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Investigation of the Effects of Hydraulic Transient due to Instantaneous Valve Closure in a Petroleum Pipeline

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Abstract

Pressure surge analysis of petroleum pipeline transporting automotive gas oil (AGO) also known as Diesel oil was carried out in this research work. Pressure transient analysis is often more significant than the steady state analysis that engineers usually use in pipeline design. Pressure transient analysis helps to understand the additional pressures the pipeline can be subjected to as a result of instantaneous rapid valve closures or pump failure. The fluid pressure and flow rate in the pipeline system may change significantly at some intervals of time due to the valve closure and such types of unsteady situations are encountered more often in pipelines where the valves are suddenly closed. In this paper, pressure surge due to instantaneous valve closure in a petroleum pipeline conveying AGO was studied in a virtual environment. WANDA Transient 4.5.1210 commercial software was used for the analysis of the pressure surge in the pipeline due to instantaneous valve closure time of 4.75s. It was observed in the study that pressure at some nodes rise significantly up to about 1400 kPa against the initial inlet pressure of 120 kPa due to the instantaneous valve closure and it drastically drops at some nodes to negative pressure of about -100 kPa and hence the formation of cavitations. The analysis showed that the magnitude of the pressure surge decreases as the valve closure is increased.

1.Introduction

Pressure surge also termed pressure transient, hydraulic transient, transient waves, fast transients, fluid transients, hydraulic hammer, oil hammer or water hammer refers to rapid changes of pressure due to changes in some of the flow parameters in a pipe system [1, 2]. Pressure surge has destructive and catastrophic consequences, such as collapsing pipes and ruptured valves [1, 3]. [4] Reported that there are two categories of damage caused by pressure transient events. Namely; catastrophic failure and fatigue like failure. Catastrophic failure is a type of failure caused by high magnitude transient waves generated as a result of valve closure or pump failure while a fatigue-like failures are normally caused as a result of prolong repeated impacts of smaller magnitude transient pressure over a long period. Therefore, it is imperative to understand and investigate the phenomena and its causes as well as accurately calculate and analyze its effects on the pipeline. The importance of carrying out pressure surge analysis cannot be over emphasised, transients analyses are carried out in pipelines networks in order to verify whether the networks are operating within acceptable maximum operating pressure as well meets the regulations and standards [5].

[6] Reported that pressure surge analysis and evaluation play a very vital role in the design, operation and maintenance of new and existing pressurized pipeline systems. Also [6 and 7] stated that pressure surge occurs in a pipeline network as a result of either pump failure or due to sudden valves closure or opening. This paper is aimed at investigating the pressure surge due to instantaneous valve closure in a petroleum pipeline conveying automotive gas oil (AGO) using simulation approach. Conducting transient analysis in a pipeline system is often more important than conducting steady state condition analysis in a pipeline [6]. There are quite large number researches conducted on hydraulic transients occurring in closed conduits [8, 9, 10, 11, 12, and 13]. Pressure surge analysis methods range from analytical methods to numerical solutions [9]. According to [14] these methods are further divided into either elastic or rigid column method. Elastic method is a method of transient analysis that involves solving partial differential equations. Elastic method also involves evaluating the acoustic pressure wave. While a rigid column method is a method of pressure surge analysis that involves solving simple ordinary differential equations mathematically or numerically. In this method, the elasticity of the pipe and the compressibility of the fluid are ignored in the analysis and whole of the fluid's column is assumed to move as a rigid body [15]. In both cases, quasi-linear hyperbolic partial differential equations are used in the analysis of unstable fluid flow in pipelines [16].

Some of the methods used in pressure surge analysis are arithmetic mean method [17], Graphical method [18], analytical [19], experimental [20], Method of characteristics (MOC) [21], Finite difference methods (FDM) [22], Wave plan method [23 and 24]. [10] reported that the most widely accepted and used methods of pressure surge analysis are the method of characteristics (MOC) and wave characteristics method (WCM) and the main distinction between the two methods is the way pressure waves are traced between pipe boundaries. The MOC use numerical method to trace a disturbance in a grid on characteristics, whereas WCM uses wave propagation method to trace the disturbance. These two outstanding methods are well documented in pressure transient [16 and 25] and have been implemented in various computer programs for pipeline system transient analysis. Nowadays computational fluid dynamics (CFD) method is used to carry out fluid flow and flow condition analysis. In this research work, CFD simulation software called WANDA Transient 4.5.1210 was used for the investigation of pressure surge in a pipeline network. WANDA is one of the most outstanding commercial simulation software that uses MOC for the analysis of fluid and heat flow in pipeline networks [26].

2. Methodology

2.1 Data Collection

The fluids and pipeline parameters required for the analysis as presented in Tables 1 and 2 were obtained from direct measurement, from the archives of the Nigeria National Petroleum Company Limited (NNPC) and literature.

Table 1: Pipe parameters

Pipe	Pipe Material	Diameter (m)	Thickness (m)	Roughness (e/d) (mm)	E_y (N/m^2)
1	Carbon steel	0.3556	0.016	0.045	210×10^9

Table 2: Fluid parameters

Fluid	Density (m^3/kg)	Flow rate Q (m^3/s)	Pressure (kN/m^2)	μ (N/m^2)	E_y (N/m^2)	Cp (kJ/kg/K)	K (N/m^2)
AGO	870	0.297	120	0.006	213.84	2.22	1.07×10^9

Change in pressure of fluid flowing in a closed conduit is directly proportional to the velocity change. The basic water hammer equation is used to express the change in pressure head produced by the surge in the pipes, as shown in Equation 1.

$$\Delta H = -\frac{a}{g}\Delta v \tag{1}$$

[21] also reported that the fundamental water hammer theory which describes the pressure amplitude was laid by Joukowsky and is presented in Equation 2.

$$\Delta P = \pm\rho a \Delta V \text{ or } \Delta H \pm = \frac{a\Delta V}{g} \tag{2}$$

Equation (3) was used for calculating wave speed propagation for transient flow in the pipeline as reported by [6 and 27].

$$a = \sqrt{\frac{\frac{k}{\rho}}{1+\left(\frac{k}{E}\right)\left(\frac{D}{e}\right)(C)}} \tag{3}$$

According to [7] the bulk modulus of elasticity of a fluid is an important parameter in the analysis of wave speed of fluid and it can be obtained by using Equation 4.

$$K = \frac{\Delta P}{\Delta\rho/\rho} \tag{4}$$

The head loss due to water hammer in the pipeline can be calculated using the Darcy-Welsbach relation presented as Equation 5:

$$\mathrm{h_f} = \frac{\mathrm{fDLV^2}}{\mathrm{2gD}} \tag{5}$$

The relative roughness of the pipe is calculated using Equation 6,

$$Relative\ roughness = \frac{\varepsilon}{D} \tag{6}$$

[28] Reported that instantaneous valve closure is characterized by valve closure time less than T and the value of T can be calculated by using Equation 7.

$$T = \frac{2L}{a} \tag{7}$$

HT behaviours in closed conduits can be analyzed by using Equations of motion and continuity [29], the Equation is shown in Equation 8 as reported by [27]

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} + \frac{1}{\rho}\frac{\partial p}{\partial x} + g\sin\theta + \frac{fV|V|}{2D} = 0 \tag{8}$$

The term $V\partial V/\partial x$ in Equation 8 is neglected in transient analysis as a result of low Mach-number and unsteady flows. [7] Reported that Equation 8 will reduce to Equation 9

$$\frac{\partial V}{\partial t} + \frac{1}{\rho}\frac{\partial p}{\partial x} + g\sin\theta + \frac{fV|V|}{2D} = 0 \tag{9}$$

Also according to [29] the general form of the continuity Equation can be presented in Equation 10.

$$\frac{1}{\rho}\frac{d\rho}{dt} + \frac{1}{A}\frac{dA}{dt} + \frac{\partial V}{\partial x} = 0 \tag{10}$$

If an elastic pipe is filled with a compressible fluid, Equation 10 will reduce to relation presented in Equation 11.

$$\frac{d\rho}{dt} + V\frac{\partial v}{dx} + \rho a^2\frac{\partial V}{\partial x} = 0 \tag{11}$$

The friction factorcan be calculated by using the Colebrook-White Equation as shown in Equation 12 [30]

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\frac{\mu}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right] \tag{12}$$

2.2 Mechanics of Water Hammering

In this study, a hypothetical petroleum pipeline network is adopted for this research work. Data used in this research were obtained from literature, NNPC archives and field. The pipeline network consists of the followings, upstream and downstream reservoirs, pipes, pump and valves (gate valve and non-return valves). The pipeline networks parameters under study are: upstream reservoir (B1) at a surface elevation of 14.1m with a pressure of 120 kPa. The pipeline network is made up of four carbon steel pipes of equal diameters of 0.3556m, thickness of 0.016m and surface roughness of 0.045mm. All the pipes are connected in series between the upstream reservoir (B1) and the downstream reservoir (B2). The upstream end of the first pipe, Pipe 1 (P1) is connected to the upstream reservoir via node A while its downstream end is connected to the pump at node B, pipe P1 has a length of 1000m. Pipe 2 (P2) is the second pipe in the series, its upstream end is connected to the pump at node C and its downstream is connected to the check valve at node D, it has a length of 10000m. The third pipe in the series of the pipes is pipe 3 (P3), P3 is also connected the check valve at its upstream at node E while at the downstream is connected to the gate valve at node F; P3 also has a length of 10000 m. The last pipe in the series is pipe 4 (P), it has a length of 1000m, the upstream end of P4 is connected to the gate valve at node G while its downstream end is connected to the downstream reservoir of the pipeline network at node H. The valve closure times used in this analysis are 4.75 s, 9.5 s and 19 s respectively.

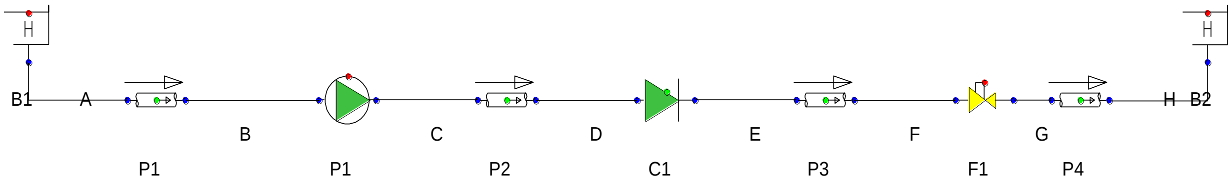

Figure 1: Pipeline Network System

In a fluid transporting pipeline network, if a valve is closed instantaneously, the momentum of the fluid will be shattered and high pressure wave will be built-up accordingly. This built-up high pressure wave will be transmitted down the pipe length with the velocity of the sound wave that may leads to knocking.

Table 3 presents some of the parameters inputted into the WANDA software for the analysis of the hydraulic transient in AGO while Table 4 presents some physical constants under which the simulation was conducted.

Table 3: Properties of AGO

Liquid name	AGO
Rheology type	Newtonian
Density	871.0 kg/m^3
Bulk modulus	1.477×10^9 N/m^2
Vapour pressure	1.100 kPa
Kinematic viscosity	2.860e-5 m^2/s

Table 4: Physical constant used in the simulations

Atmospheric pressure	101.4 (kPa)
Gravitational acceleration	9.810 (m/s^2)
Ambient temperature	37.00 (°C)

3. Results and Discussion

Figure 2 shows the pressure head distribution before the advent of the valve closure in the pipeline network. That figure indicated that pressure head starts to rise from node B and reached a peak of 0.107164 m at node C, this is due to the presence of pump at that node which adds more pressure to the fluid. After node C, the pressure starts to drop across nodes D, E and F. The pressure stabilises between nodes G and H a pressure head of 0.3 m. It was observed in this study that the pressure head was maximum at the upstream of the pump after development of first pressure wave which is due to instantaneous closure of the valve at the downstream end of the pipe. This condition is in agreement with what reported by [6]. The pressure head was not dampened but they were found to be oscillating by increasing and decreasing in the total simulation time which may be due to wave propagation time and consideration of series pipe in the current study.

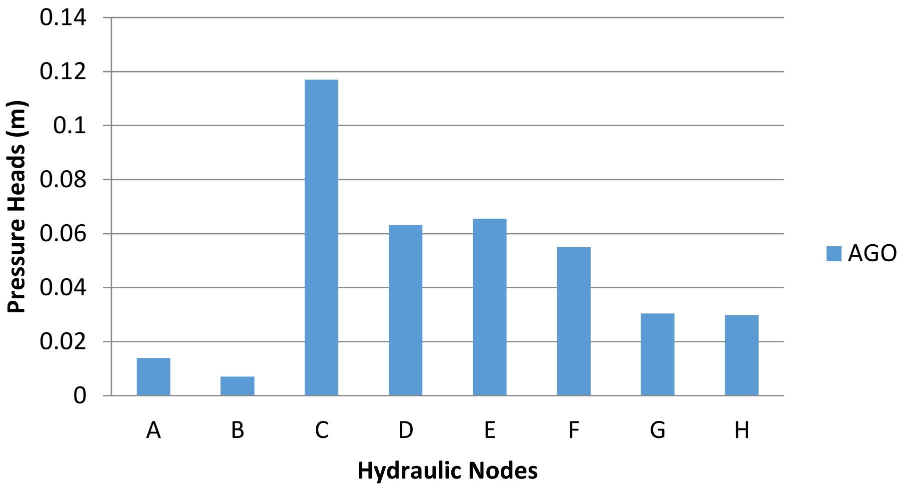

Figure 2: Pressure heads at various hydraulic nodes of the pipeline

3.1 Simulated results for AGO at instantaneous valve closure times of 4.75 s, 9.5 s and 19 s.

The effects of the instantaneous valve closure were observed as pressure oscillation at different types of closing times as reported by [32]. The results of the analysis are in agreement with [33] which reports that the pressure wave will travel back and forth in the pipeline until the kinetic energy is dissipated by friction. And this process will occur both upstream and downstream from the valve. However, the initial pressure will increase on the upstream side of the valve and decrease on the downstream of the valve as shown in figures 3, 4 and 5.

3.1.1 Simulated results for AGO at instantaneous valve closure times of 4.75 s

Figure 3 present results of pressure transients due to instantaneous valve closure time of 4.75s. The figure depicts that there is variation in pressure in the various hydraulic nodes of the pipeline. The pressure of the fluid under normal operating conditions at nodes A, B, C, D, E, F, G and H are 118.72 kPa, 60 kPa, 1000 kPa, 540 kPa, 560 kPa, 470 kPa, 260 kPa and 254.73 kPa respectively. But when the gate valve is closed instantaneously, the pressure of the fluid fluctuates and oscillates between minimum and maximum pressures before stabilising as shown in Figure 3.

The pressure at node A fluctuates and oscillates between minimum pressure of 118.4 kPa and 118.9 kPa at times of 5 s and 68.1 s respectively. At node B, the pressure of the fluid oscillates between – 100.5 kPa and 367 kPa. The development of negative pressure at node B also leads to the formation of cavitation voids at the node and in pipe P1 respectively. At node C the pressure of the fluid fluctuates between 347.4 kPa and 1262 kPa. The pressure of the fluid drops to a minimum pressure of 295.5 kPa at a time of 8.3 s before rising to a maximum pressure of 1307 kPa after 59.1 s. The Figure also depicts that pressures at node E and F fluctuates and oscillates between minimum pressures of 295.5 kPa, 223.7 kPa at times of 9.8 s and 16.5 s and maximum pressures of 1317 kPa and 1417 kPa respectively. Nodes G and H are the two nodes at the downstream side of the gate valve. The pressure of the fluid at the nodes also fluctuates between minimum pressures of 106.8 kPa at 16.5 s and 254.8 kPa occurring at 187.4 s respectively.

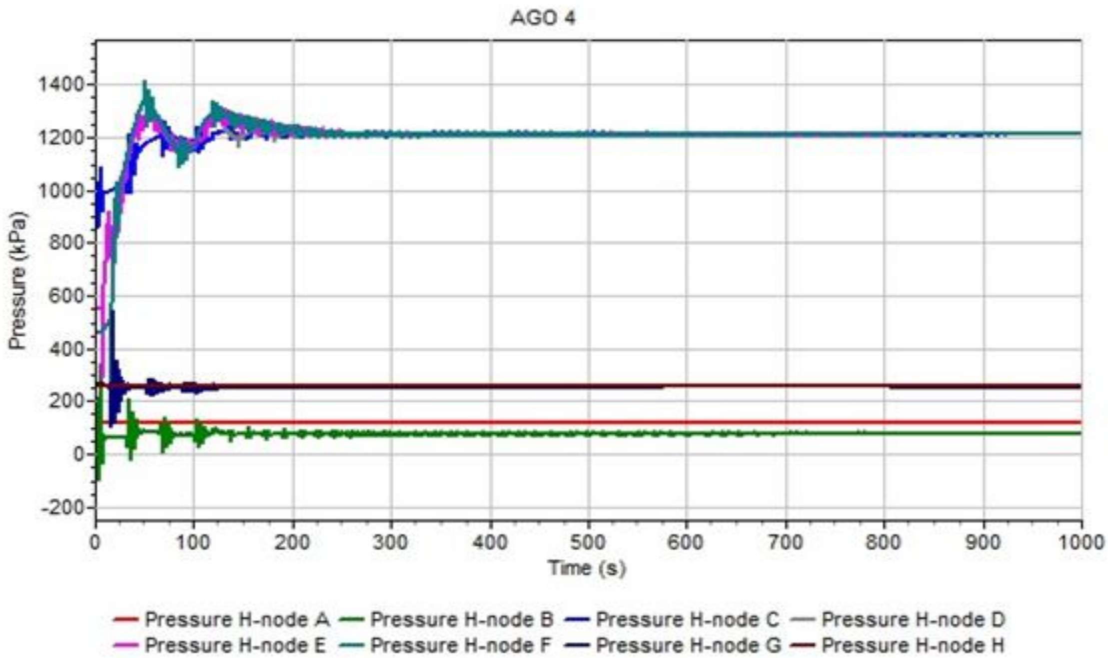

Figure 3: Pressure Transients at Hydraulic Nodes for a valve closure time of 4.75 s

3.1.2 Simulated results for AGO at instantaneous valve closure times of 9.5 s

Figure 4 present results of pressure transients due to instantaneous valve closure time of 9.5 s in the pipeline network. The figure depicts that there is variation in pressure in the various hydraulic nodes of the pipeline. The pressure of the fluid under normal operating conditions at nodes A, B, C, D, E, F, G and H are 118.72 kPa, 60 kPa, 1000 kPa, 540 kPa, 560 kPa, 470 kPa, 260 kPa and 254.73 kPa respectively. But when the gate valve is closed instantaneously, the pressure of the fluid fluctuates and oscillates between minimum and maximum pressures before stabilising as shown in Figure 4.

The pressure of the fluid fluctuates and oscillates between minimum and maximum pressures as a result of the instantaneous valve closure. The pressure at node A fluctuates and oscillates between minimum pressure of 118.4 kPa and 119 kPa at times of 5 s and 28.5 s respectively. At node B, the pressure of the fluid rises to 376 kPa at a time of 0.1 s but later after about 3.5 s the pressure drops to -100.5 kPa. The pressure keeps oscillating before stabilisation. The drop in pressure to a negative pressure leads to the development of cavitation voids at the node and along pipe P1. At node C the pressure of the fluid fluctuates between a minimum pressure value of 347.4 kPa and a maximum pressure of 1264 kPa at times of 0.1 s and 70.5 s respectively. The pressure of the fluid at nodes D and E drops to a minimum pressure of 295.5 kPa at a time of 8.3 s and 9.3 s respectively but later the pressure at D rise to a maximum pressure of 1303 at a time of 59.1 s. Also, the pressure at node E rises to 1307 kPa at a time of 131.2 s. The figure also depicts that pressure at node F fluctuates and oscillates between minimum pressures of 200.1 kPa at a time of 16.5 s and maximum pressures of 1391 kPa at a time of 18.1 s. Nodes G and H are the two nodes at the downstream side of the gate valve. The pressure of the fluid at the nodes fluctuates between minimum pressures of 101.8 kPa at 16.5 s and 254.6 kPa occurring at 187.4 s and a maximum pressure of 565.8 kPa and 254.8 kPa respectively at times of 18.9 and 197.4s.

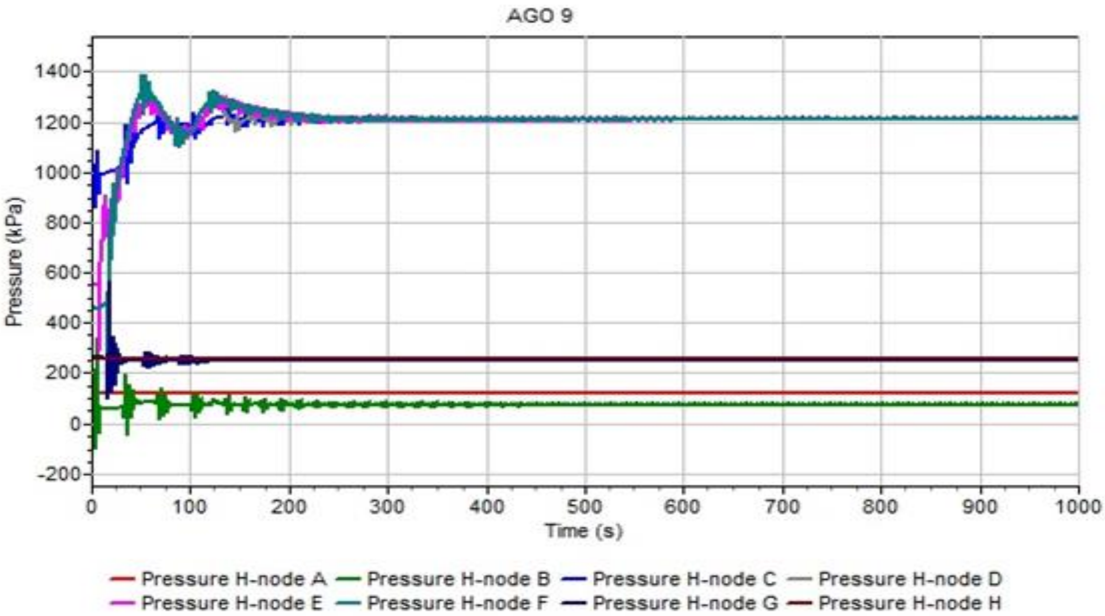

Figure 4: Pressure Transients at Hydraulic Nodes for a valve closure time of 9.5 s

3.1.3 Simulated results for AGO at instantaneous valve closure times of 19 s

Figure 5 present results of pressure transients due to instantaneous valve closure time of 19 s in the pipeline network. The Figure depicts that there is variation in pressure in the various hydraulic nodes of the pipeline. The pressure of the fluid under normal operating conditions at nodes A, B, C, D, E, F, G and H are 118.72 kPa, 60 kPa, 1000 kPa, 540 kPa, 560 kPa, 470 kPa, 260 kPa and 254.73 kPa respectively. But when the gate valve is closed instantaneously, the pressure of the fluid fluctuates and oscillates between minimum and maximum pressures before stabilising as shown in Figure 5.

The pressure of the fluid fluctuates and oscillates between minimum and maximum pressures as a result of the instantaneous valve closure. The pressure of the fluid at node A fluctuates and oscillates between minimum pressure of 118.4 kPa and 119 kPa at times of 5 s and 134.2 s respectively. At node B, the pressure of the fluid rises to 367 kPa at a time of 0.1 s but later after about 3.5 s the pressure drops to -100.5 kPa. The drop in pressure to a negative pressure leads to the development of cavitation voids at the node and along pipe P1. At node C the pressure of the fluid fluctuates between a minimum pressure value of 347.4 kPa and a maximum pressure of 1260 kPa at times of 0.1 s and 139.3 s respectively. The pressure of the fluid at nodes D and E drops to a minimum pressure of 295.5 kPa at a time of 8.3 s but later the pressures at these two nodes rise to a maximum pressure of 1293 kPa at a time of 134.9 s. The figure also depicts that pressure at node F fluctuates and oscillates between minimum pressures of 180.6 kPa at a time of 16.5 s and maximum pressures of 1371 kPa at a time of 57.9 s.

Nodes G and H are the two nodes at the downstream side of the gate valve. The pressure of the fluid at nodes G fluctuates between minimum pressures of 94.94 kPa at 16.5 s and maximum pressure of 578.6 kPa occurring at 18.1 s while the pressures at node H fluctuates between a maximum pressure of 254.8 kPa and 254.4 kPa respectively at times of 18.9 and 161.1s.

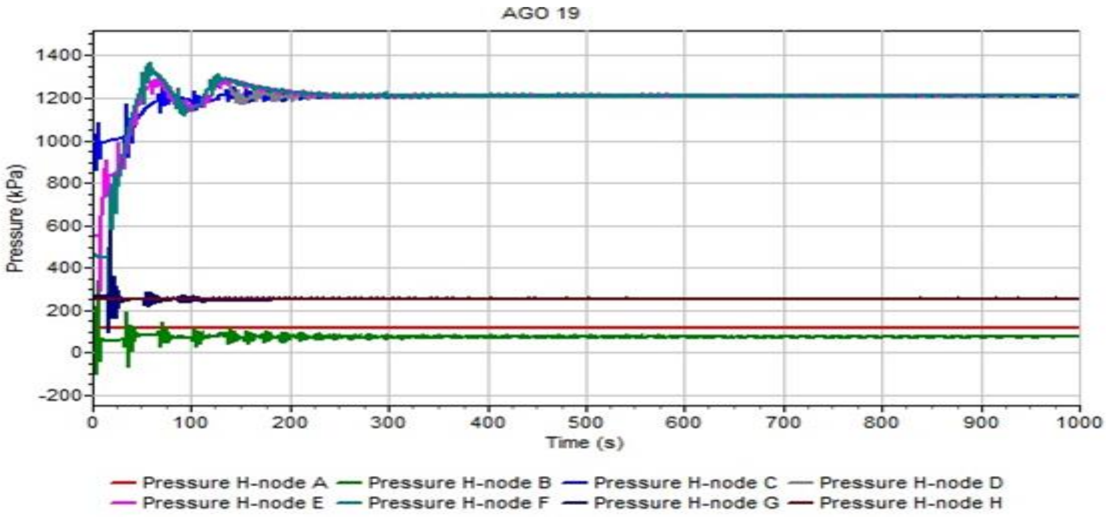

Figure 5: Pressure Transients at Hydraulic Nodes for a valve closure time of 19 s

3.2 Comparison of the high-pressure transients due to various valve closure times

The comparison of the simulated results for various valve closure times in the pipeline transporting the AGO is shown in Figures 6. The graph depicts that pressure transient due to instantaneous closure of a gate valve in a petroleum pipeline transporting AGO reduces as the valve closure time increases. Therefore, in a pipeline network, it is better to have a longer valve closure time so as to reduce or eliminate the possibility of pressure transients, column separation or the formation of cavitation voids that may eventually leads to pipeline failure. The results obtained in this analysis are in agreement with the results reported by [31] in which the rise in pressure inside network has different magnitudes depending upon the valve closure times. The valve closure time has to be sufficiently increased to avoid drastic pressure rise inside the pipe due to water hammer phenomenon.

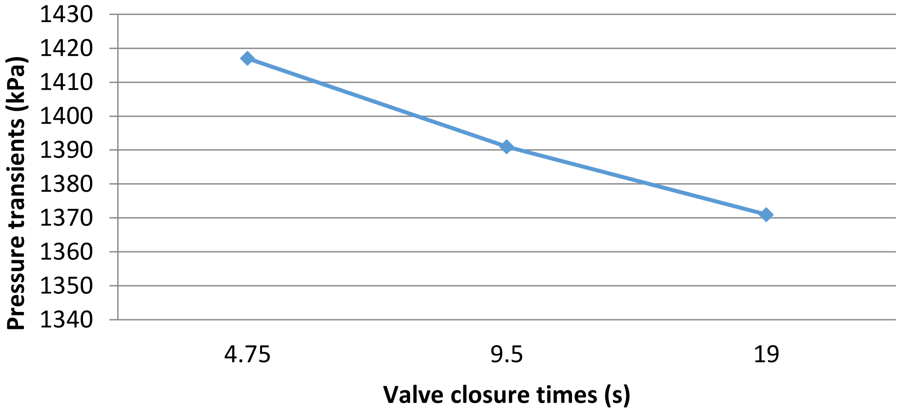

Figure 6: Comparison of pressure transient in AGO at different valve closure times

4. Conclusion

Effects of hydraulic transient due to instantaneous valve closure in a petroleum pipeline were investigated in this study. It was observed in the study that wave and pressure propagations in the pipeline network oscillate between high- and low-pressure values due to valve closure. The study showed that the velocities at nodes after the gate valve reduce to zero. Pressure rise was also observed at the node where the valves are located. In this research WANDA Transient 4.5.1210 simulation software was used to analyze pressure surge in the pipeline network due the instantaneous closure. Pressure fluctuations were observed in the simulation analysis as a result of the valve closure and nodes F where the gate valve is located records highest pressure surge while nodes B a node before the pump records negative pressures and cavitations in all the pipeline networks considered with different valve closure time. The research found that as the time of valve closure increases, the magnitude of pressure surge developed decreases. The research recommends that surge tank should be installed at node F to stabilize the pressure surge and also air vessels are to be installed at nodes B to curtail damages due to cavitations at the node and pipe P1.

Notations

A	*Area of pipe, m^2*
C	*Shock wave speed, m/s*
C_p	*Specific heat of fluid at constant pressure, kJ/kgK*
d	*Diameter of pipe, m*
E_y	*Young's Modulus for the pipe material, N/m^2*
f	*Moody friction factor*
g	*Acceleration due to gravity, m/s^2*
h_f	*head loss due to friction, m*
K	*Fluid bulk Modulus, N/m^2*
L	*Length of pipe, m*
m	*Mass flow rate, Kg/s*
P	*Pipe pressure, N/m^2*
P_o	*Stagnation pressure, N/m^2*
R_e	*Reynolds number*
R	*resulting force on the bend (N)*
R_x	*resulting force in x-direction (N)*
R_y	*resulting force in x-direction (N*
t	*Period (time), s*
th	*Pipe thickness, m*
T	*Temperature, K*
T_o	*Stagnation temperature, K*
V	*Flow velocity, m/s*
Greek Letters	
ρ	*Mass density of fluid, Kg/m^3*
γ	*Ratio of specific heats*
μ	*Dynamic viscosity* (N/m^2)
π	pye

References

[1] Duan, H. F. (2017). Transient Flow Analysis and Utilization in Urban Water Supply Systems. *Journal ofHydroinformatics*, *2*(1), 1–4.

[2] Naik, U and Bhat, D. S. (2015). Water Hammering Effects in Pipe System and Dynamic Stress Prediction, International Journal of Emerging Research in Management &Technology, 4(6), 236-243

[3] Mylapilli, L.K. (2015). Hydraulic and Surge Analysis in a Pipeline Network using Pipeline Studio, International Journal of Engineering Research & Technology, vol. *4, no.* 2, pp. 41–48.

[4] Starczewska, D., Collins, R., & Boxall, J. (2016). Occurrence of Transients in Water Distribution Networks. *13th Computer Control for Water Industry Conference, CCWI, Procedia Engineering, vol. 119, pp. 1473 – 1482.*

[5] Rodriguez, G. and Pavel, B. (2016). A Rational Methodology for Detailed Pipeline Transient Hydraulic Analysis, *Proceedings of the 9th International Pipeline Conference*, pp. 1–8

[6] Nerella, R. and Rathnam, E.V. (2015). Fluid transients and wave propagation in pressurized conduits due to valve closure, International Conference on Computational Heat and Mass Transfer, *Procedia Engineering*, vol. *127*, pp. 1158–1164
[7] Gómez, A.M. (2018). Physical aspects of air in pipe systems , including its effect on pipeline flow capacity and surge pressure (water hammer), Msc Aalborg University.
[8] Ali, N.A., Mohamed, H.I. and El-darder, M.E. (2010). Analysis of Transient Flow Phenomenon In Pressurized Pipes System and Methods of Protection, Theoretical Considerations, vol. *38*, *no.* 2, pp. 323–342.
[9] Elbashir, M.AM. and Amoah, S.OK. (2007). *Hydraulic Transient in a Pipeline, Using Computer Model to Calculate and Simulate Transient*, MSc Lund University.
[10] Malppan, P.J. and Sumam, K.S. (2015). Pipe Burst Risk Assessment Using Transient Analysis in Surge 2000, *Aquatic Procedia*, vol. *4*, pp. 747–754. https://doi.org/10.1016/j.aqpro.2015.02.157
[11] Mohammed, H.I. and Gad, A.A.M. (2012). Effect of Pipes Networks Simplification on Water Hammer Phenomenon, *Journal of Engineering Sciences, Assiut University*, vol. *40, no.* 6, pp. 1625–1647.
[12] Simão, M., Mora-rodriguez, J. and Ramos, H.M. (2015). Mechanical Interaction in Pressurized Pipe Systems: Experiments and Numerical Models, *Water*, vol. (2015), no. 7. pp. 6321–6350.
[13] Noorbehes, N. and Ghaseminejad, P. (2013). Numerical Simulation of the Transient Flow in Natural Gas Transmission Lines Using a Computational Fluid Dynamic Method, *American Journal of Applied Sciences*, vol. *10, no.* 1, pp. 24–34. https://doi.org/10.3844/ajassp.2013.24.34
[14] Larock, B.E., Jeppson, R.W. and Watters, G.Z. (2000). Hydraulics of Pipeline Systems, First Edition, CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431
[15] Abuiziah, I., Oulhaj, A., Sebari, K. and Ouazar, D. (2013). Simulating Flow Transients in Conveying Pipeline Systems by Rigid Column and Full Elastic Methods : Pump Combined with Air Chamber, *International Journal of Mechanical and Mechatronics Engineering*, vol. *7*, *no.* 12, pp. 2391–2397.
[16] Liu, E., Zhu, S., Li, J., Tang, P., Yang, Y. and Wang, D. (2014). Liquid Pipeline Transient Flow Analysis, *The Open Fuels & Energy Science Journal*, vol. *7*, pp. 9–11.
[17] Abuiziah, I., Oulhaj, A., Sebari, K. and Ouazar, D. (2014). Comparative Study on Status and Development of Transient Flow Analysis Including Simple Surge Tank, *International Journal of Civil and Environmental Engineering*, vol. *8, no.* 2, pp. 228–237.
[18] Salmanzadeh, M. (2013). Numerical Method for Modeling Transient Flow in Distribution Systems. *International Journal of Computer Science and Network Security*, vol. 13, no. 1, pp. 72–78.
[19] Lebele - Alawa, B.T. and Oparadike, F.E. (2015). Pressure Surge Dependence on Valve Operations in a Pipeline Loading System, *Engineering*, vol. 7, pp. 322 -330. http://dx.doi.org/10.4236/eng.2015.76028
[20] Simão, M., Mora, J. and Ramos, H.M. (2014). Dynamic Behaviour of a Pipe System Under Unsteady Flow and Structure Vibration,*Conferência Nacional de Mecânica Dos Fluidos, Termodinâmica E Energia MEFTE 2014, pp. 11–12*
[21] Carlsson, J. (2016). Water Hammer Phenomenon Analysis using the Method of Characteristics and Direct Measurements using a " stripped " Electromagnetic Flow Meter by, MSc, Royal Institute of Technology.
[22] Kim, Y.I.L. (2008). Advanced Numerical and Experimental Transient Modelling of Water and Gas Pipeline Flows Incorporating Distributed and Local Effects, PhD Thesis, The University of Adelaide, Australia.
[23] Bettaieb, N. (2015). Transient flows in petroleum pipe networks, *International Conference on Advances in Mechanical Engineering and Mechanics*, 1–6.
[24] Svindland, R.C. (2005). Predicting The Location And Duration of Transient Induced Low or Negative Pressures Within A Large Water Distribution System, PhD Thesis, University of Kentucky.
[25] Ramalingam, B.Y.D., Lingireddy, S. and Wood, D.O.N.J. (2009). Using the WCM For Transient Modeling of Water Distribution Network, *American Water Works Association*, pp. 75–89.
[26] Akpan, P. U., Jones, S., Eke, M. N., & Yeung, H. (2015). Modelling and transient simulation of water flow in pipelines using WANDA Transient software. *Ain Shams Engineering Journal*, 1–10. https://doi.org/10.1016/j.asej.2015.09.006
[27] Yang, B., Deng, J., Liu, K., & Ye, F. (2017). Theory Analysis and CFD Simulation of the Pressure Wave Generator. *Chemical Engineering Transactions*, vol. 61, pp. 481–486.
[28] Pires, L.F.G., Ladeia, R.C.C. and Barreto, C.V. (2017). Transient Flow Analysis of Fast Valve Closure in Short Pipelines, *International Pipeline Conference, Calgary, Alberta, Canada*, pp. 2–8. https://doi.org/10.1115/IPC2004-0347
[29] Carey, M. A. (2014). Water Hammer Fracture Diagnostics, PhD Thesis, The University of Texas at Austin.
[30] Wang Hai, X.L. and Weiguo, Z. (2011). Transient Flow Simulation of Municipal Gas Pipelines and Networks Using Semi Implicit Finite Volume Method, *Conference on Engineering Modelling and Simulation (CEMS 2011)*, pp. 217–223.
[31] Bhattacharyya, E. M. &Saikia, M. D (2017). Numerical Modelling for Prediction of Hydraulic Pipe Transients in Water Hammer Situations by the MOC for Different Valve Closure Times, International Journal of Engineering Science and Computing, vol. 7, no. 4, pp. 11001-11006

[32] Subani, N. and Amin, N. (2015). Analysis of Water Hammer with Different Closing Valve Laws on Transient Flow of Hydrogen-Natural Gas Mixture, Hindawi Publishing Corporation, Abstract and Applied Analysis, Volume 2015, Article ID 510675, 12 pages http://dx.doi.org/10.1155/2015/510675

[33] LeChevallier, M. W., Gullick, R. W. and Karim, M. (n.d). The Potential for Health Risks from Intrusion of Contaminants into the Distribution System from Pressure Transients, U.S. Environmental Protection Agency Office of Ground Water and Drinking Water Standards and Risk Management Division 1200 Pennsylvania Ave., NW Washington DC 20004