SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

The Effects of Water Hammer on Pipeline Systems: A Review

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ARTICLE INFO

Article history:
Received 5 June 2026
Received in revised form 5 August 2026
Accepted 10 August 2026
Available online 17 August 2026

Keywords:
Water hammer; transient flow; MOC; surge tank; water transport systems

ABSTRACT

Water hammer is a serious problem in fluid transport systems that results from abrupt changes in flow velocity or direction, usually triggered by fast valve closure or pump shutdown. Such pressure spikes can lead to pipe failure, damage to equipment, severe vibration and instability of operation. The purpose of this paper is to give a complete evaluation of the causes, modelling methodologies and protective strategies of water hammer in pipeline systems. A review and analysis of relevant works was conducted in terms of numerical methods, e.g. Method of Characteristics (MOC), Finite Difference Method (FDM), Mac Cormack Method and simulation tools, e.g. MATLAB, HAMMER, WANDA, FORTRAN codes. The literature examined demonstrates that in general these numerical methods accurately anticipate transient pressure behavior and are in excellent agreement with experimental findings. It was also concluded that the best mitigating solutions include surge tanks, hydro pneumatic hydro pneumatic tanks, slow valve closing strategies and bypass systems. Recent improvements in numerical simulation and surge protection technology have greatly enhanced the understanding and control of water hammer events, leading to safer and more dependable pipeline operation.

1. Introduction

Water transmission lines, which include pumping stations, supply and storage tanks, and pipelines, are used to supply, transmit, treat, and distribute sanitary drinking water to both urban and rural consumers. Given the high cost of operating transmission lines, protection and risk mitigation are crucial, and one of the biggest threats is the water hammer phenomenon [1], which has always posed a serious risk to long-distance water transfer pipeline systems, with the potential to induce structural failures or pipeline collapse [2].

If there is a sudden change in the chosen parameter describing flow velocity or pressure, characterizing the transitory state becomes necessary. The "water hammer phenomenon," in which the valve at the pipe's far end abruptly closes, is the most hazardous scenario of potential

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https://doi.org/10.37934/araset.62.5.99114

pressure pulsations. This phenomenon should be thoroughly investigated to accurately forecast and be able to safeguard systems in the future against excessive pressure rise, which could harm pipeline components [3] all across the hydraulic system. The resulting pressure changes are negligible and do not jeopardize the pipeline's integrity if the conditions change slowly enough. On the other hand, if conditions change quickly, a lot of destructive pressure may be produced, sometimes to the point that pipes rupture or other equipment is harmed. Dangerous high- and low-pressure waves in water supply systems can be caused by several factors, including pump power failure, abrupt valve movements, rapid hydrant use, poorly managed line filling, abrupt air release or compression, and the functioning of automatic control systems. Water distribution systems can be made less susceptible to surge events by managing or suppressing transients using various techniques [4] as shown in Fig .1. Water Hammer Phenomenon Due to Sudden Valve Closure [5].

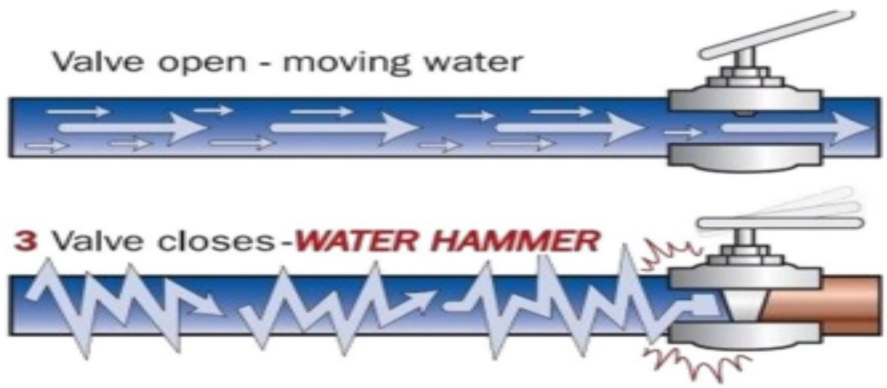

Fig.1. Water Hammer Phenomenon due to sudden valve closure

Transient pipe flow can be studied using a variety of numerical techniques, including finite difference methods (FDM), finite volume methods (FVM), graphical approaches, and analytical methods. The features technique is the most widely used one-dimensional strategy. The 1-D finite volume technique represents conservative algebraic forms of partial differential equations [6].

Surge Protection Strategy Selection Transients in water distribution systems can be controlled utilizing a variety of approaches. Some strategies merely consider operational and design factors, whilst others incorporate additional surge protection devices. Maximum pressures are routinely regulated using devices such as pump bypass lines, surge (air) vessels, surge tanks, pressure relief valves, or any combination of these. Increasing pump inertia, installing surge vessels, surge tanks, air-release/vacuum valves, pump bypass lines, or any combination of these components can all aid to regulate minimum pressures. The major purpose is to reduce the rate of flow change [7].

Water hammer has been extensively investigated using analytical, numerical, and experimental approaches. Previous research can be categorized into four main areas: protection and mitigation strategies, numerical modeling techniques, computational fluid dynamics (CFD) approaches, and experimental investigations:

1.1 Protection and Mitigation Strategies

Hydraulic transients or water hammer can cause excessive pressure surges and threaten the integrity of pipelines, equipment safety and system dependability. As a result, pipeline design and operation have increasingly utilized protection and mitigation techniques. These techniques are designed to reduce pressure variation by avoiding sudden flow changes and by dissipating the transient energy within the system. Mechanical protection devices and operational procedures are commonly used to reduce the effects of water hammer and to maintain the pipeline in a stable and safe condition.

1.1.1 Surge tanks

At its most basic, a surge tank is an extra reservoir in a pipe system that is subjected to changing flow rates. Surge tanks are used to protect turbine and pipelines from pressure waves generated by sudden fall of flow rate. Surge tanks are most often used in hydroelectric power facilities with large pipelines at quite high flow rates. But they may be utilized in a lot of various pipe systems including waste water management, manufacturing water supply and even in the car sector. Water flow management surge tanks vary widely, ranging from 40-gallon pressurized units to atmospheric reservoirs containing thousands of gallons. Surge tanks have been around for a long time but are still a. Although surge tanks have been around for a long time, the issue is always being researched and improvements are routinely being proposed [8]. where the design elements of sloping ceiling tail race tunnels and surge tanks might reflect water hammer waves. Fig.2 depicts the standard configuration of a hydroelectric plant with a surge tank [9].

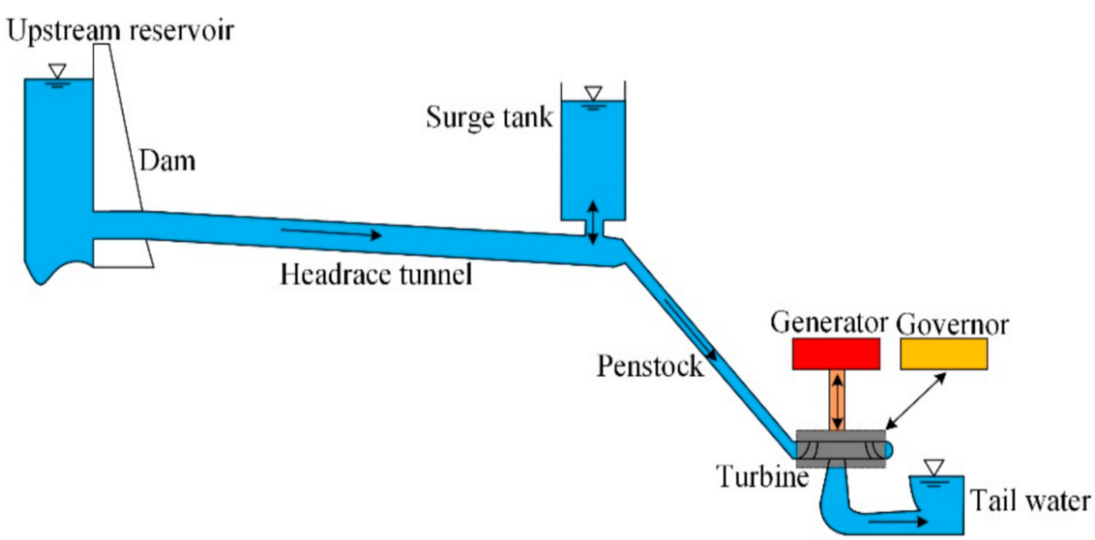

Fig. 2. A typical hydro power station configuration including a surge tank

Water hammer is a transient hydraulic phenomenon that can cause significant damage to water transmission lines, such as pipe bursts or damage in this study using the irrigation pipeline system of the proposed Taq-Taq dam in northeastern Iraq. The transmission line, which controls the water level in two major reservoirs at both ends, is susceptible to a potential water hammer.

Bentley HAMMER, a software program, adopted the hydraulic simulation model used in the design and analysis of hydraulic and transverse behavior (water hammer) through two scenarios (with and without control device). It was suggested that a surge tank implement an operational control method to reduce the likelihood of a water hammer incident occurring and to safeguard the dam from this issue. The results showed that the use of a balancing tank effectively protects the pipe network from the effects of water hammer [10].

A theoretical analysis based on certain surge tank design concerns. The effects of different parameters such as the friction losses coefficient and the surge tank cross-sectional area on the water surface oscillations tank and the total discharge are investigated. System of non-linear ordinary differential equations are numerically solved and manipulated. According to the results, the surge tank level and discharge rates decrease as the cross-sectional area and friction losses coefficient increase. Additionally, the water hammer will cause the pressure waves and fluctuations to be lower and more stable in height. This analysis indicates that the surge tank [11].

This study of the Basra Water Project of water pumping stations in Iraq essential hydraulic parameters of water pumping stations under transient flow situations shutdowns, and surge tank installations on pressure stability and system flexibility using hydraulic modeling with HAMMER V8i. The results demonstrate significant variations in pressure over short periods of time. Pipes L1 and L2 experienced hydraulic transient effects after an abrupt shutdown without surge tank protection, which led to minimum pressures of 12.5 m. Under typical conditions, the maximum pipe pressure was 17.5 m (L3). The analysis finds that L1 is the most dangerous pipeline due to its exposure to low-pressure events. The study demonstrated that installing surge tanks—especially three tanks significantly reduce pressure fluctuations and water hammer effects, thereby improving system stability, durability, and operational efficiency [12] as shown in Fig .3. Surge Tank Response to Transient Flow [10].

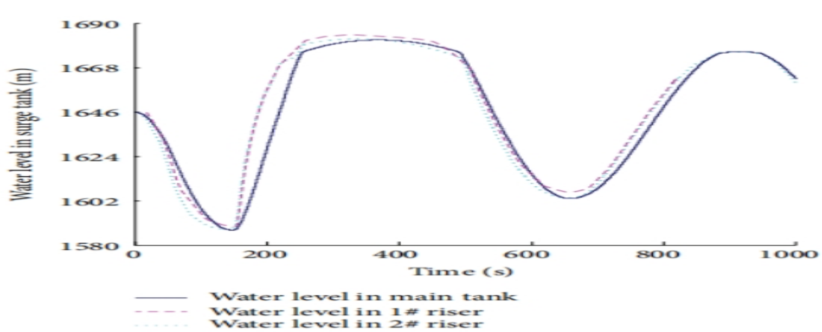

Fig. 3. Surge tank response to transient flow

The author applied the method of characteristics (MOC) to statistically investigate the performance of a surge tank in pressured pipelines, emphasizing the influence of the connection and discharge capacity. An intelligent self-controlled surge tank (IST) was proposed for varying discharge capacity under varied situations. The results showed that the performance of the surge tank is improved and the pressure fluctuations are reduced by modifying the discharge capacity of the connection. The suggested IST was better than traditional surge tanks in pressure control and application [13].

The author developed a one-way surge tank model, including the check valve activity, by means of the characteristics approach and evaluated the effects of the valve operation and position of the installation on a real water supply system. The results showed that including check valve behavior resulted in lower expected pressures and slower water replenishment than typical models, indicating potential safety hazards if the valve action is neglected. It was also observed that the slower the valve opening, the lower the minimum pressure, and negative pressure can occur. The optimum configuration is to place surge tanks near the pump and at high points [14].

A numerical model based on the method of characteristics (MOC) has been developed for assessing the efficiency of surge tanks in water hammer control in pressurized pipelines. The model was validated using experimental data and was then used to analyze different combinations of the surge tank diameter and intake diameter of the hydroelectric system under different boundary conditions. The surge tank's geometric characteristics are shown to have a great influence on its performance. The optimal design (D = 6 m, d = 3.4 m) might avoid the head pressure changes in the upstream pipeline, but the water hammer effects would be more likely to happen in the starting part of the pipeline [15].

1.1.2 Hydro pneumatic tanks

One of the best tools for preventing water hammer in long-distance transmission pipe systems and water distribution systems is the dipping tube hydro pneumatic tank. Although dipping tube hydro pneumatic tanks have numerous necessary benefits due to its low cost and simple maintenance features, it can be challenging to calculate the ideal size and gas volume for practical engineering applications. A solid approach to resolving the issues from theory and application is presented in this study. In order to prevent water hammer, this work derives the equations for modeling dipping tube hydro pneumatic tanks in water distribution systems using the Method of Characteristics (MOC) equations. MOC, the differential orifice head loss equation, the gas law, IBM's SSP package was used to solve the equations and integrate them into the HAMMER software. A case study is presented to determine the tank's size and compare it with other protection methods [16].

The authors analyzed water hammer effects in the SMD water supply pipeline using Bentley HAMMER to evaluate transient pressures and surge protection measures under different operating scenarios. Results revealed that preventive measures, including 2000-L hydro tanks, made pressure changes far less likely, lowered the danger of cavitation, made pipelines safer and more reliable, and cut down on maintenance expenses [17].

The authors examined pressure surges induced by the quick activation of high-response hydraulic control valves in transmission lines. We built a lumped-parameter math model that took into account the effects of resistance, inertia, and capacitance to see how well oleo-pneumatic accumulators might guard against surges. We then used existing experimental data to test the model. The research developed an analytical formula to ascertain the necessary accumulator dimensions for safeguarding against pressure surges. The results indicated that the installation of a correctly sized hydraulic accumulator markedly decreased both the amplitude and duration of transient pressure oscillations, hence enhancing system safety [18].

The author assessed the efficacy of hydro-pneumatic tanks (HPTs) in alleviating water hammer by employing rigid and elastic water column models inside the ALLIEVI simulation environment, then validated through a case study. The results showed that the rigid model was good at doing calculations quickly, but the elastic model was better at making predictions (up to 100% accurate). The study confirmed the capability of these models to predict pipeline failure and improve decision-making in transient flow analysis [19].

1.1.3 Air vessels

Air vessels, also known as air chambers, are placed behind tank valves in locations where water hammer occurs often. They are filled with air and have the shape of a thin, inverted bottle with a tiny hole attached to the pipe Fig. 4. In order to protect the fitting and pipes and absorb the shock, the air is compressed. Another name for an air vessel is a pneumatic tank, pressurized surge tank, or air chamber. The air tank's operation is determined by its water and air volumes [20].

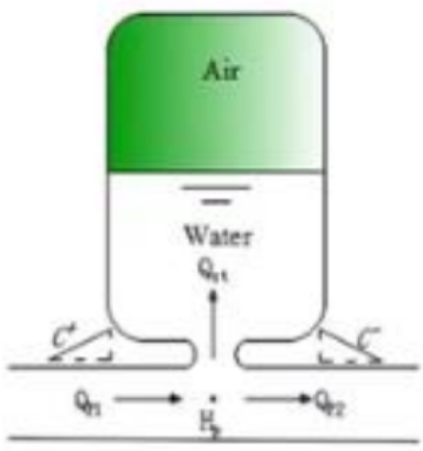

Fig. 4. The pipeline's installed air vessel

The authors analyzed surge protection in the Omar Al-Mokhtar reservoir pipeline system using the WANDA simulation program based on the method of characteristics to evaluate surge control devices. Results showed that an air tank capacity of 1500 m³ successfully controlled transient pressures, while 1000 m³ was inadequate, and proper installation of upstream air valves was necessary for safe system operation [7].

The authors investigated water hammer effects in an irrigation pipeline system located in the Al-Salihiya agricultural area by conducting field measurements of flow and pressure during normal operation and power failure conditions. The study analyzed transient behavior and evaluated protection devices using AFT Impulse simulation. Results showed that sudden pump shutdown and valve closure generated severe pressure fluctuations causing potential pipeline damage. The installation of protection devices such as water–air tanks, overflow tanks, and safety valves as shown in Fig.5. effectively mitigated water hammer effects and improved the safety of the irrigation system [21].

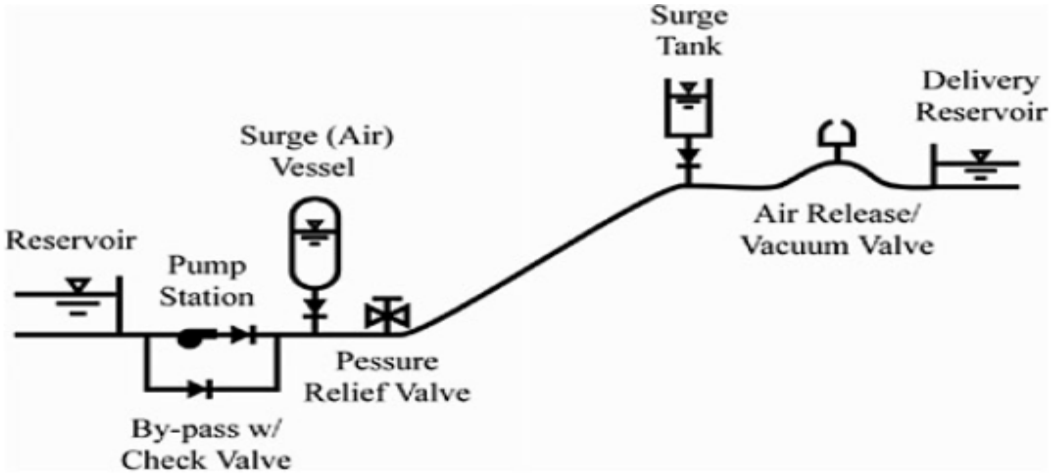

Fig.5. Common places to find a water hammer control device

The author developed a mathematical model based on the unsteady one-dimensional momentum and continuity equations, solved using the method of characteristics, to analyze the performance of a pressurized air vessel in controlling water hammer. We wrote the model in FORTRAN and tested it with a test rig that had a rapid-closing valve and pressure sensors. The results demonstrated that the pressurized air vessel does a good job of lowering water hammer pressure. Researchers observed that the orifice width has the most effect on the water hammer head, the air pressure within the vessel, and the water level. The throttling action has a big effect on the size of the vessel that is needed [22].

The author studied water hammer pressure transients that happen when pumps stop suddenly, such as when water columns separate and overpressures happen. We looked at many ways to safeguard the system, such surge tanks, discharge tanks, in-line valves, pump bypass valves, air vessels, and release valves. We also looked at how pump inertia affects these strategies. The results showed how to choose the right protective devices for different system circumstances. For example, air vessels like the one in Fig.6. and release valves work best for high-head systems, while other approaches work better for low-head systems. The research also provided design charts and equations to help with the right design and use of these safety measures [23].

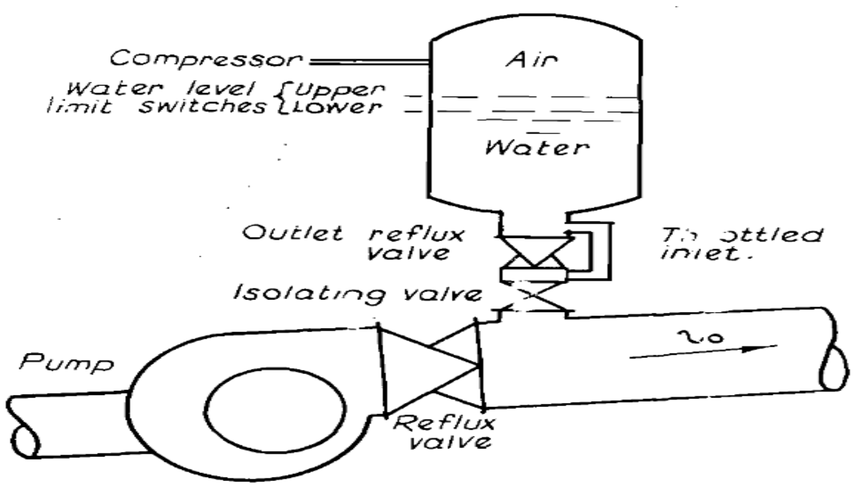

Fig. 6. Air vessel arrangement

1.2 Experimental and Numerical of Water Hammer

The current research comprises a series of experiments on various cases of water hammer, a phenomenon occurring in pressurized water pipes, reviewing key previous studies and methods for mitigating the phenomenon. Several pipe fittings were tested to find simple alternatives to imported brakes used in domestic plumbing. The results showed that some easily implemented, locally manufactured solutions were effective in reducing the impact of water hammer. The study also offers a set of conclusions and recommendations supporting these findings [24].

The authors developed a numerical model based on MacCormack's method to analyze water hammer caused by valve closure under fast and slow operating conditions. We looked at how well linear and quadratic valve closure rules worked for controlling pressure by comparing them. The quadratic closure rule was better at lowering excess pressure, with a maximum drop of 0.05 bar. The best value for the valve closure exponent m was between 1.117 and 1.599 for reducing over pressure and between 0.95 and 1.419 for preventing under pressure. The range got smaller as the closure duration got longer [25].

The authors examined hydraulic transients in straight pipes by integrated experimental and computational analysis. A mathematical model based on partial differential equations was transformed using the Method of Characteristics and a predictor–corrector approach. Laboratory experiments on a single steel pipe showed strong agreement between measured and predicted pressure oscillations. The model was further applied to a complex pipe network consisting of 17 loops, 48 pipes, and 33 nodes, successfully simulating water hammer induced by valve closure [26].

In this work, the Method of Characteristics was used to analyze the hydraulic flow variation in a simple pipeline system consisting of a tank, pipe and valve. We have developed and validated a numerical program, dubbed WH (Water Hammer), against comparison with other existing models. The effects of valve-closing time, pressure variation and spatial-temporal discretionary on the transient behavior were studied. The results indicated the influence of velocity of interruption and characteristics of the operation on the behaviour of pressure waves in water hammer phenomena [27].

The authors have studied the hydraulic transients that occur during the closing and stopping of the pumps by use of numerical models in FORTRAN and graphs. We studied a variety of different operating scenarios, both with and without pumps to determine their response to transients. The results revealed that both the stepwise shutting of the valve and an increased inertia of the pump are good solutions to reduce the transient pressures. It was proven that the transient flow behavior is influenced by two significant parameters, namely water speed and the coefficient of friction. The graphical and computational solutions [28] were in good agreement.

In this work we study the conditions of the occurrence of the water hammer effect in a pipeline. Water hammer can burst the pipe if the pressure is strong enough. In order to avoid the water hammer effect occurring, the experiment will be set-up to explore the water hammer effect. The prevention of water hammer effect will be suggested and the preventive approach will be proved to be successful in reducing the water hammer effect. The preventive precaution adopted is the installation of a bypass pipe with a non-return valve. The vibration signal of the experiment is recorded by the accelerometer and data gathering equipment. The valve snaps shut and gets the pressure signal. Then the signal is analyzed and turned into wave velocity. The phenomena of water hammer are separated and contrasted with different pipe materials, lengths, diameters of intake pipe and pressures in pipeline. The result of experiment indicates that the longer pipes, smaller intake diameter pipes and lower strength material pipes would be able to endure higher water hammer impact. Also, the water hammer phenomenon may be eliminated successfully by installing a pass pipe with non-return valve which decreases pressure by 33.33 % [29].

Water hammer phenomenon is a short flow in pipes due to sudden variations in velocity of the pipeline. This might happen due to high positive or negative pressures in water pipes. In short, water hammer is caused when valves close suddenly, when pumps are stopped or re-started. In this work, the momentum (Euler) equation and continuity equation of a water hammer are simulated numerically by MATLAB software. Sensitivity analysis has been explored using variety of elements such as pipe diameter, wave velocity and friction factor. The work was done using the Method of Characteristics (MOC). The data shows that the maximum pressure head reduced by 31.5 % with a 1.2 m diameter pipe and by 47.7 % with a 1.4 m diameter pipe, when compared to the use of a 1 m diameter pipe. It is shown that changing the friction factor values leads to decreasing the maximum pressure head by 0.86% when the friction factor value (0.008) is used instead of (0.007) and by 0.81% when the friction factor value (0.009) is used instead of (0.007). The study on the influence of wave velocity on pressure head showed that the maximum pressure head rose by 10.6% with the wave's velocity (300 m/sec) instead of (250 m/sec), 19.13% with (350 m/sec) instead of (250 m/sec) and 26.1% with (400 m/sec) instead of (250 m/sec). It discovered serious water hammer in the end pipe [30].

This study investigates combined pump-pressurized and gravity water delivery systems; nevertheless, the transient control tactics for these integrated arrangements are still not well covered. This article outlines the functional arrangement of each hydraulic section and includes an examination into the system's water hammer protection methods. The pump-valve relationship is analyzed using a theoretical framework operation has proven the efficacy of the suggested preventative measures. The water replenishment volume formula calculates replenishment volumes for the high-level surge tank and the findings indicate that simultaneous valve closure effectively reduces water level fluctuations, and the derived formulas agree with numerical simulation results. The research provides a practical basis for designing reliable protection strategies while reducing a computational effort in transient analysis [31].

Based on certain surge tank design factors, a theoretical analysis is conducted. Investigations are conducted into how various parameters, such as the friction losses coefficient and the cross-sectional area of the surge tank, affect the water surface oscillations tank and overall discharge. A system of non-linear ordinary differential equations is controlled and solved numerically. The results indicate that the surge tank level and discharge rates decrease as the cross-sectional area and friction losses coefficient increase. Additionally, the water hammer-induced pressure waves and oscillations will be lower in height and more stable [32].

This study investigates the effect of the valve switching valve has an impact on the amplitude, waveform, and periodicity of the water hammer pressure pulsation under the continuous on/off of the valve n the digital hydraulic system is affected by the frequency of the valve switching valve, which is greatly deviated from the prediction and evaluation results of the traditional water hammer model. Therefore, to improve the prediction accuracy of the pressure pulsation (water hammer) model in continuous switching digital hydraulic systems is created by taking into account the fluid's compressibility and the elasticity of the pipe walls. Experimental validation confirmed high accuracy, with prediction error less than 5% [33]. Researchers are now concentrating on the variance of water hammer characteristics in the viscoelastic pipeline due to the growing popularity of long-distance water supply projects and advancements in materials technology. An experiment was set up to investigate the direct water hammer produced by the quick closure of the downstream valve in the poly methyl meth acrylate (PMMA) pipe, with six flow velocities in nearly 70 tests, in order to determine the mechanism of water hammer in the viscoelastic pipe of both elastic and viscous properties. The experimental findings demonstrated that, for all flow velocities, the maximum water hammer pressure produced in the relativistic pipe was at most 20% higher than the conventional value of Joukow sky's formula. The water hammer pressure increased as the valve closed more quickly. the difference in water hammer pressure generated between the fastest and the slowest closing time of the valve was 14–17% at each flow velocity. The explanation for why the water hammer characteristic in the viscoelastic pipeline deviated from the conventional value was provided by the relationship between the stress and strain of the pipe wall. A reference on the mechanism of transient flow in viscoelastic pipes is provided by the study as shown in Fig. 7 [34] as shown in the Fig 7. Effect of Valve Closure Time on Pressure Surge [35].

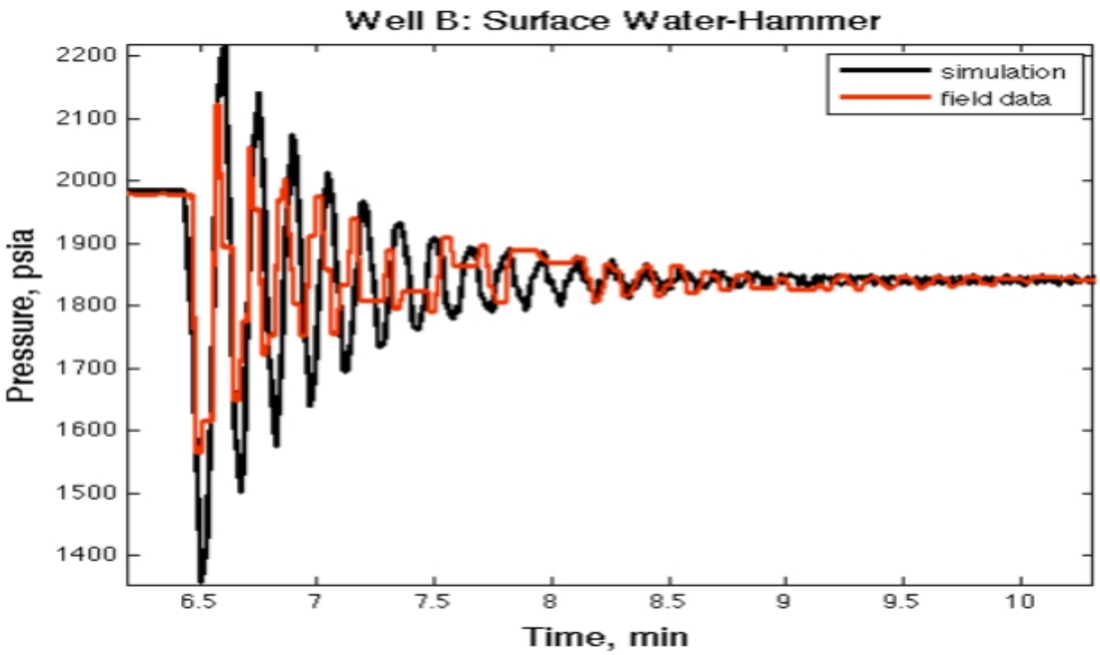

Fig. 7. Effect of valve closure time on pressure surge

1.3 CFD (Computational Fluid Dynamics)

Water hammer studied in water distribution networks using experimental and numerical models in two different setups, with and without a riser pipe. The measured data for different discharges and times were compared with the results of computational fluid dynamics (CFD) after selecting appropriate network and turbulence models, with a simulated sudden flow interruption using Fluent software. The results maximum and minimum pressure calculated values, with the accuracy range from 0.12% to 2.64%, confirming the accuracy and efficiency of numerical modeling in representing the phenomenon and predicting transient pressure behavior [36].

We compared quasi-2D, axisymmetric CFD and complete 3D CFD models for water hammer simulation and showed that the amplitude, phase and attenuation of the transient are almost comparable when calculated by the quasi-2D water hammer model and the axisymmetric CFD model. The results presented also indicate the computational efficiency of the quasi-2D model, using a grid density one order of magnitude lower than that required for the full 3D CFD model and giving pretty good results with respect to the full 3D CFD model results [37].

The author developed a three dimensional CFD model to study water hammer based on the Navier–Stokes equations. In this model, the SIMPLE approach was utilized for the weakly compressible flow, to account for the flexibility of the pipes and water. The model was validated by comparing its output to empirical data. The results showed that the model could successfully simulate the water hammer dynamics and assess the main factors influencing the behavior, including unsteady friction, valve closure law, and wave velocity, providing a sound basis for the analysis of the transient flow in hydropower pipeline systems [38].

The research was conducted using the computational fluid dynamics (CFD) modeling program FLUENT to investigate the flow and heat transmission in a pipeline network that underwent a water hammer collapse in the thermal power plant, and to assess an upgraded network design. The results indicated that the buildup of liquid caused the steam to flow at rates of around 50 m/s, causing large variations in pressure at the elbows of the pipes and finally leading to the rupture. the study also demonstrated the improved design helped make the pressure, temperature and speed more consistent, making it safer and better for a wider range of purposes [39].

Researchers used three-dimensional CFD simulation to look at how transient flow affects the water hammer effect in a high-pressure injection system. the results shown that the model can precisely depict pressure and velocity behavior in comparison to experimental data. the research also showed that 3D simulation gives a more complete picture of how flow is distributed than other approaches [40].

Research Gap Comprehensive review studies are uncommon but a large number of publications on water hammer phenomena, numerical modeling, and traditional surge prevention technologies are available. The available research has not yet explored recent advances in numerical simulation and new protective solutions such as the Dipping Tube Tank (DTT). Thus, an updated assessment is required to describe current progress and compare conventional and innovative surge protection approaches. Significance of the Study This paper includes a complete examination on water hammer phenomena, numerical modeling methodologies, and surge prevention measures in pipeline systems. It also emphasizes current development of the Dipping Tube Tank (DTT) technology and makes comparison with the standard protective measures. The results are likely to help researchers and engineers choose appropriate surge protection methods and suggest future research topics.This review is intended to critically assess the available literature relating to water hammer in pipeline systems. This review, in particular, aims to summarize the causes and consequences of water hammer, review the commonly used numerical simulation methods, compare the performance of conventional and emerging surge protection techniques, and identify the current research gaps and future research opportunities in water hammer mitigation.

2. Methodology

This review research was performed by a comprehensive search of the scholarly literature on water hammer phenomena and mitigation strategies in pressurized pipeline systems. Relevant papers were retrieved from major scientific databases, including Google Scholar, Science Direct, Springer Link, Wiley Online Library, and Scopus.

The search was performed using the terms "Water Hammer", "Hydraulic Transients", "Surge Protection Devices", "Hydro pneumatic Tank", "Air Vessel", "Surge Tank" and "Dipping Tube Tank". We evaluated peer-reviewed journal publications, conference papers and technical reports published between 2010 and 2026.

The gathered research was selected for relevance to the mechanics of water hammer formation, transient pressure analysis and protection strategies. Special emphasis was devoted to current studies on Dipping Tube Tank technology and its hydraulic performance. The collected material was grouped into numerous areas such as basics of water hammer, causes of hydraulic transients, conventional protective systems, hydro pneumatic tanks and Dipping Tube Tanks.

Then a comparison study was made to analyze the research trends, limits of the existing studies and possible future research areas.

3. Result

The reviewed research show that water hammer is still one of the primary hydraulic concerns in terms of safety and reliability of pipeline systems. Most researches agreed that the main causes of significant pressure transients are quick valve closure and abrupt pump shut down, which may result in pipeline collapse, excessive vibration, cavitation, and equipment damage [2-4].

From the literature studied in the numerical analysis, the most used approach is the Method of Characteristics (MOC) because of its computational accuracy and capacity to forecast the transient pressure behavior. Other numerical methods like FDM, Mac Cormack Method and Computational Fluid Dynamics (CFD) have also provided credible findings and are in excellent agreement with the actual observations [25,30,36,40].

The evaluated research also show that surge protection systems can greatly lower the amplitude of pressure surges. In lengthy transmission pipes, surge tanks were seen to be very successful and hydro-pneumatic tanks and air vessels increased pressure stability and reduced danger of cavitation. Recent research have indicated that Dipping Tube Tank (DTT) technology has promising hydraulic performance, compact design and cheaper installation costs compared to traditional protective systems. Yet there is little study on DTT [10,16,23].

4. Discussion

The literature evaluation shows a strong progress in the investigation of water hammer during the previous decade. Previous studies were mostly based on analytical and one-dimensional numerical models. However, new studies are using sophisticated CFD simulations and combined numerical‑experimental methodologies for better prediction accuracy. The comparison of prior studies reveals that there is no surge protection device suited for all operational situations . The pipeline features, operational circumstances and economics determine the selection of a suitable protective system instead [17,19,25,40].

In addition, while traditional surge tanks and hydro-pneumatic tanks have been widely studied, emergent technologies such as the Dipping Tube Tank have been relatively neglected. This conclusion confirms the research gap indicated in this study and indicates the necessity for further computational and experimental investigations to improve design parameters of DTT and assess its performance under varied hydraulic situations [16,31,32].

5. Conclusions and Recommendations

5.1 Conclusions

1. Water hammer happens when the valve position change quickly or when pumps are shut off.
2. High pressures can destroy pipes.
3. The Method of Characteristics is the most efficient and widely used method in numerical analysis.

4. Air valves alone are not sufficient for protection in long pipelines.
5. Surge tanks and air vessels are among the most common protection methods.
6. Gradual valve closure reduces risk
7. The factors affecting the water hammer phenomenon include wave speed, friction coefficient, and valve closing time.

5.2 Recommendations

1. don't close the valve suddenly
2. Use multiple protection methods combined, such as a surge tank and air valves.
3. Conduct a transient analysis before implementing a water project.
4. Study the effect of pipe material during design, especially for flexible and elastic pipes.
5. Install surge tanks at critical locations such as near pumps and at high points.
6. Perform periodic maintenance for valves and protection devices.
7. Use software such as MATLAB, HAMMER, and WANDA.

Acknowledgment
The authors would like to express their sincere appreciation to the Department of Mechanical Engineering, College of Engineering, University of Mosul, Iraq, for providing academic support throughout this study. The authors also acknowledge the valuable contributions of the researchers whose published works formed the basis of this review. This research was not funded by any grant.

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