32nd International Conference
ENGINEERING MECHANICS 2026
Medlov, Czech Republic, May 11 – 13, 2026

INFLUENCE OF PIPING SYSTEM PARAMETERS ON WATER HAMMER USING 1D CFD APPROACH

Burda R.[1], Vondál J.[2], Sedlář M.[3], Abrahámek P.[4]

Abstract: *Water hammer poses a significant risk to the integrity of piping systems and pumps, particularly in critical applications such as nuclear power plants. This transient phenomenon is characterized by rapid changes in pressure and flow, often resulting from pump shutdowns or valve closures. This paper presents a detailed computational analysis of water hammer using the 1D CFD software Flownex. The study investigates the impact of various system parameters on the pressure response, specifically focusing on the influence of pump characteristics, the number of hydraulic accumulators, the gas-to-liquid ratio within those accumulators, and the presence of non-condensable air in the water. Results indicate that additional accumulators and optimized gas ratios mitigate pressure peaks. Also, the presence of non-condensable gas plays a crucial role in damping pressure fluctuations through the alteration of the fluid's bulk modulus.*

Keywords: Water hammer, Flownex, Accumulator, Air content, Mitigation of pressure pulsations

1. Introduction

The accurate prediction and mitigation of water hammer are critical for ensuring the safety and longevity of hydraulic systems, as the resulting rapid pressure fluctuations can lead to catastrophic structural failures, cavitation-induced fatigue, and severe damage to pumping components (Ghidaoui et al., 2005; Bergant et al., 2006). To model these transient events efficiently across complex pipe networks, one-dimensional (1D) Computational Fluid Dynamics (CFD) solvers are employed, offering a necessary balance between computational speed and the ability to capture essential flow characteristics averaged over the pipe cross-section (Himr, 2013). These simulations are indispensable for the sizing and optimization of protective devices such as hydraulic accumulators, which act as local energy reservoirs to absorb pressure surges and prevent column separation.

2. Method

The Flownex software is used in the analysis, which is based on the numerical solution of the equations of motion and heat transfer. A 1D CFD approach to simulate fluid flow in piping systems is used, which takes into account the flow parameters averaged over the pipe cross-section. Fluid compressibility and pipe wall flexibility are also included and the adaptive time stepping algorithm is used to adjust the time step based on the rate of change in flow. Single-phase water is used, and the algorithm can drop to negative values of pressure, while not going into cavitation. Therefore, regions of negative pressure only indicate the phase change in real application.

The piping system contains 2 outlet branches with up to 6 pumps and 5 accumulators (see Fig. 1). The 3 and 3 pumps are connected with the connecting valve and all the pumps have their own check valve to protect from water hammer during system failure. With the connecting valve the most dangerous scenario

---

[1] Ing. Radim Burda, PhD.: SVS FEM s.r.o., rburda@svsfem.cz

[2] Ing. Jiří Vondál, PhD.: SVS FEM s.r.o., jvondal@svsfem.cz

[3] RNDr. Milan Sedlář, CSc.: CENTRE OF HYDRAULIC RESEARCH, m.sedlar@sigma.cz

[4] Ing. Petr Abrahámek.: CENTRE OF HYDRAULIC RESEARCH, p.abrahamek@sigma.cz

ISSN: 1805-8256, doi: 10.21495/em2026-21

of 6 pumps into 1 outlet piping branch is possible but is never operational. The inlet and outlet share the same boundary conditions of atmospheric pressure and 20 °C temperature. The maximum volume of accumulators is 30 m^3 with 10 m^3 of initial gas with reference pressure of 1.5 MPa.

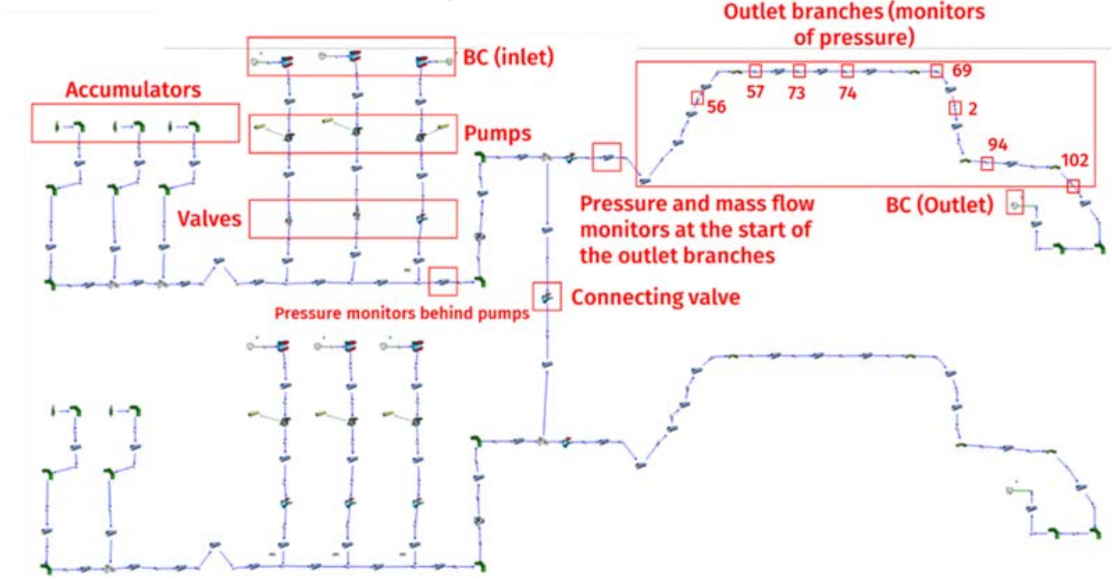

Fig. 1: Piping system of the pumping station.

The length as well as the elevation of the outlet branches can be seen in Fig. 2. The important nodes of the outlet branches are labelled with numbers that are then used for pressure monitoring. In Fig. 2 you can also see the characteristics of the closure of the check valve. The closing time as well as the valve flow coefficient can have a large impact on the final pressure course in the piping system during the water hammer mitigation. The characteristics of the pumps for various rotational speeds and even for negative flow rates need to be included as the flow can change direction during the shut-down of the pump. This is especially important when properly assessing the decreasing rotational speed during the shutdown. During the assessment of various parameters, different numbers of accumulators (ACC), pumps (C) and outlet branches (V) are assessed. The initial state of the piping system is the steady state operation of the pump station. During the first timestep the shut-down of the pump happens which replicates the power outage.

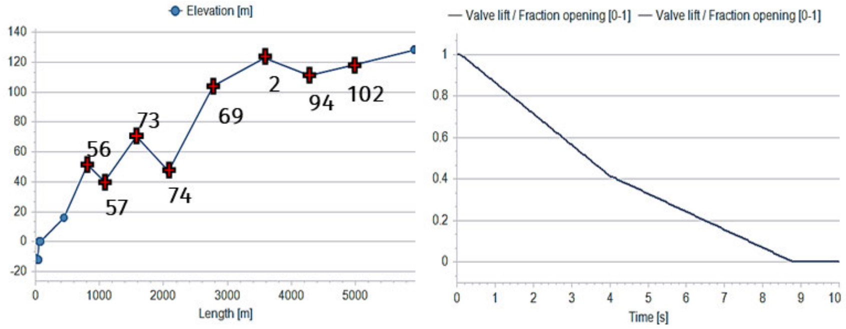

Fig. 2: Elevation of the nodes used for monitoring (left), characteristics of the check valve closure (right).

3. Results

This chapter is devoted to the effect of various system parameters on the resulting pressure waves during the water hammer phenomenon. The results are showcased as the pressure course as a function of time for all important nodes of the outlet branches. The simulation can also track the pressure behind the pump, the change of the gas/liquid content in accumulators and rotational speed and torque of the pump. Typically, there is a limit for the minimum and maximum pressure in the system. The minimum is usually connected to either saturation pressure when cavitation occurs and the atmospheric pressure when pipes start to deform inwards. The maximum pressure is connected to the potential of deforming outwards but is usually less problematic than the minimum pressure of the travelling wave. The minimum pressure typically occurs in the highest elevation point of the system whereas the maximum pressure occurs right after the connection of the pumps. The overall protection might mean increasing the accumulators in the system, prohibiting the scenario all together or locally resolving the nodes of low pressure with air valve, which sucks air into the system a thus does not allow for the pressure to drop below atmospheric pressure.

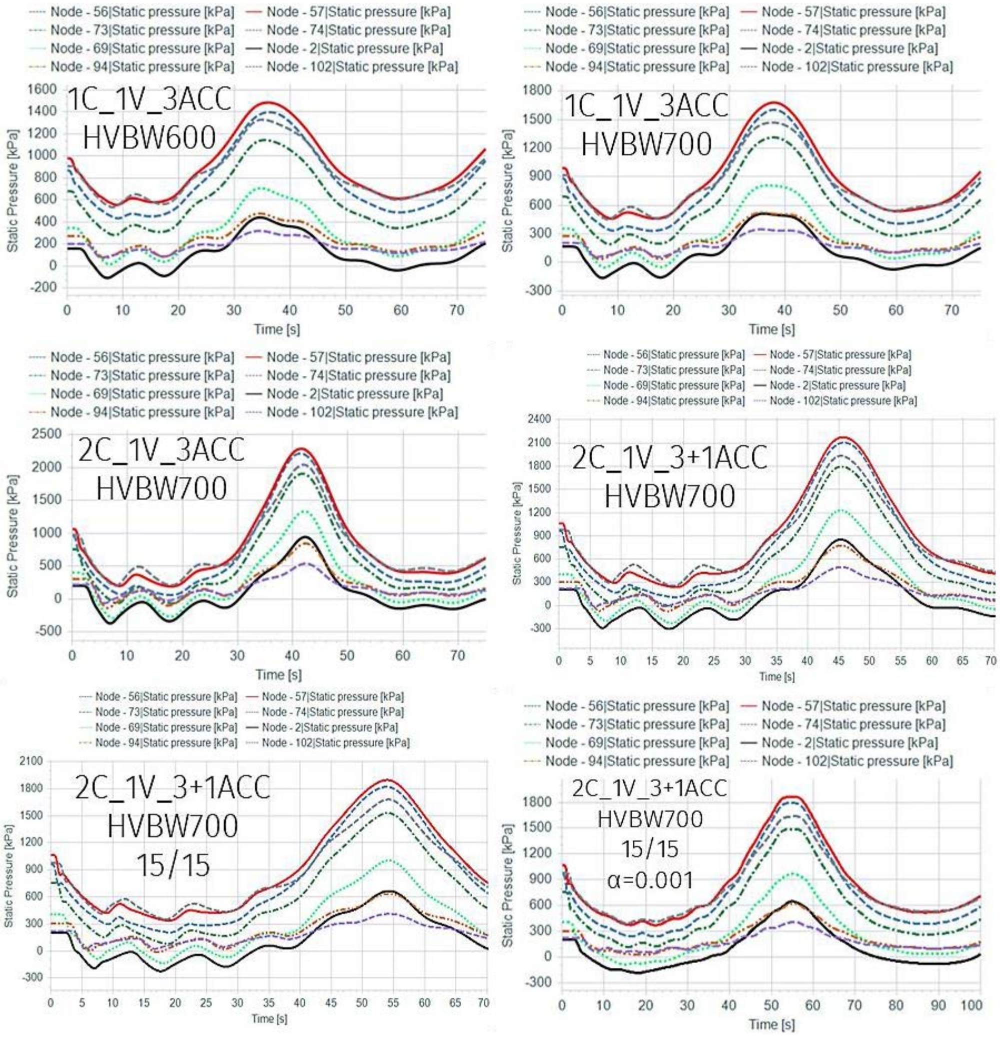

Fig. 3: Influence of various parameters of the pumping station on the pressure course in important nodes.

The first two images of Fig. 3 showcase the difference between pump HVBW600 and HVBW700, which is a change proposed by the customer to ensure sufficient water supply. We can see that both the pressure maximum and minimum for the same scenarios as pump 600 HVBW exceed the original values. The pump 700 HVBW allows for higher flowrate with the same pressure drop which results in stronger water hammer phenomenon. Based on these simulation results we can see that even with just 1 pump the pressure in nodes 69, 2, 94 and 102 goes into negative values, which indicates cavitation. The third image shows inclusion of the secondary pump to the previous scenario with HVBW700. We can clearly see that 2 pumps result in higher maxima and minima of pressure in the system, which is once again connected to the higher flowrate in the regular operation state. The saturation pressure is reached even for node 56 and 73. The fourth image shows introduction of additional accumulator. We can see that the introduction of just 1 accumulator almost resolved the node 56 and 102 but the rest of the nodes are still problematic. Introducing additional accumulators can be costly and therefore solving each piping system by introducing as many accumulators as possible is not ideal. The next chart shows the influence of the different ratio of gas/liquid in the accumulator at the start of the simulation. The ratio is changed to 15/15 m^3 from the original 10/20 m^3 gas/liquid content. The change results in the decrease of maximum pressure behind the pumps from 2800 kPa to 2550 kPa. The pressure minimum was also slightly affected (raising the pressure above 0 Pa for nodes 94 and 102). Therefore, the change is beneficial but does not resolve the potential of cavitation. The last image shows the introduction of air content which effects the bulk modulus of the water and thus damp the pressure fluctuations. The water is taken from the system which is estimated to have between 0.005 and 0.001 air volume fraction ($\alpha = 0.001$ is used). The change of the bulk modulus based on the air content implemented here can be found in Adamec (2010). From the image, it is clear that the region of lower pressure is influenced more, whereas the pressure peak maximum does not change. This is in agreement with the Adamec (2010), where we can find constant value of bulk modulus for region of high pressure.

The simulations with all included factors were conducted for all operation scenarios (see Fig. 4). We can see that nodes 69 and 2 are still dangerous for all the simulated variants which are in accordance with the actual state of the physical piping system, which was supplemented with the air valves, which should also improve the nodes 94 and 102. The scenario 3C_1V_4Acc (3 pumps into 1 outlet branch) was restricted. This was mainly due to highest pressure peak behind the pumps.

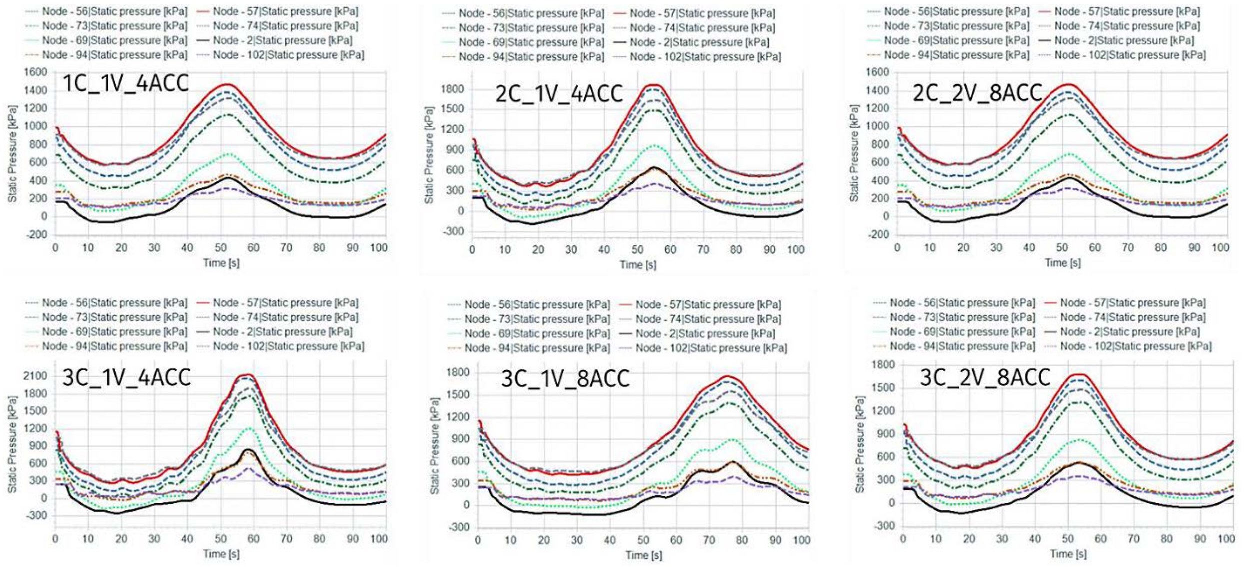

Fig. 4: The pressure in the important nodes of the outlet branches for all operation scenarios (HVBW700, gas/liquid ratio 15/15 m^3, α = 0.001).

4. Conclusions

In this study the water hammer effects in a pumping station were analysed using 1D CFD simulations to evaluate system response during a power outage. It was found that while increasing the number of hydraulic accumulators and optimizing gas-to-liquid ratios effectively lowered maximum pressure peaks, these measures alone could not prevent cavitation at high-elevation nodes. The inclusion of non-condensable air content proved vital, as it lowered the fluid's bulk modulus and provided significant damping of pressure fluctuations. To ensure system integrity, strategic air valve placement was implemented at critical nodes to mitigate vacuum pressures. Future work will focus on the direct numerical inclusion of these air valves within the simulation environment to further refine the mitigation strategy.

References

Ghidaoui, M. S., Zhao, M., McInnis, D. A., & Axworthy, D. H. (2005). A review of water hammer theory and practice. *Appl. Mech. Rev.*, *58*(1), 49-76.

Bergant, A., Simpson, A. R., & Tijsseling, A. S. (2006). Water hammer with column separation: A historical review. *Journal of fluids and structures*, *22*(2), 135-171.

Himr, D. (2013). Numerical simulation of water hammer in low pressurized pipe: comparison of SimHydraulics and Lax-Wendroff method with experiment. In *EPJ Web of Conferences* (Vol. 45, p. 01037). EDP Sciences.

Adamec, R. (2010). *Vliv obsahu vzduchu na hydraulický ráz* [Influence of air content on water hammer] [Bachelor's thesis, VŠB – Technical University of Ostrava]. DSpace at VŠB-TUO. https://dspace.vsb.cz/handle/10084/81309