Water Hammer

A significant, nearly instantaneous pressure shock wave may be generated when a valve opens or closes too quickly, or when a pump starts with an empty discharge line or suddenly shuts down. This phenomenon is the result of the sudden change in velocity of the fluid flow in combination with the characteristics of the piping. This shock wave is manifested by a series of hammerblow-like sounds, called water hammer, which may have sufficient magnitude to cause catastrophic failure within the piping system.

TO AVOID WATER HAMMER CONDITIONS, CONSIDER THE FOLLOWING:

1. Fluid velocities in excess of five feet per second in plastic piping systems increase the hydraulic shock effect resulting from the starting and stopping of pumps and rapid opening and closing of valves. Fluid velocity not exceeding five feet per second is considered safe, and will minimize the effects of water hammer.
2. Install pressure relief valves to dampen the effects of water hammer and relieve excess pressure and flow.
3. Slow-closing actuated valves should be installed to control the speed at which valves open and close. They can be controlled electrically or pneumatically, eliminating the chances of human error.

The pressure rise created by water hammer is added to the nominal actual working pressure of the system.

In order to calculate this pressure rise, it is first necessary to come up with a combined modulus of elasticity for the pipe/liquid system as shown here:

$$E' = \frac{1}{\frac{1}{E_w} + \frac{d}{4\,t\,E_p}(5 - 4e)} = 37{,}531\text{PSI}$$

Where:
- E' = modulus of elasticity of liquid/pipe combination (PSI)
- d = inside pipe diameter (in)
- e = Poisson's ratio for thermoplastic pipe material, a value within the range from 0.38 to 0.42 may be used
- E_p = modulus of elasticity for pipe (PSI, from Table 1)
- E_w = modulus of elasticity of liquid, water = 300,000 PSI
- t = pipe wall thickness (in)

TABLE 1 – MODULUS OF ELASTICITY AT 73°F

MATERIAL	PVC	CPVC
MODULUS (PSI)	400,000	360,000

EXAMPLES

EXAMPLE ONE

For a 4" Schedule 80 PVC pipe (I.D. 3.786", wall thickness 0.337"), carrying water, the combined modulus of elasticity is calculated below:

$$E' = \frac{1}{\frac{1}{300{,}0000} + \frac{3.786}{4\,(.337)\,400{,}000}[5 - 4\,(.42)]} = 37{,}531 \text{ PSI}$$

The pressure rise due to water hammer is:

$$\Delta P = \frac{V\sqrt{\frac{m}{G_c}E'}}{12}$$

Where:
- ΔP = pressure rise due to water hammer (PSI)
- m = density of liquid, water = 62.4 lbm ft^3
- G_c = dimensional constant = 32.2 lbm ft/(lbf sec^2)
- E' = modulus of elasticity of liquid/pipe combination (PSI)
- V = velocity reduction causing water hammer (ft/sec)

EXAMPLE TWO

Water is flowing at 250 gpm (6.5 ft/sec) at a line pressure of 40 PSI. If a valve in the line is closed suddenly, the resultant pressure rise is calculated by:

$$\Delta P = \frac{6.5\sqrt{\frac{62.4}{32.2}\,37{,}531}}{12} = 146 \text{ PSI}$$

Total line pressure: $P_{total} = 40 + 146 = 186$ PSI

A 4" Schedule 80 PVC pipe is rated for 320 PSI at room temperature and is, therefore, acceptable for this application.

Note: Insure that all other system components are rated for this pressure.

For convenience, Table 2 lists "Wave Surge Constants" for common sizes of pipe carrying water at 73°F.

The wave surge constant may be used to quickly calculate pressure rise due to water hammer as illustrated to the right: $\Delta P = VC$

Where:
- P = pressure rise due to water hammer (PSI)
- C = wave surge constant from Table 2
- V = velocity reduction causing water hammer

TABLE 2 – WAVE SURGE CONSTANTS (FOR PIPE CARRYING WATER AT 73°F, E = 0.42)

SIZE	1/2"		3/4"		1"		1-1/2"		2"		3"		4"		6"		8"		10"		12"	
SCHEDULE	40	80	40	80	40	80	40	80	40	80	40	80	40	80	40	80	40	80	40	80	40	80
PVC	30.1	35.4	27.3	32.1	26.8	30.8	22.7	26.9	20.9	25.0	20.3	23.1	18.7	22.5	16.7	20.9	15.7	19.7	15.0	19.2	14.5	19.0
CPVC	28.9	34.1	26.1	30.8	25.2	29.6	21.7	25.7	19.9	23.9	19.4	22.1	17.8	21.4	15.9	19.9	14.9	18.8	14.2	18.3	13.8	18.1