacceptable performance or damage the pipeline system Chaudhry, (1979). Due to its destructive effects that can cause, hydraulic transient have been studied by many researchers for more than a century but most of them were not considering the effect of friction source in the system of the hydraulic transient. Its analysis is very important in determining the values of transient pressures that can result from flow control operations; also the analysis results are important to establish the design criteria for system equipment and devices and operational guidelines for hydraulic systems in order to provide an acceptable level of protection against system failure due to pipe collapse or break (Schmitt,2006, Tijseeling, 2007a and 2007b). Numerical models are used to analyze hydraulic transients due to the complexity of the equations needed to describe the transients, besides carrying out experiments to evaluate the various operational scenarios is time consuming, costly and the results may not apply to unanticipated situations. An effective numerical model allows the hydraulic engineer to analyze potential transient events and to identify and evaluate alternative solutions for controlling hydraulic transients, thereby protecting the integrity of the hydraulic system. Equations for the conservation of mass and momentum are used to describe the hydraulic transient flow in closed conducts commonly known as water hammer. These equations are commonly referred as to as momentum and continuity equations and they are set of partial differential equations since the pressure and flow velocity in the transient state are functions of time and distance Chaudhry, (1979). The problem of water hammer was studied by many researchers as mentioned by Ghidaoui, (2005). Back to the beginning of the nineteenth century, many researchers such as Carpenter, (1893) and Frizell, (1898)) tried to develop expressions relating pressure and velocity changes in a pipe. Later on Joukowsky and other in their famous paper published in 1904, they attracted greater attention by producing the best known equation in the hydraulic transient flow theory in which the compressibility of water and elasticity of pipe wall were ignored, which is called the ''fundamental equation of water hammer.'' they also studied the use of surge tanks and air chambers and wave reflections from an open branch. Allievi ,(1904) developed a general theory for water hammer showing that the convective term in the momentum equation was negligible. The widely used two parameters was introduced that characterize pipeline and valve behaviour and produced charts for uniform valve closure showing the pressure rise at the valve. Later on and due to the combined efforts of many researchers such as Parmakian, (1963), Zhang, (2003), Wood (2005), and their refinement to the governing equations of hydraulic transient in closed conduct had resulted in classical mass and momentum equations for one dimensional water hammer flows. Although these classical equations contain all physics necessary to model wave propagation in simple and complex pipe systems (Boulos, 2005), ever since these equations had been analyzed, discussed, re-derived and elucidated in many texts and journals attempting to improve them and getting more efficient results while solving them. Various methods were developed to analyze the hydraulic transient flow problem in pipes among of these the method of charactristic has been used in simulation the pipeline system such as in work of Guo, (2012) and Lee, (2013). These methods range from approximate analytical solutions were the friction term in the momentum equation is either linearized or neglected, to the numerical approaches of the system with the non-linear friction terms. Hence, this paper aims to develop a computer model for transient flow in closed conduct using MATLAB program using the method of characteristics and finite difference method with two different approaches for the fiction term approximations and then compare and analyse the two methods of friction term approximation used for transient flow calculations. Furthermore, apply the model to many scenarios to study the transient phenomena and factors affecting on it.

2. MATHEMATICAL MODEL

The following equations are the basic momentum and continuity equations for hydraulic transient in closed conduct. These equations were derived and simplified based in some assumptions; see figure 1, and limitations in which can be found in Chaudhry, 1979 and 2014, Chaudhry 1987, Ghidaoui 2005.

$$L_1 = \frac{\partial H}{\partial t} + \frac{a^2}{g}\frac{\partial V}{\partial x} = 0 \qquad (1)$$

$$L_2 = \frac{\partial V}{\partial t} + g\frac{\partial H}{\partial x} + \frac{f}{2D}V|V| = 0 \qquad (2)$$

Where H is the pressure head, V is the velocity of flow in the pipe, A is the pipe cross-sectional area, D is the pipe diameter, a is the wave speed, t is time, x is the spatial coordinate along pipeline, g is the gravitational acceleration and f is the pipe friction factor. These two equations are set of first order quasi-linear partial differential equations and there is still no analytical solution for them are available therefore, many numerical approximations methods is available with convenient results. Among these methods, the characteristics method and the finite difference scheme which are presented in following section are depended in this work.

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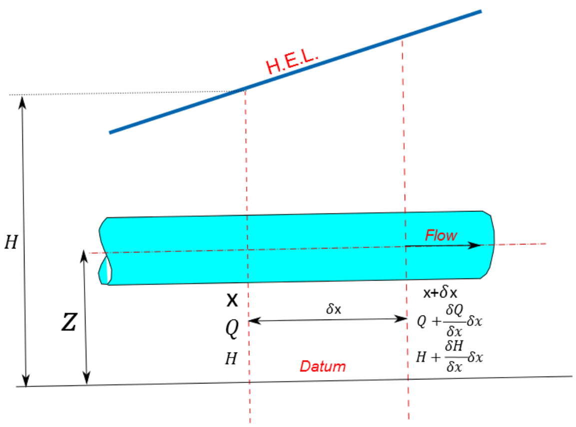

Fig. (1): Definition sketch of a flow through a pipe used to derive water momentum equation (Chaudhry, 1979).

3. Method of characteristics

The method of characteristics converts the two partial differential equations into two ordinary differential equations (mentioned in the previous section), (Chaudhryzc, 2014). These ordinary differential equations are then expressed in finite difference form, using a certain time interval with initial and boundary conditions; the solution is carried out using MATLAB to simulate the transients

By considering a linear combination of equations 1 and 2 yield

$$L = L_1 + \lambda . L_2 \qquad (3)$$

In which λ is an unknown multiplier. By multiplying equation 3 by λ and adding the result to equations 1 and 2 and rearranging the terms we obtain:

$$\left(\frac{\partial V}{\partial t} + \lambda a^2 \frac{\partial V}{\partial x}\right) + \lambda g \left(\frac{\partial H}{\partial t} + \frac{1}{\lambda}\frac{\partial H}{\partial x}\right) + \frac{f}{2D} V|V| = 0 \qquad (4)$$

The variables H and V are functions ofx and t, then from calculus the total derivatives gives:

$$\frac{dV}{dt} = \frac{\partial V}{\partial t} + \frac{\partial V}{\partial x}\frac{dx}{dt} \qquad (5)$$

$$\frac{dH}{dt} = \frac{\partial H}{\partial t} + \frac{\partial H}{\partial x}\frac{dx}{dt} \qquad (6)$$

By examining the above equations, it would be noted that the unknown multiplier λ can be defined as:

$$\frac{1}{\lambda} = \frac{dx}{dt} = \lambda . a^2 \qquad (7) \quad and \quad \lambda = \pm\frac{1}{a} \quad (8)$$

Now by using equations 5 and 6, equation 4 may be written as the following:

$$C^+ : \frac{dV}{dt} + \frac{g}{a}\frac{dH}{dt} + \frac{f}{2D}V|V| = 0 \quad \text{if} \quad \frac{dx}{dt} = a \qquad (9)$$

and

$$C^- : \frac{dV}{dt} - \frac{g}{a}\frac{dH}{dt} + \frac{f}{2D}V|V| = 0 \quad \text{if} \quad \frac{dx}{dt} = -a \qquad (10)$$

Equations 9 and 10 are called the characteristic equations. And as we can realize that these equations are ordinary differential equations and the independent variable x has been eliminated via using the finite difference method.

4. Numerical Scheme

To calculate transient pressure heads and velocities the finite deference method is used. First the initial values of the velocity V and pressure head H at time $t = t_0$ are calculated depending on the initial conditions of the steady state flow. At time $t = t_0 + \Delta t$ the unknown values of V and H will be calculated for all nodes on the pipeline. Referring to the equation 4 and taking its integration which yields

$$\int dV + \frac{g}{a}\int dH + \frac{f}{2D}\int V|V|dt = 0 \qquad (11)$$

The first two integrals of the equation (11) can be easily evaluated. However for the third term which represents the friction term, it's impossible, because one does not know the explicitly variation of the velocity V with respect to time t. To overcome this, many approximations have been made. First order approximation assumes that the velocity remains constant between two consequent points. Hence, in this work two types of the friction term approximation are used as follow:

4.1 Numerical approximation of friction term

4.1.1 Approach - I

As described by (Chaudhry, 2014), the friction term is approximated as follows:

$$\frac{f}{2D}\int_A^P V|V|dt \approx \frac{f}{2D}V_A|V_A|(t_p - t_A) = \frac{f}{2D}V_A|V_A|\Delta t \qquad (12)$$

Now equation (11) becomes:

$$C^+: (V_P - V_A) + \frac{g}{a}(H_P - H_A) + \frac{f}{2D}V_A|V_A|\Delta t = 0 \qquad (13)$$

By processing similarly, considering the negative wave celerity c will results in:

$$C^-: (V_P - V_B) - \frac{g}{a}(H_P - H_B) + \frac{f}{2D}V_B|V_B|\Delta t = 0 \qquad (14)$$

From equations (13):

$$V_P = V_A - \frac{g}{a}(H_P - H_A) - \frac{f}{2D}V_A|V_A|\Delta t \qquad (15)$$

By substituting equation (15) into equation (14) we obtain:

$$V_A - \frac{g}{a}(H_P - H_A) - \frac{f}{2D}V_A|V_A|\Delta t - V_B - \frac{g}{a}(H_P - H_B) + \frac{f}{2D}V_B|V_B|\Delta t = 0 \qquad (16)$$

Rearranging equation (16) we obtain:

$$H_P = \frac{1}{2}\left[\frac{a}{g}(V_A - V_B) + (H_A + H_B) - \frac{a}{g}\frac{f}{2D}\Delta t(V_A|V_A| - V_B|V_B|)\right] \qquad (17)$$

Similarly, the value of V_P can be obtained from substituting equation (17) into equation (13) and rearranging it yields:

$$V_P = \frac{1}{2}\left[(V_A + V_B) + \frac{g}{a}(H_A - H_B) - \frac{f}{2D}\Delta t(V_A|V_A| + V_B|V_B|)\right] \qquad (18)$$

Now equations (17) and (18) will be used to calculate H_P and V_P at the internal point of the pipeline at time $t = t_0 + \Delta t$. However, at the boundaries, either equation (13) or equation (14) is available. Therefore, the boundary conditions are needed to determine the conditions at the boundaries at time $t_0 + \Delta t$.

For the next time steps and considering a characteristic grid for different time steps Δt and pipe divisions Δx, the value of the flow velocity at any internal point of the pipe at any time step V_i^j

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(where i denotes to the node number and j refers to the time step) and the same for the value of the pressure head H_i^j, can be used in equations 17 and 18 to compute the values H_i^{j+1} and V_i^{j+1} as follows :

$$H_i^{j+1} = \frac{1}{2}\left[\frac{a}{g}V_{i-1}^j - V_{i+1}^j) + (H_{i-1}^j + H_{i+1}^j) - \frac{a}{g}\frac{f}{2D}\Delta t(V_{i-1}^j\left|V_{i-1}^j\right| - V_{i+1}^j\left|V_{i+1}^j\right|)\right] \quad (19)$$

$$V_i^{j+1} = \frac{1}{2}\left[(V_{i-1}^j + V_{i+1}^j) + \frac{g}{a}(H_{i-1}^j - H_{i+1}^j) - \frac{f}{2D}\Delta t(V_{i-1}^j\left|V_{i-1}^j\right| + V_{i+1}^j\left|V_{i+1}^j\right|)\right] \quad (20)$$

These final equations is used for internal point for $i = 2,3,4 \ldots\ldots, n-1$ in which n is the total number of nodes on the pipeline for different time steps j=1,2,3,……,m.

4.1.2 Approach II

According to (wylie, 1967), another approach can be used to approximate the friction term in the characteristic equations. This approach is illustrated as follow:

$$\frac{f}{2D}\int_A^P V|V|dt \approx \frac{f}{2D}P|V_A|(t_p - t_A)$$
$$= \frac{f}{2D}V_P|V_A|\Delta t \quad (21)$$

where A and p any two sequence point, now equations 13 and 14 becomes:

$$C^+: (V_P - V_A) + \frac{g}{a}(H_P - H_A) + \frac{f}{2D}V_A|V_A|\Delta t = 0 \quad 22)$$

$$C^-: (V_P - V_B) - \frac{g}{a}(H_P - H_B) + \frac{f}{2D}V_B|V_B|\Delta t = 0 \quad (23)$$

From C+

$$H_P = H_A - \frac{a}{g}(V_P - V_A) - \frac{a}{g}\frac{f}{2D}V_P|V_A|\Delta t \quad (24)$$

From C-

$$H_P = H_B + \frac{a}{g}(V_P - V_B) + \frac{a}{g}\frac{f}{2D}V_P|V_B|\Delta t \quad (25)$$

Equating the two equations 24 and 25 yields:

$$H_A - \frac{a}{g}(V_P - V_A) - \frac{a}{g}\frac{f}{2D}V_P|V_A|\Delta t = H_B + \frac{a}{g}(V_P - V_B) + \frac{a}{g}\frac{f}{2D}V_P|V_B|\Delta t \quad (26)$$

Rearranging equation 26 gives:

$$2\frac{a}{g}V_P + \frac{a}{g}\frac{f}{2D}V_P(|V_A| + |V_B|) - \frac{a}{g}(V_B + V_A) + (H_B - H_A) = 0 \quad (27)$$

And finally from equation 27 we get

$$V_P = \frac{\frac{a}{g}(V_B + V_A) + (H_A - H_B)}{(2\frac{a}{g} + \frac{a}{g}\frac{f}{2D}(|V_A| + |V_B|))} \quad (28)$$

And from equation 24

$$H_P = H_A - \frac{a}{g}(V_P - V_A) - \frac{a}{g}\frac{f}{2D}V_P|V_A|\Delta t \quad (29)$$

For a more general case, for all internal point in the pipeline (i=2, 3, 4,….., n-1) different time steps (j=1, 2, 3, 4 …... m), equations 28 and 29 are written as:

$$V_i^{j+1} = \frac{\frac{a}{g}\left(V_{i-1}^j + V_{i+1}^j\right) + \left(H_{i-1}^j - H_{i+1}^j\right)}{\left(2\frac{a}{g} + \frac{a}{g}\frac{f}{2D}\left(\left|V_{i-1}^j\right| + \left|V_{i+1}^j\right|\right)\right)} \tag{30}$$

And

$$H_i^{j+1} = H_{i-1}^j - \frac{a}{g}\left(V_i^{j+1} - V_{i-1}^j\right) - \frac{a}{g}\frac{f}{2D}V_i^{j+1}\left|V_{i-1}^j\right|\Delta t \tag{31}$$

5. Test case and applications

In the following, the results of the simulation model of the considered test case are shown as a relationship between the pressure head H and time t, and the flow velocity V in relationship with time t during the transient state generated from a valve closure. Both approaches of the friction term approximation are presented and compared. The two models applied to some different scenarios study the hydraulic transient behaviour. The initial conditions are provided from the steady state flow results in which the initial flow velocity is constant through the pipe for all point i at time t=0. As mentioned by (Chaudhry, 2014), the stability of investigation of a finite difference scheme is obtained by using the method developed by Von Neumann point out in Colombo (2009). To satisfy a stability conditions, the Courant Stability Condition or the Courant number C_N throughout the test cases its value was taken to be less than 1.0. It is worth to mention that the MATLAB code is developed and used in obtaining the results of this section. In figure 2

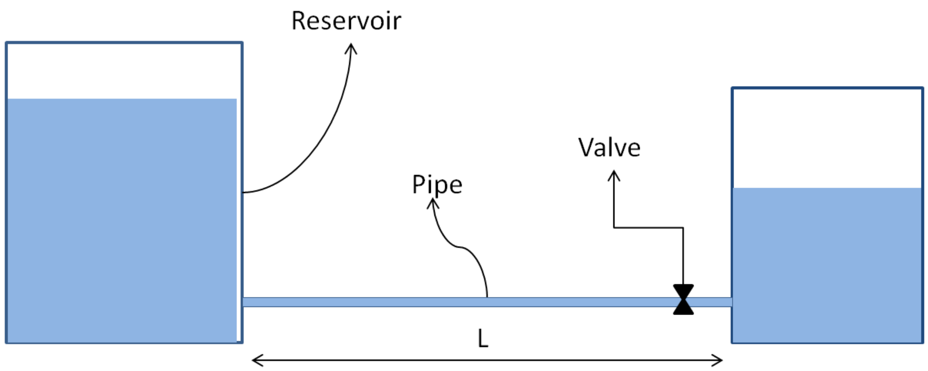

Fig.(2):- the Pipeline system used in the modelling of the hydraulic transient.

5.1: Hydraulic Transient Flow Due to Valve Closure Operation

5.1.1 Friction term approximation approach - I

To calculate the pressure head variation at the valve in relationship with time, Figure 3 shows the pressure head at the valve (i = n) in which the pipe is divided into 6 segments (n = 7) for time t=190 seconds and valve closure time (Tz) is chosen to be 10 seconds. As clear from the Figure 3 the maximum and the minimum pressure head values occurs in the first oscillation at the valve and decreasing as time passes due to the friction effects. The maximum pressure head is (315.4 meters) and the minimum is (-95.11 meters). For a point in the middle of the pipe, Figure 4 shows the pressure head against time in comparison to the pressure head at the valve. On the other hand, velocity profiles during transient are shown in Figures 5 and 6 at mid-point of the pipe and at the valve respectively. It can be seen that the velocity in Figure 5 is periodic starting from the maximum ranging from (2.24 to -1.5 m/sec) and then reduced throughout the simulation time and this is normal due to the boundaries. But it can be noticed that at the valve Figure 6, the velocity drops from its highest value of (2.14 m/s) to a zero value. It means that the valve is entirely closed at time t is equal to the time of closure (Tz) or after 10 seconds from the transient initiation.

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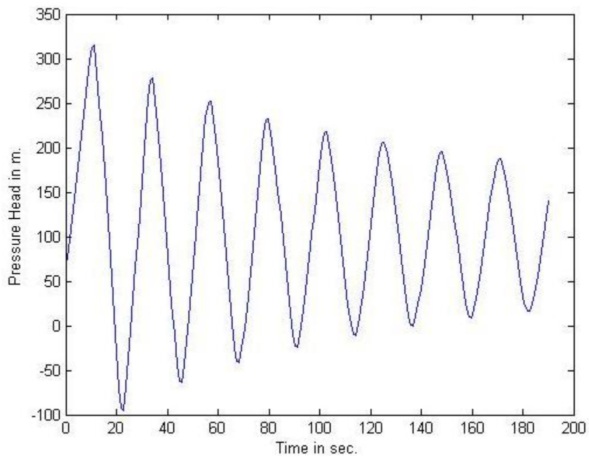


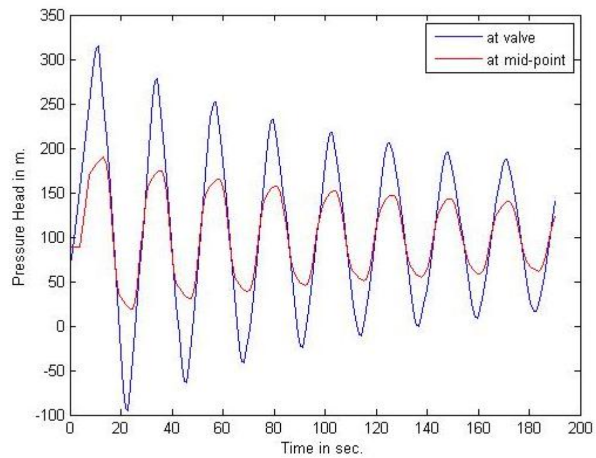
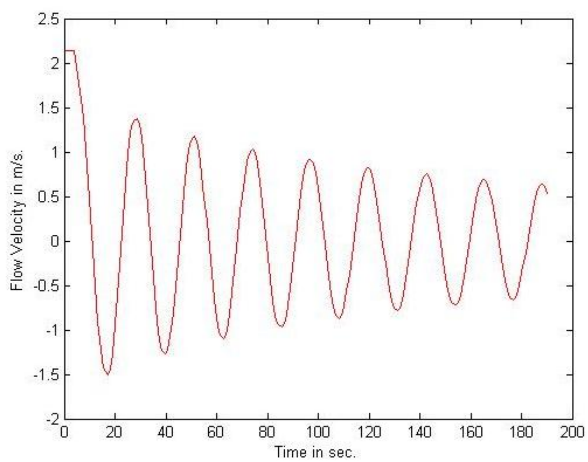


Fig.(3): Pressure head variation at the valve against time for case I
Fig.(4): Pressure head variation at mid-point of the pipe against time for case I



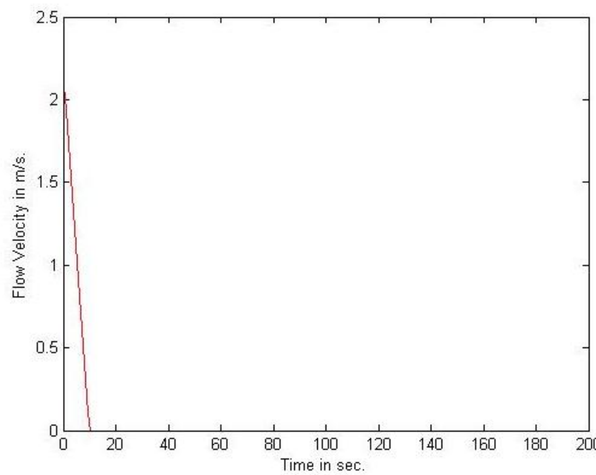


Fig.(5): velocity profile at mid-point of the pipe against time for case I
Fig.(6): Flow velocity at the valve against time for case I

5.1.2 Friction term approximation approach - II

To calculate the pressure head variation at the valve in relationship with time for the case II, Figure 7 shows the pressure head at the valve (i=n) for the same parameters used in case I. Same as in Case I, we can notice from the figure 7 the maximum and the minimum pressure head values occurs in the first oscillation at the valve and decreasing as time passes due to the friction effects. However in this case the maximum pressure head value in (324.29 m) which slightly higher than the first case and the minimum value is (-108.69 m) which is also less than the value from case I. For a point in the middle of the pipe the pressure head variation in comparison the one at the valve is as shown in Figure 8. Velocity profiles during transient are shown below in Figures 9 and 10 at mid-point of the pipe and at the valve respectively.

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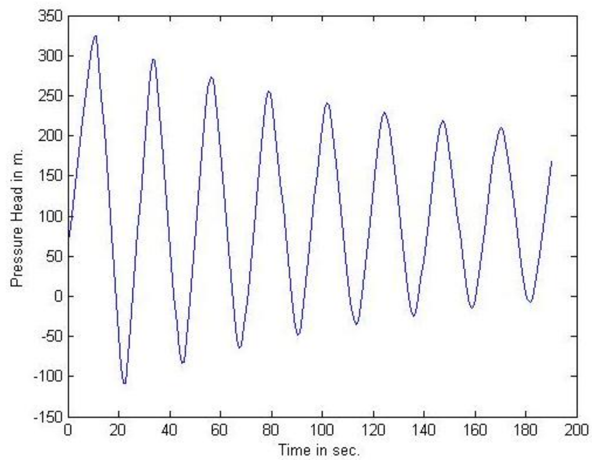

Fig.(7): Pressure head variation at the valve against time for case - II

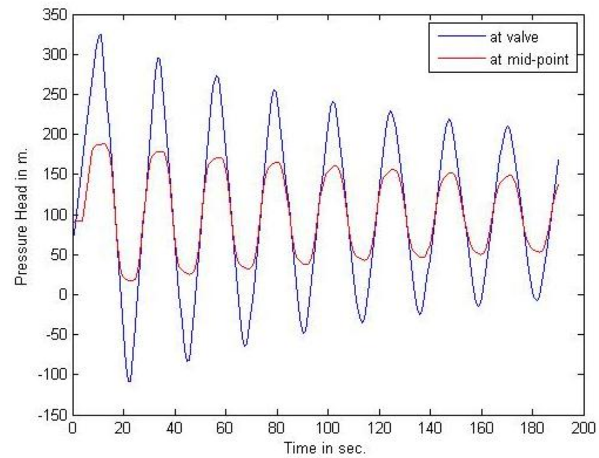

Fig.(8): Pressure head variation at mid-point of the pipe against time for case - II

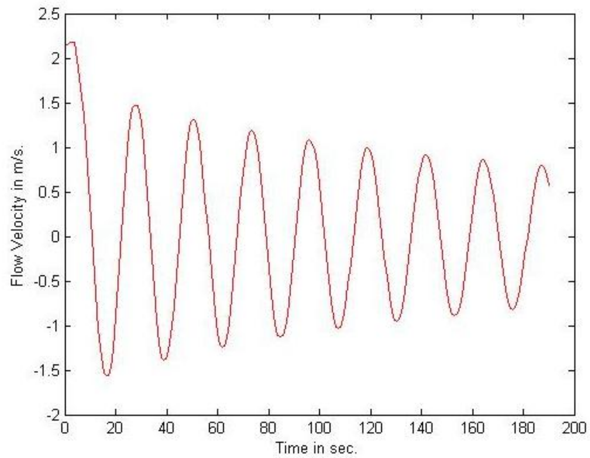

Fig.(9): velocity profile at mid-point of the pipe against time for case - II

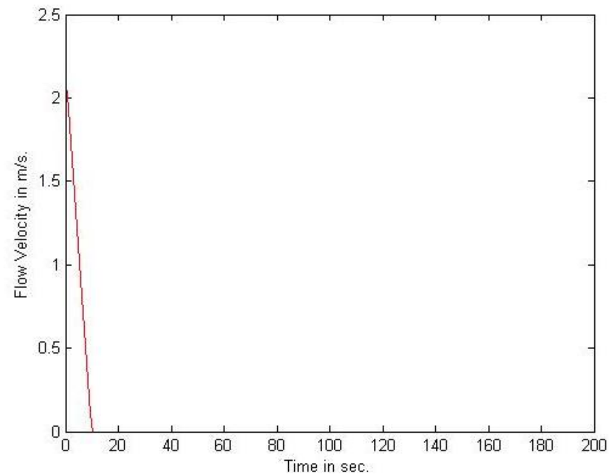

Fig.(10): velocity profile at the valve against time for case - II

As in case I, we can notice that at the valve Figure 10, the velocity drops from its highest value of (2.19 m/s) which is slightly higher than the case I of (2.14 m/s), to a zero value and stays like that till the end of the analysis time. It means that the valve is entirely closed at time t is equal to the time of closure (Tz) or after 10 seconds from the transient initiation. As for the node the reservoir boundary where (n = 1), Figure 11 show the velocity profiles with the same parameter taken before but with time (t = 47.5) seconds.

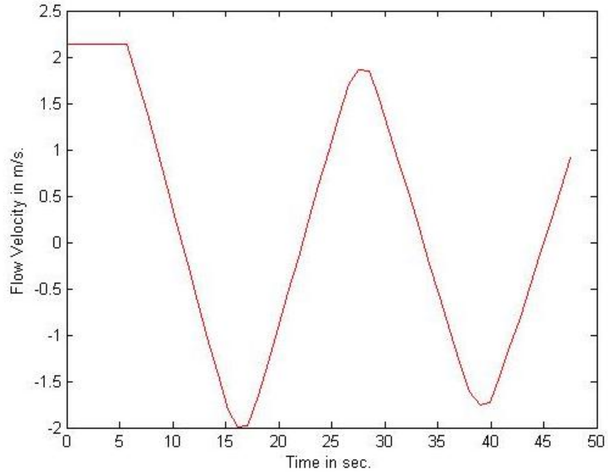

Fig.(11): velocity profile at upstream end against time for case II for t=47.5 seconds.

As we can see from these Figures that the steady state initial velocity is dominant and constant during the transient state at the upstream end of the pipe until the pressure waves reach it at time = L/a in which L is the length of the pipe and a is the pressure wave velocity, then it starts to change as time passes.

5.2 Models Evaluation by comparing the two cases of friction term approximation

The two models produced from two different friction term approximations are compared. In Figure 12, the pressure head fluctuation at the two cases is shown at the valve for the same parameters used in the MATLAB codes and with time t = 190 seconds. It can be noticed that case II gives lightly higher results and the difference is getting slightly higher as time passes as can be noticed from figure 12 which is the result from running the analysis for longer time (t = 380 seconds) , however both cases follows the same scheme of oscillation.

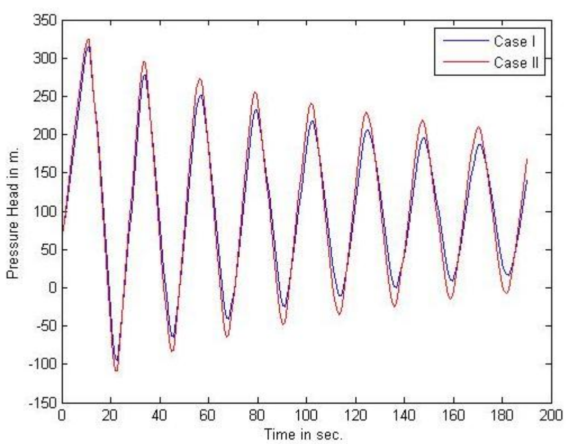

Fig.(12): Pressure head comparison from the two cases with t=190 sec.

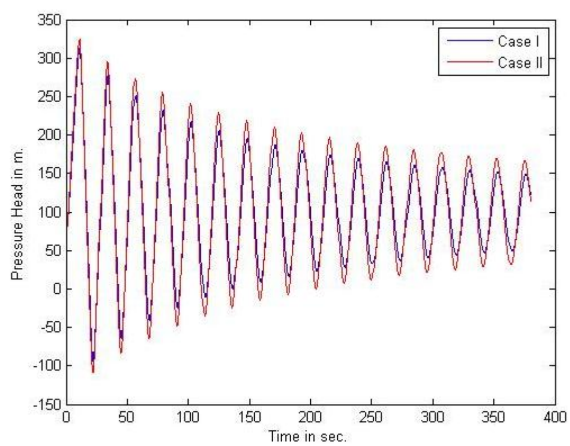

Fig.(13): Pressure head comparison from the two cases with t=380 sec.

To compare the velocity profiles resulted from the two cases, the mid-point of the pipeline is considered, see Figure 14. As it can be seen, case II again gives slightly higher velocity values and the difference with case I is increased with time see Figure 15.

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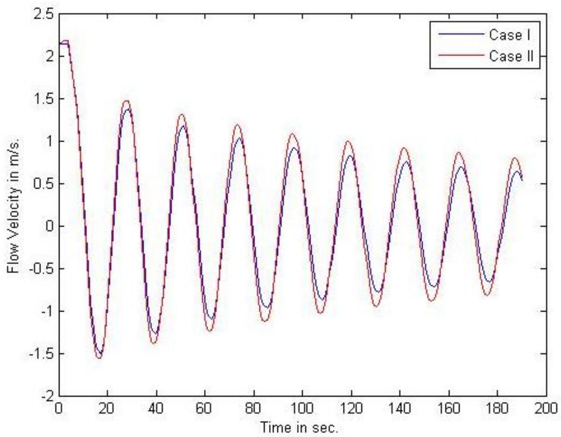

Fig.(14): Velocity profiles from the two cases with t=190 sec.

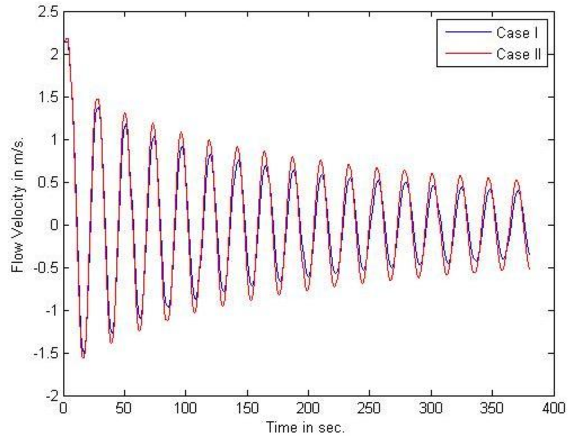

Fig. (15): Velocity profiles from the two cases with t=380 sec.

5.3 Investigating the Effect of Different Parameters on transients using both models

In order to study the hydraulic transients' phenomena certain parameters are investigated. The analysis presented below shows the effect of fluid flow velocity, wave speed, pipeline friction coefficient. Also the model is investigated using different computational time step and different pipe mesh divisions.

5.3.1 The effect of different initial flow velocity on the transients

The initial steady state flow velocity used in previous calculation in the MATLAB model was 2.13 m/s the Darcy-Weisback formulas. The effect of a lower initial flow velocity of 1.5 m/s and a higher flow velocity of 3 m/s, are illustrated in Figure 16 for the same parameters used before.

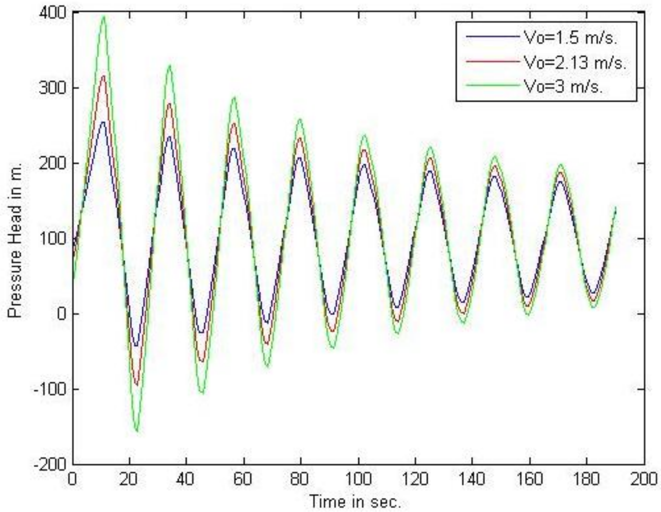

Fig.(16): the effect of different initial flow Velocities at the valve using approach I**.**

These results show that the transient pressure head is proportional with the initial fluid flow velocity. The higher initial velocity results in the higher pressure generation and vice versa. This means is systems with high initial flow velocities, the design of the hydraulic system should take the transient state in serious consideration and providing suitable protection for the system.

5.3.2 The effect of different wave velocities on the transients

Many factors affecting the pressure wave velocity during the transient state, from pipe

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properties to fluid characteristics. Wave speed is one of the most important parameter during transients. Analyzing the transients with different wave velocities means that the implicitly investigating of the phenomena with different fluid characteristics and pipe material properties. The previous analyses were taking with the wave speed of 1051.7 m/s calculated using equation 31. Figures 17 and 18 show that the transient state analysis with different wave velocities that using the model from approach I. From the analysis results, pressure head during transients is proportional to the pressure wave. It can be noticed also the time of analysis changes with changing the wave speed.

$$a = \frac{\sqrt{K/\rho}}{\sqrt{1 + \varphi.(K.D)/(E.e)}} \quad (31)$$

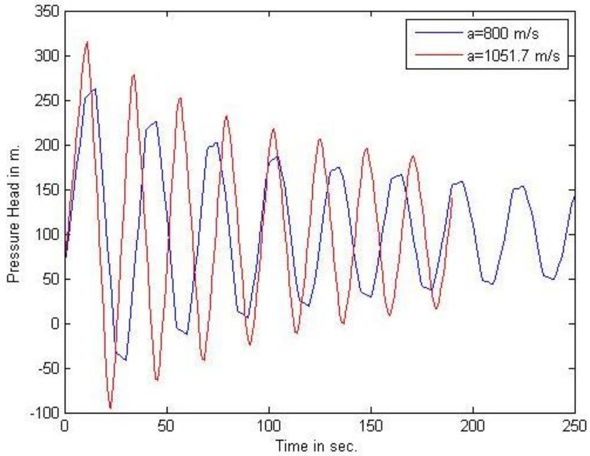

Fig.(17): the effect of lower wave speeds at the valve using approach I.

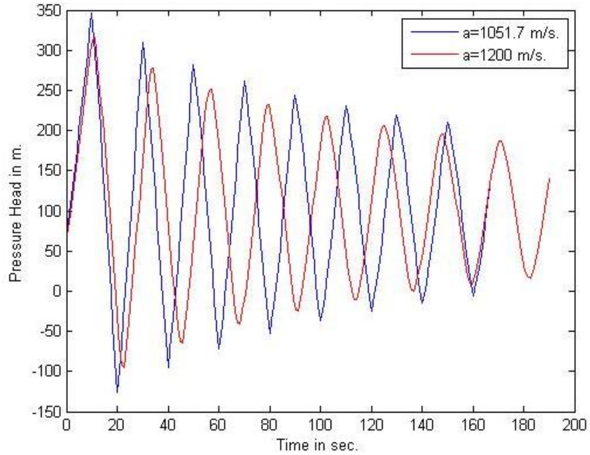

Fig.(18): the effect of a higher wave speeds at the valve using approach I.

5.3.3 The effect of different frictional coefficients on the transients

The friction coefficient used in the models earlier is assumed to be 0.02. The following analysis is taken for different friction factors on the pressure head during the transient state as shown in Figure 19. Friction coefficient plays a significant role in the transients. Special attention should be given to the calculations it. As it can be seen with low friction coefficients the higher the pressure heads resulted. Since the friction during transient state still not know phenomena and steady state one is taken when calculating transient pressures, the steady state friction coefficient models should be calculated carefully when used to analyze transients. Figure 20 shows the effect of different friction coefficient on the velocity profiles at mid-point of the pipe during transients.

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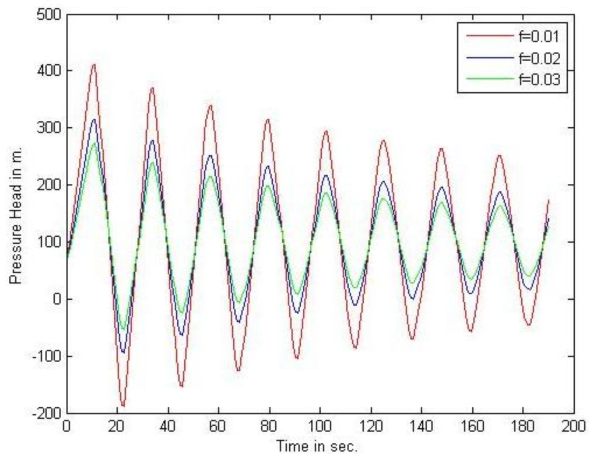

Fig.(19): the effect of different pipe frictional coefficients at the valve using approach I.

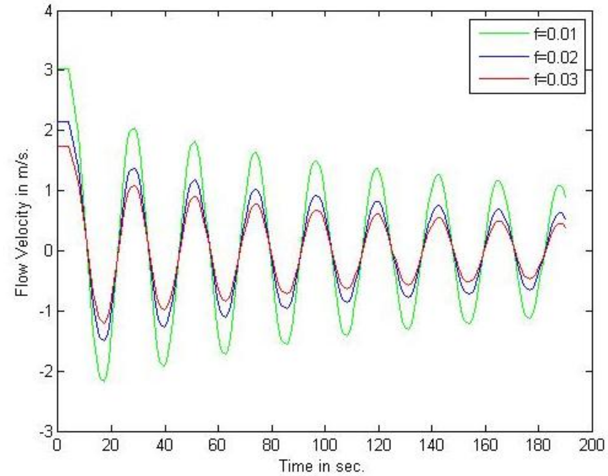

Fig.(20): the effect of different pipe frictional coefficients on velocity profiles during transients at a md-point on the pipe using approach I.

5.3.4 The effect of different computational time steps on the transient Models

The analysis carried on the two models for the transient state evaluation so far were based on a computational time step depending on the pipeline sub-divisions and the pressure wave speed using the expression $\Delta t = \Delta x / a$ which satisfies the Courant stability condition. Below the model are investigated using different time steps as shown in Figures 21 and 22.

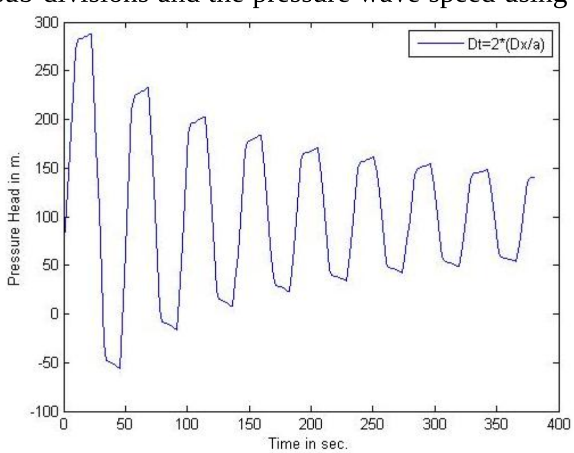

Fig. (2)1: pressure head variation at the valve during transient with doubling the time step using approach I**.**

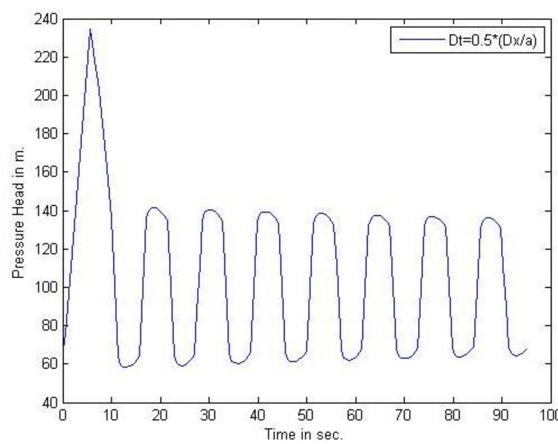

Fig.(22): pressure head variation at the valve during transient with 0.5 Dt using approach I**.**

By doubling the time step, the analysis shows unstable results and longer time as in Figure 21. While by taking half of the time step the analysis shows totally inconvenient results, Figure 22. Moving away from Courant number CN=1 gives unsatisfactory results as shown in Figures 21 and 22. While coming closer the value of CN=1 gives convenient as seen in Figures 23 and 24.

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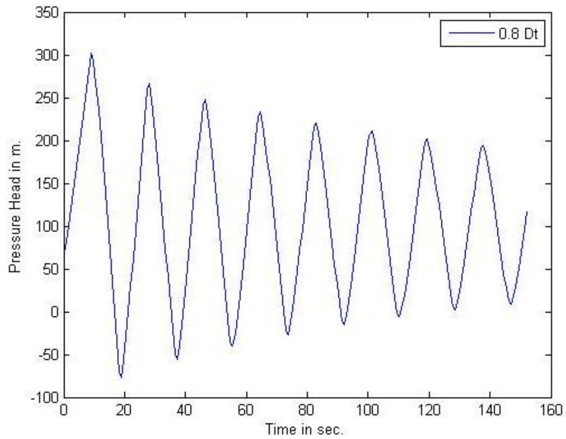

Fig. (23): pressure head variation at the valve during transient with 0.8 Dt using approach I.

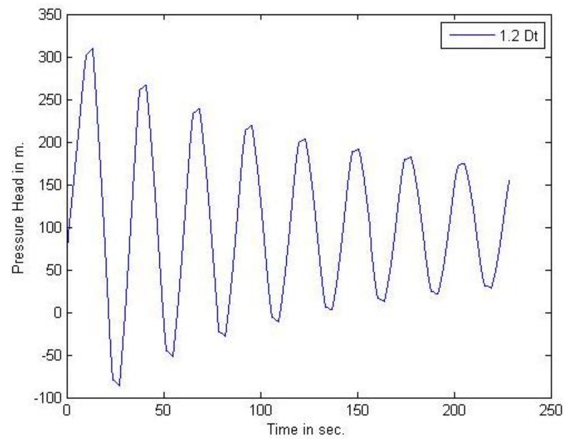

Fig.(24): pressure head variation at the valve during transient with 1.2 Dt using approach I.

5.3.5 The effect of different pipeline segment divisions on the transients

All the previous analysis were based on dividing the pipe into 7 nodes or n=7. The following analysis will show the effect of choosing different spatial number n for the pipeline using both approaches as seen in Figures 25 and 26.

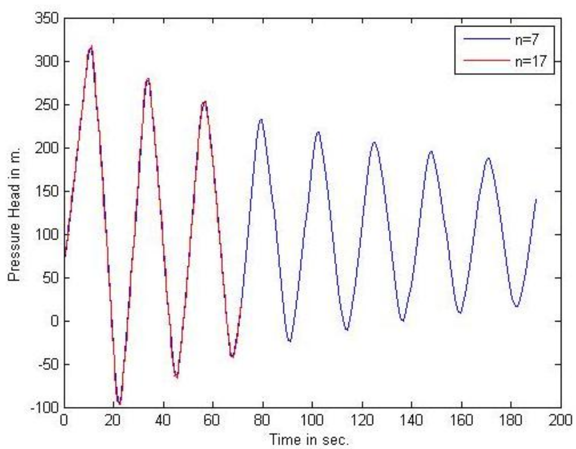

Fig.(25): the effect of different spatial divisions approach I.

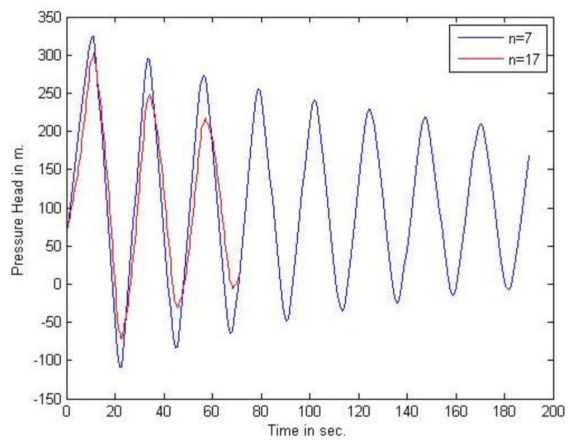

Fig.(26): the effect of different spatial divisions approach II.

Both approaches shows totally different results with changing the spatial division number n. in the first approach the results accuracy did not changed means the friction term approximation is linear. While in approach II, results with different n values affects the accuracy of the results meaning the approximation used is not linear.

5.3.6 The effect of different valve closure time on the transients

Since the valve operations is the main reason for the transient occurrence in this work, studying the effect of its operation closing time is very important. The following graphs shows the resulted pressure head with different valve closure time using the MATLAB Model with the first approach of friction term approximation. Valve operation can controls the transient and limit its effects upon the pipeline system. It can be seen from Figure 27, the pressure head decreases as the valve operation time increases. A suitable design for the valve operation time can help in avoiding the transient phenomena or minimize its effect.

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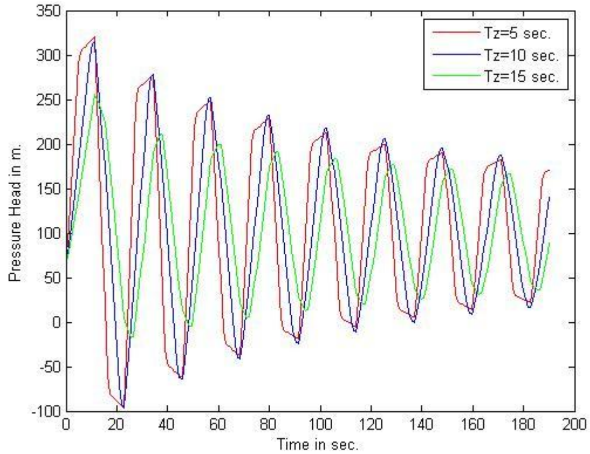

Fig.(27): the effect of different valve closure time using approach I.

6. Conclusion and Recommendations

In this paper, an overview of the hydraulic transient phenomena in closed conduct was presented highlighting many issues associated with it, ranging from causes and effects to consequences and control measures. The basic equations for analyzing the transient flow in closed conduct was derived and the method of characteristics for solving the governing equations was presented with the finite difference scheme used for approximation the solution. Based on the method of characteristics, two different numerical simulation techniques were used in the model development depending on the friction term. First order approximation for the friction term is used with two different approaches. After investigating the two approaches for the friction term approximation, the first one which is used widely proven to be a linear approximation while the second one gave slightly linear results but was appeared to be a non-linear approximation. This was concluded using different spatial division of the pipe used in the analysis. It was proven that in the first approach with different spatial division, the results were the same. In the other hand using the second approach models with different spatial divisions, different results were obtained. The effect of certain parameters upon the hydraulic transients were studied and their influence on the model outputs. It was proven that the initial state flow velocity and the pressure wave velocity have a great effect on the pressure head generated during the transients. Also the friction coefficient has a significant effect of the resulted pressure. Courant stability condition was investigated and proven that with choosing analysis time step depending on the Courant number yields stable results. Valve operation time can control the transient also was investigated and the results support it, notably it was shown that the valve closing time is inverse proportional with the pressure head resulted during transients. Future work for hydraulic transient in closed conduct due to valve closure should include more experiments to compare the two first order approaches used to approximate the friction term in the finite difference scheme. The second approach non linearity needed to be tested by experiments if it gives realistic results. The second order approximation for the friction term needed to be tested and evaluated through models and experiments. The friction coefficient used in the transient was assumed to be the same as the steady state, for better accuracy the friction model for the transients should be used. As it was clear from the results obtained, valve operation time is a key parameter in the transient and suitable relationship should be derived between the flow velocity and valve closure time to minimize the effect of the transients.

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