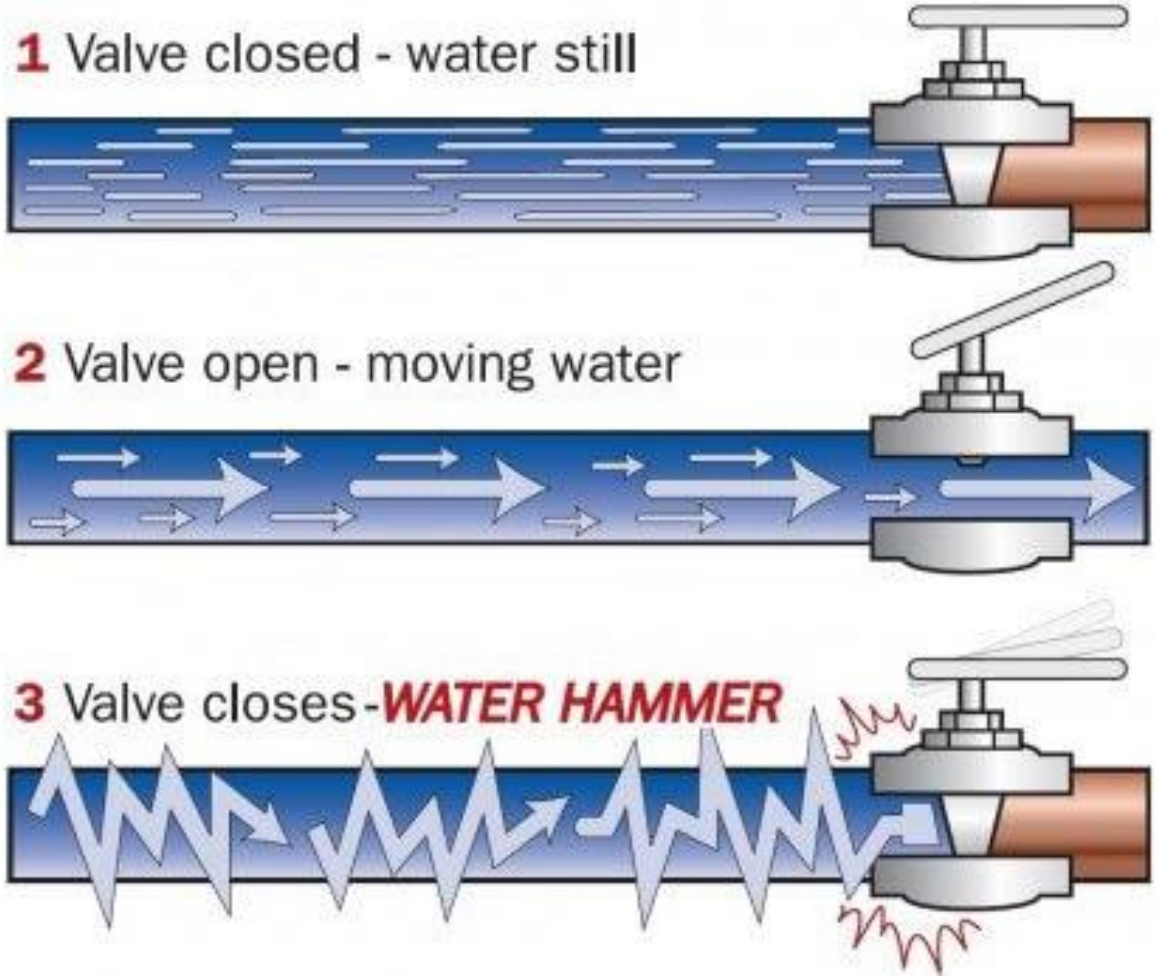
Water Hammer Joukowsky Equation



25 June 2024

Joukowsky's overpressure













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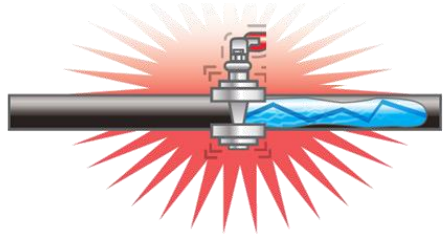
Joukowsky's overpressure

Joukowsky's overpressure, also known as the Joukowsky shock or water hammer, is a phenomenon that occurs in fluid dynamics when there is a sudden change in the flow velocity of a liquid within a pipeline, typically due to rapid valve closure or pump shutdown. This sudden change can cause a significant pressure surge or shock wave within the system. The overpressure generated can potentially cause damage to the pipeline and its components if not properly managed.









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Joukowsky's overpressure

Pressure Surge

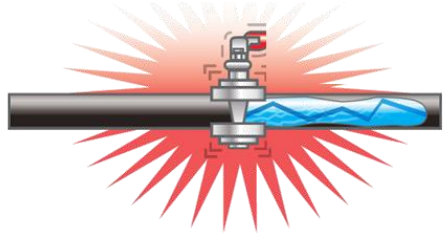
This occurs due to the rapid deceleration of the fluid. If the valve closes too quickly or the pump stops suddenly, the momentum of the moving fluid is converted into a pressure wave.



Potential Damage

The overpressure can cause various issues such as pipe bursts, leaks, or damage to fittings and supports. It's critical to design the system to handle these surges.







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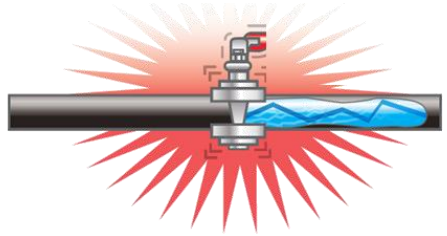
Joukowsky's overpressure

Accuracy

While the Joukowsky equation provides a good estimate, the actual pressure surge can be influenced by factors such as pipe material, fluid properties, and system geometry. Detailed hydraulic transient analysis using computational methods may be necessary for more accurate predictions in complex systems.









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Joukowsky's overpressure

Mitigation Measures

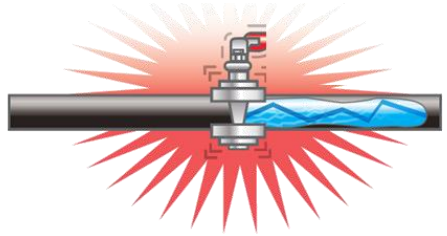
To prevent damage from water hammer, several strategies can be employed, including:

- Using slow-closing valves to reduce the rate of flow change.
- Installing surge tanks or air chambers to absorb the pressure spikes.
- Implementing pressure relief valves to release excess pressure.
- Ensuring proper support and anchoring of the pipeline to withstand pressure changes.









Joukowsky Equation

The magnitude of the pressure change (ΔP) can be calculated using the

Joukowsky equation:

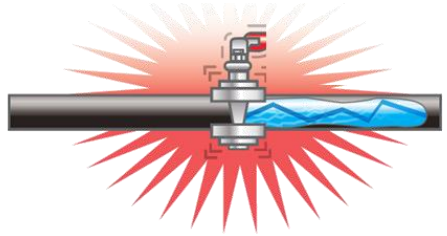
$$\Delta P = \rho \cdot a \cdot \Delta V$$

where:

- ΔP is the change in pressure (overpressure) (Pa)
- ρ is the density of the fluid (kg/m^3)
- a is the speed of sound in the fluid (also called the wave speed) (m/s)
- ΔV is the change in fluid velocity (m/s)









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Joukowsky Equation (cont.)

Speed of sound in fluid - Wave Speed (a)

This depends on the compressibility of the fluid and the elasticity of the pipe material. It can be calculated using:

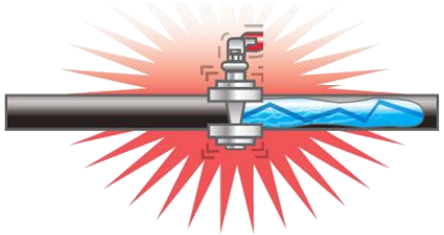
$$a = \sqrt{\frac{K}{\rho\left(1+\frac{K}{E}\cdot\frac{D}{t}\right)}}$$

where:

- K is the bulk modulus of the fluid (Pa)
- ρ is the density of the fluid (kg/m^3)
- E is the Young's modulus of the pipe material (Pa)
- D is the internal diameter of the pipe (m)
- t is the wall thickness of the pipe (m)









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Assumptions and Limitations

1. **Incompressible Fluid:**

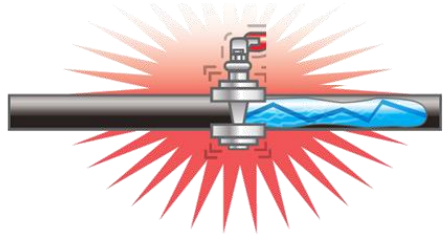
   The equation assumes that the fluid is incompressible, which is a reasonable approximation for liquids like water but may not be accurate for gases or highly compressible fluids.

2. **Rigid Pipes:**

   It assumes that the pipeline walls are rigid. In reality, pipes can have some elasticity, which can affect the wave speed and the pressure surge.









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Assumptions and Limitations

3. **Instantaneous Valve Closure:**

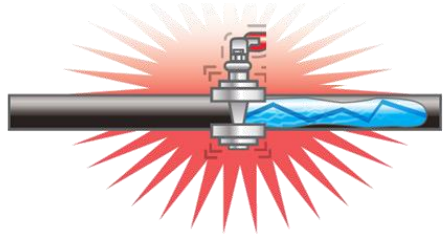
   The Joukowsky equation presumes an instantaneous change in velocity, such as a rapid valve closure or pump stop. If the change in velocity is gradual, the actual pressure surge may be lower.



4. **Unsteady Flow:**

   It is derived for unsteady flow conditions where a sudden change in flow velocity occurs, leading to the propagation of a pressure wave.







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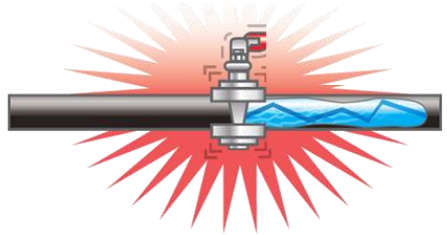
Assumptions and Limitations

5. Linear Elasticity:

The equation considers linear elasticity of the pipe material. For materials exhibiting non-linear elastic behavior, the results might not be as accurate.









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Example

Consider a water pipeline with the following parameters:

- Density of water, $\rho = 1000\ kg/m^3$
- Initial flow velocity, $V_i = 2\ m/s$
- Final flow velocity, $V_f = 0\ m/s$ (sudden stop)
- Bulk modulus of the fluid, $K = 2.2 \times 10^9\ Pa$
- Young's modulus of the pipe material, $E = 2.1 \times 10^{11}\ Pa$
- Internal diameter of the pipe, $D = 0.5\ m$
- Wall thickness of the pipe, $t = 0.01\ m$







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Example

$$a = \sqrt{\frac{K}{\rho\left(1+\frac{K}{E}\cdot\frac{D}{t}\right)}}$$

$$\frac{K}{E} = \frac{2.2\times10^{9}\,\text{Pa}}{2.1\times10^{11}\,\text{Pa}} = \frac{2.2}{210} \approx 0.01048$$

$$\frac{K}{E}\cdot\frac{D}{t} = 0.01048\cdot\frac{0.5\,\text{m}}{0.01\,\text{m}} = 0.01048\cdot 50 = 0.524$$

$$a = \sqrt{\frac{2.2\times10^{9}\,\text{Pa}}{1000\,\text{kg/m}^3(1+0.524)}}$$

$$a = \sqrt{\frac{2.2\times10^{9}}{1000\times1.524}}$$

$$a = \sqrt{\frac{2.2\times10^{9}}{1524}}$$

$$a = \sqrt{1.443\times10^{6}}$$

$$a \approx 1201\,\text{m/s}$$

$$\Delta P = \rho\cdot a\cdot\Delta V$$

$$\Delta V = V_f - V_i = 0\,\text{m/s} - 2\,\text{m/s} = -2\,\text{m/s}$$

$$\Delta P = 1000\,\text{kg/m}^3\cdot 1201\,\text{m/s}\cdot(-2\,\text{m/s})$$

$$\Delta P = 1000\cdot 1201\cdot(-2)$$

$$\Delta P = -2402000\,\text{Pa}$$

The pressure surge (ΔP) resulting from the sudden stop of the water flow is 2402000 Pa or **2402 kPa**. This significant pressure increase needs to be considered in the design and operation of the pipeline to prevent potential damage.







M. Jehia Process Engineer



Process Calculations and Simulations using Aspen HYSYS (ARABIC)

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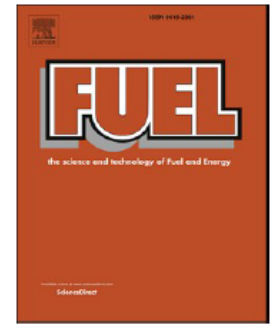
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Full Length Article

Improving energy efficiency in ammonia production plants using machine learning

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Water Hammer

Joukowsky Equation

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