Tech Brief

A NATIONAL DRINKING WATER CLEARINGHOUSE FACT SHEET

Water Hammer

by **Z. Michael Lahlou, Ph.D.**, Technical Assistance Consultant

Summary

Water hammer refers to fluctuations caused by a sudden increase or decrease in flow velocity. These pressure fluctuations can be severe enough to rupture a water main. Potential water hammer problems should be considered when pipeline design is evaluated, and a thorough surge analysis should be undertaken, in many instances, to avoid costly malfunctions in a distribution system. Every major system design change or operation change—such as the demand for higher flow rates—should include consideration of potential water hammer problems. This phenomenon and its significance to both the design and operation of water systems is not widely understood, as evidenced by the number and frequency of failures caused by water hammer.

What is water hammer?

Water hammer (or hydraulic shock) is the momentary increase in pressure, which occurs in a water system when there is a sudden change of direction or velocity of the water. When a rapidly closed valve suddenly stops water flowing in a pipeline, pressure energy is transferred to the valve and pipe wall. Shock waves are set up within the system. Pressure waves travel backward until encountering the next solid obstacle, then forward, then back again. The pressure wave's velocity is equal to the speed of the sound; therefore it "bangs" as it travels back and forth, until dissipated by friction losses. Anyone who has lived in an older house is familiar with the "bang" that resounds through the pipes when a faucet is suddenly closed. This is an effect of water hammer.

A less severe form of hammer is called surge, a slow motion mass oscillation of water caused by internal pressure fluctuations in the system. This can be pictured as a slower "wave" of pressure building within the system. Both water hammer and surge are referred to as transient pressures. If not controlled, they both yield the same results: damage to pipes, fittings, and valves, causing leaks and shortening the life of the system. Neither the pipe nor the water will compress to absorb the shock.

Investigating the Causes of Water Hammer

A water transport system's operating conditions are almost never at a steady state. Pressures and flows change continually as pumps start and stop, demand fluctuates, and tank levels change. In addition to these normal events, unforeseen events, such as power outages and equipment malfunctions, can sharply change the operating conditions of a system. Any change in liquid flow rate, regardless of the rate or magnitude of change, requires that the liquid be accelerated or decelerated from its initial flow velocity. Rapid changes in flow rate require large forces that are seen as large pressures, which cause water hammer.

Entrained air or temperature changes of the water also can cause excess pressure in the water lines. Air trapped in the line will compress and will exert extra pressure on the water. Temperature changes will actually cause the water to expand or contract, also affecting pressure. The maximum pressures experienced in a piping system are frequently the result of vapor column separation, which is caused by the formation of void packets of vapor when pressure drops so low that the liquid boils or vaporizes. Damaging pressures can occur when these cavities collapse.

The causes of water hammer are varied. There are, however, four common events that typically induce large changes in pressure:

1. Pump startup can induce the rapid collapse of a void space that exists downstream from a starting pump. This generates high pressures.
2. Pump power failure can create a rapid change in flow, which causes a pressure upsurge on the suction side and a pressure downsurge on the discharge side. The downsurge is usually the major problem. The pressure on the discharge side reaches vapor pressure, resulting in vapor column separation.
3. Valve opening and closing is fundamental

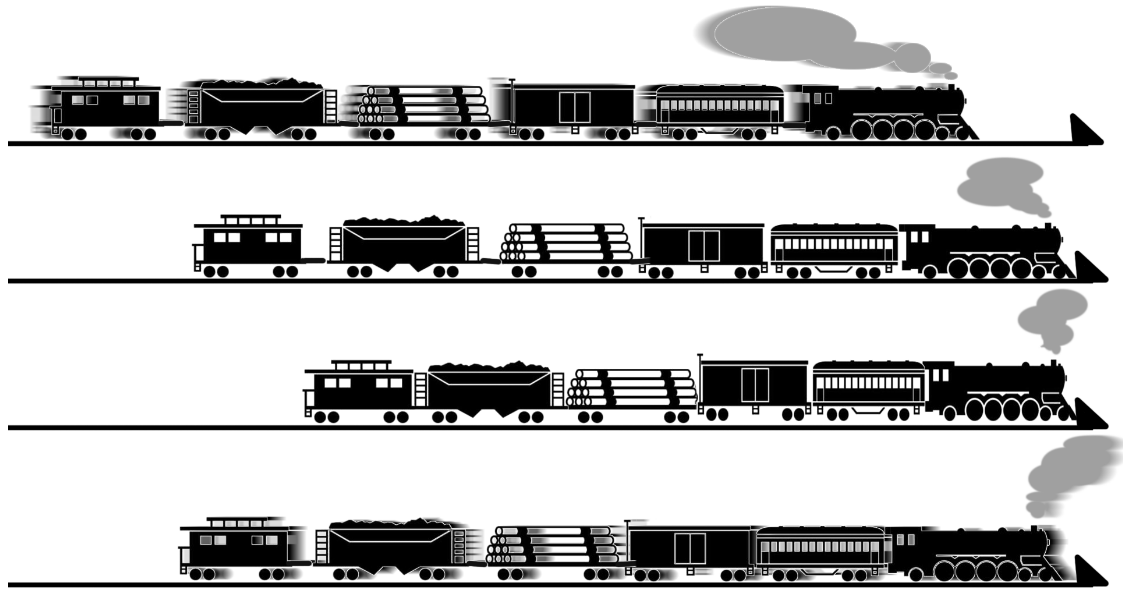


Figure 1 - Illustration of Water Hammer

Source: Pickford, John. 1969. *Analysis of Water Surge*. Gordon and Breach Science Publishers.

A column of water acts like a freight train suddenly stopping when an outlet valve is suddenly closed.

to safe pipeline operation. Closing a valve at the downstream end of a pipeline creates a pressure wave that moves toward the reservoir. Closing a valve in less time than it takes for the pressure surge to travel to the end of the pipeline and back is called "sudden valve closure." Sudden valve closure will change velocity quickly and can result in a pressure surge. The pressure surge resulting from a sudden valve opening is usually not as excessive.

4. Improper operation or incorporation of surge protection devices can do more harm than good. An example is oversizing the surge relief valve or improperly selecting the vacuum breaker-air relief valve. Another example is to try to incorporate some means of preventing water hammer when it may not be a problem.

Finding Practical Solutions

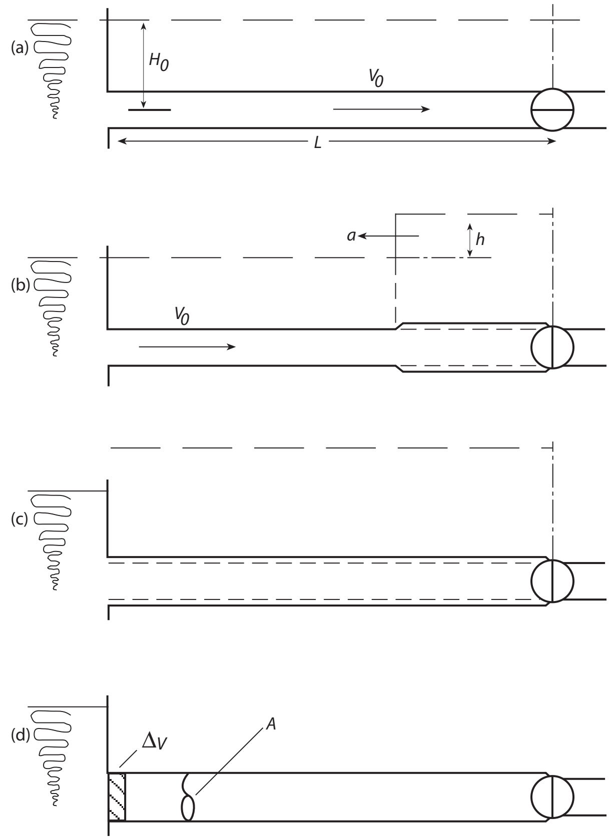
The surge pressure must be incorporated with the operating pressure in the design of the pipe. The recommendations and requirements regarding allowances for surge pressure are given in the American Water Works (AWWA) standards and manuals for water supply practice, and vary depending on the type of pipe used. The following are some tools to reduce the effects of water hammer:

Valves

Water hammer often damages centrifugal pumps when electrical power fails. In this situation, the best form of prevention is to have automatically-controlled valves, which close slowly. (These valves do the job without electricity or batteries. The direction of the flow controls them.) Closing the valve slowly can moderate the rise in the pressure when the downsurge wave—resulting from the valve closing—returns from the reservoir.

Entrained air or temperature changes of the water can be controlled by pressure relief valves, which are set to open with excess pressure in the line and then closed when pressure drops. Relief valves are commonly used in pump stations to control pressure surges and to protect the pump station. These valves can be an effective method of controlling transients. However, they must be properly sized and selected to perform the task for which they are intended without producing side effects.

If pressure may drop at high points, an air and vacuum relief valve should be used. All downhill runs where pressure may fall very low should be protected with vacuum relief valves. Vacuum breaker-air release valves, if properly sized and selected, can be the least expensive means of protecting a piping system. A vacuum breaker valve should be large enough to admit sufficient quantities of air during a



(a) Valve in open position.

(b) Valve is shut. A pressure wave moves upstream with velocity "a". At the same time water still enters the pipe with velocity V_0.

(c) Wave front continues upstream until it reaches the end taking time L/a to reach there. The time $2L/a$ is known as the "period" of the pipe μ.

(d) If the total quantity of water that enters the pipe during this time $1/2\,\mu$ is ΔV then because it is moving with velocity V_0, $\Delta V = 1/2\, V_0 A \mu$. This whole extra volume of water is occupying the space $(A \times L)$ where A is the cross section of the pipe. The resulting increase in pressure or "water hammer" pressure is $P = K \frac{\Delta V}{\Delta L}$.

Figure 2 - Sudden Valve Closing

Source: Pickford, John. 1969. *Analysis of Water Surge*. Gordon and Breach Science Publishers.

downsurge so that the pressure in the pipeline does not drop too low. However, it should not be so large that it contains an unnecessarily large volume of air, because this air will have to be vented slowly, increasing the downtime of the system. The sizing of air release valves is, as mentioned, critical.

Pump

Pump startup problems can usually be avoided by increasing the flow slowly to collapse or flush out the voids gently. Also, a simple means of reducing hydraulic surge pressure is to keep pipeline velocities low. This not only results in lower surge pressures, but results in lower drive horsepower and, thus, maximum operating economy.

Surge Tank

In long pipelines, surge can be relieved with a tank of water directly connected to the pipeline called a "surge tank." When surge is encountered, the tank will act to relieve the pressure, and can store excess liquid, giving the flow alternative storage better than that provided by expansion of the pipe wall and compression of the fluid. Surge tanks can serve for both positive and negative pressure fluctuations. These surge tanks can also be designed to supply fluid to the system during a downsurge, thereby preventing or minimizing vapor column separation. However, surge tanks may be an expensive surge control device.

Air Chamber

Air chambers are installed in areas where water hammer is encountered frequently, and are typically seen behind sink and tub fixtures. Shaped like thin, upside-down bottles with a small orifice connection to the pipe, they are air-filled. The air compresses to absorb the shock, protecting the fixture and piping.

Conclusion

Water hammer will continue to challenge engineers, operators, and managers of water systems because it is associated with systems that cannot be exactly defined due to the size and length of the water distribution system with ondulating profile or the lack of definition of the system components such as valves or pumps. There is a need for a more practical approach while research continues to provide better descriptions of the physics of water hammer and for useful computational solutions including those basics.

Where can I find more information?

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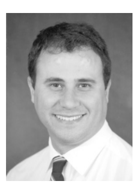

Z. Michael Lahlou holds a doctorate in environmental and natural resource economics and a master's in civil and environmental engineering. Formerly the technical assistance coordinator for the National Drinking Water Clearinghouse, Lahlou now resides in Huntington Beach, California.

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