Water Hammer Pressure Rise (Joukowsky)

Pressure surge when flow in a pipe is stopped, by the Joukowsky equation with the wave speed from liquid and pipe elasticity, and the effect of a slower valve closure.

Method: Joukowsky (1898); Korteweg wave speed; ...

Input parameters

Unit system: SI

Parameter	Value	Unit
Bulk modulus of the liquid	2.2000	GPa
Liquid density	998.00	kg/m³
Pipe inside diameter	200.00	mm
Pipe wall thickness	6.0000	mm
Young's modulus of the pipe wall Steel about 200 GPa; ductile iron about 170 GPa; HDPE about 1 GPa.	200.00	GPa
Change in flow velocity	2.0000	m/s
Pipe length from the valve to the reservoir or tank	500.00	m
Valve closing time	2.0000	s

Calculated results

Parameter	Value	Unit
Pressure wave speed	1,270.0	m/s
Pressure rise for rapid closure (Joukowsky)	25.350	bar
Head rise for rapid closure	259.01	m
Critical closing time (wave round trip)	0.78738	s
Pressure rise for the given closing time	9.9800	bar

Notes for this case

- Closing slower than 2L/a: the rise is estimated by the Michaud relation 2ρLΔv/t_c; a surge analysis gives the exact value.

Formula and method

$$a = \sqrt{\frac{K/\rho}{1 + \frac{KD}{Ee}}}$$

$$\Delta p = \rho\, a\, \Delta v, \quad \Delta H = \frac{\Delta p}{\rho g}$$

$$2L/a, \quad \Delta p_c = \frac{2\rho L \Delta v}{t_c} \text{ for } t_c > 2L/a$$

Variables

K	liquid bulk modulus	Pa
ρ	liquid density	kg/m³
D	pipe inside diameter	m
e	wall thickness	m
E	Young's modulus of the pipe	Pa
Δv	change in velocity	m/s

L	pipe length	m
t_c	valve closing time	s
a	wave speed	m/s
Δp	pressure rise, rapid closure	Pa
ΔH	head rise	m
$2L/a$	critical closing time	s
Δp_c	pressure rise for the closing time	Pa
g	standard gravity	m/s²

Method and standards

Stopping a liquid column sends a pressure wave along the pipe at speed a, set by the liquid's compressibility and the pipe wall's elasticity (Korteweg). The Joukowsky rise ρ a Δv applies to closures faster than the wave's round trip 2L/a; slower closures are estimated by Michaud's relation.

Assumptions and limits

- Single uniform pipe, thin wall, anchored with expansion joints (restraint factor 1 in the Korteweg wave speed). A pipe anchored against axial movement or buried has a factor below 1 (about 1 − ν² for a fully anchored pipe), which gives a slightly higher wave speed and surge.
- Column separation is not checked: when the downstream or low-pressure side of a closure falls to vapour pressure, the cavity's collapse can give a surge above the Joukowsky value.
- Friction and cavitation not included; complex systems need a transient analysis.

References

- Joukowsky (1898)
- Korteweg wave speed
- Michaud slow-closure relation

Report details

Report reference	FCC-4Z48-7AXE (the same inputs always give the same reference)
Generated	17 November 2026, 19:45 UTC
Calculator	Water Hammer Pressure Rise (Joukowsky)
Method last reviewed	12 November 2026
Software release	FireCAD Calc, release of 17 November 2026
Release checks	3 reference cases of this calculator, computed independently, are checked on every release

Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/mechanical/piping/water-hammer

Open this case on calc.firecad.com →

Reopens the calculator with the inputs of this report.