Analysis of Water Hammering in Pipeline and its CFD Simulation

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ABSTRACT
Water hammer is a transient flow in pipes which is created by sudden changes of velocity in pipeline lines. This phenomenon can cause strong positive and negative pressures in water conveyance pipes and usually it poses pipeline to danger. Water hammer is created by rapidly closing valves, shutting off or suddenly restarting pumps. It has destructive hydrodynamic effects in pressurized pipelines. This phenomenon cannot be eliminated but can be reduced by using different protection devices. In this study, the pipeline has been modeled using the GAMBIT software. Further, the steady state pressure drop and governing equations of water hammer are numerically simulated using FLUENT software. The simulation helps the designers to have good understanding of water hammer phenomenon and work on the ways to reduce the same.

Key words
Water hammer, Transient flow, Pump Positive and negative pressure, GAMBIT, FLUENT

1. Introduction [2,1]
Many researchers have used experimental as well as theoretical methods to examine the phenomena of the water hammer in straight pipes. Under unfavorable circumstances, damage due to water hammer may occur in pipelines measuring more than one hundred meters and conveying only several tenths of a liter per second. But even very short, unsupported pipelines in pumping stations can be damaged by resonant vibrations if they are not properly anchored the damage caused by water hammer by far exceeds the cost of preventive analysis and surge control measures. The ability to provide reliably designed surge control equipment, such as an air vessel or accumulator1, flywheel and air valve, has long been state of the art. Water Sector clearly states that pressure transients have to be considered when designing and operating water supply systems, because they can cause extensive damage. This means that a surge analysis to industry standards has to be performed for every hydraulic piping system at risk from water hammer. Dedicated software is available for this purpose.

Using CFD tool we are making efforts to preview the effect of water hammer and suggest methods to reduce the same. Through modeling of pipe networks pressure surge analysis for piping systems with different objectives are investigated. The results of pressure surge analysis are used to optimize the system/piping system or are used for assessment of plant safety.

1.1 What is water hammer [1]
The term ‘water hammer’ is used to describe the fluid flow characteristics when a fluid in motion is forced to stop in closed systems such as a pipe network. This phenomenon produces intense pressure waves that travel periodically along the pipe. Water hammer mostly occurs in piping systems, e.g., in power plants and urban water carrier systems, due to a sudden change in the flow rate during a sudden closure (or opening) of a valve or pump failure. In general we can say hydraulic transients or surge is a phenomenon in a closed conduit or pipe is associated with rapid changes in discharge or velocity is accompanied by a change in pressure, which propagates through the pipe.

1.2 Causes of water hammer [4,7]
Water hammer is mainly caused due to sudden closing of valves. When valve closes, there is high pressure spikes generation due to which pipe suffers vibration and thudding sound.
Typical events that require transient considerations include:
1. Pump startup or shutdown;
2. Valve opening or closing -variation in cross-sectional flow area
3. Changes in boundary pressures -e.g. losing overhead storage tank, adjustments in the water level at reservoirs, pressure changes in tanks, etc.
4. Rapid changes in demand conditions -e.g. hydrant flushing
5. Changes in transmission conditions -e.g. main break or line freezing
6. Pipe filling or draining—air release from pipes; and
7. Check valve or regulator valve action

1.3 Effects of water hammer [6]
The above phenomenon may cause the following problems:
1. When the non-return valve or the pump discharge valve closes, depending on the magnitude of the reverse flow already established, a pressure rise occurs, which may exceed the design/test pressure of the pipe.
2. During the initial down surge phase, the magnitude of the pressure drop may be such that, at an elevated location along the alignment, vapor pressure occurs. This is termed as water column separation, which on cavity collapse create a shock pressure rise, which travels on the both sides and may cause the pressure to exceed design/test pressure. For large diameter steel pipes, the occurrence of vapor pressure is a severe problem.
3. Pump damage
4. Intense pressure spikes
5. Bursting of pipes, seals
6. Destroyed meters and gauges
2. EXISTING TECHNIQUES [6]
Water hammer effect is studied practically on basis of theoretical data and calculations. After that to reduce water hammer, some protecting devices are installed on the pipeline. Following surge protection systems are considered to control high and pressure and vacuum conditions in pipeline-

- Surge Vessel (Air Chamber)
- Surge Tanks
- Air Valves (Vacuum Valve)
- Zero Velocity Valve

3. RESULTS AND DISCUSSION[8,9]
To study the dynamics of flow mathematically, CFD technology is used. Computational Fluid Dynamics or CFD is the analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer based simulation. The technique is very powerful and spans a wide range of industrial and non-industrial applications areas.

CFD tool is thus used to analyze the flow through pipeline in order to locate critical location in pipeline where water hammer is severe. Therefore before installation of protecting devices on pipe, the water hammer and its variation along the pipe is analyzed using CFD tool. This will reduce cost and time consumption required to analyze the effect than practical method.

In this analysis we are using CFD tool- Gambit for pipe modeling and meshing and Ansys Fluent for analyzing the water hammer.

3.1 Steady state analysis
The plot shows normal working pressure line which is steady state plot.
1) Fluent Result
"Surface Integral Report"
Area-Weighted Average Static Pressure (Pascal)

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Inlet</td>
<td>11008.202</td>
</tr>
<tr>
<td>Outlet</td>
<td>0</td>
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</tbody>
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Pressure drop: 11008.202

2) Calculated Result

Here pressure drop = 238.72 mbar = 23872 Pascal
The calculator shows double value as it considers resistance from the vertical walls as well. Our Fluent simulation being 2D, we just consider the horizontal walls. Therefore, Pressure Drop = 23872/2 = 11936 Pascal
Validation
Calculated Pressure Drop – Fluent Pressure Drop = 11936 – 11008.202
= 927.798 pascal
Therefore, Percentage Pressure Variation = (927.798/11936)*100
= 7.77 %
This shows that fluent calculations are within the valid range.

3.2 Transient analysis
As per the steps followed in transient analysis, the water hammer phenomenon will be generated. The drastic pressure spikes along the interior of the pipeline are shown by color scheme.

Significance of contour plot:
Dark blue colour shows minimum pressure value and red colour shows maximum pressure value. Flowing water possesses inertia. When the valve closes, high pressure waves generated travel to and fro until the pressure is dissipated and is shown by the red colour in the graph.
1. Inlet
Due to sudden valve closure, there is negative pressure generation i.e. vacuum is created. This variation is shown by blue colour at inlet section.
2. Middle section
As the pressure waves progress, there is pressure variation as shown.
3. Outlet
For 0.1 sec the high pressure spikes do not reach the outlet yet. As a result, the pressure at outlet is minimum but greater than vacuum pressure at inlet. By contour plot, critical vacuum and high pressure regions are detected so that protection devices are chosen and installed accordingly.

4. CONCLUSION
Water hammer phenomenon cannot be completely eliminated but it can be minimized by using various protection devices like zero velocity valve, air valve, surge vessel, surge tank etc. In steady state analysis, we get the pressure distribution along the interior of the pipeline i.e. working pressure. When water hammer occurs, due to sudden closure of valve, the water due to inertia travels forward and vacuum is created as there is no further supply of water. Flow reversal occurs due to the slope
and bangs on the valve creating high surge waves. If the pressure due to these waves is greater than a particular limit then it may cause severe damage to pipeline and its accessories. To avoid this, analysis is done to identify the critical locations of positive high pressures and negative low pressures and accordingly protection devices can be installed.

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6. REFERENCES
1. “Computation of laminar and turbulent waterhammer flows”, S. D. Saemi, M. Raisee, M. J. Cervantes and A. Nourbakhsh, Hydraulic Machinery Research Institute (HMRI), University of Tehran,
3. “Water hammer” K S B Know - how, Volume 1
5. “Water hammer analysis of pipeline system”, Rafiq Hama Osman
6. www.wikipedia.com
7. www.google.com
10. GAMBIT (2.4.6), Help File, Chapter-(1-8)