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Feature Report

The Number One Problem in a Steam System: Water Hammer

There is only one time to correct water hammer — immediately

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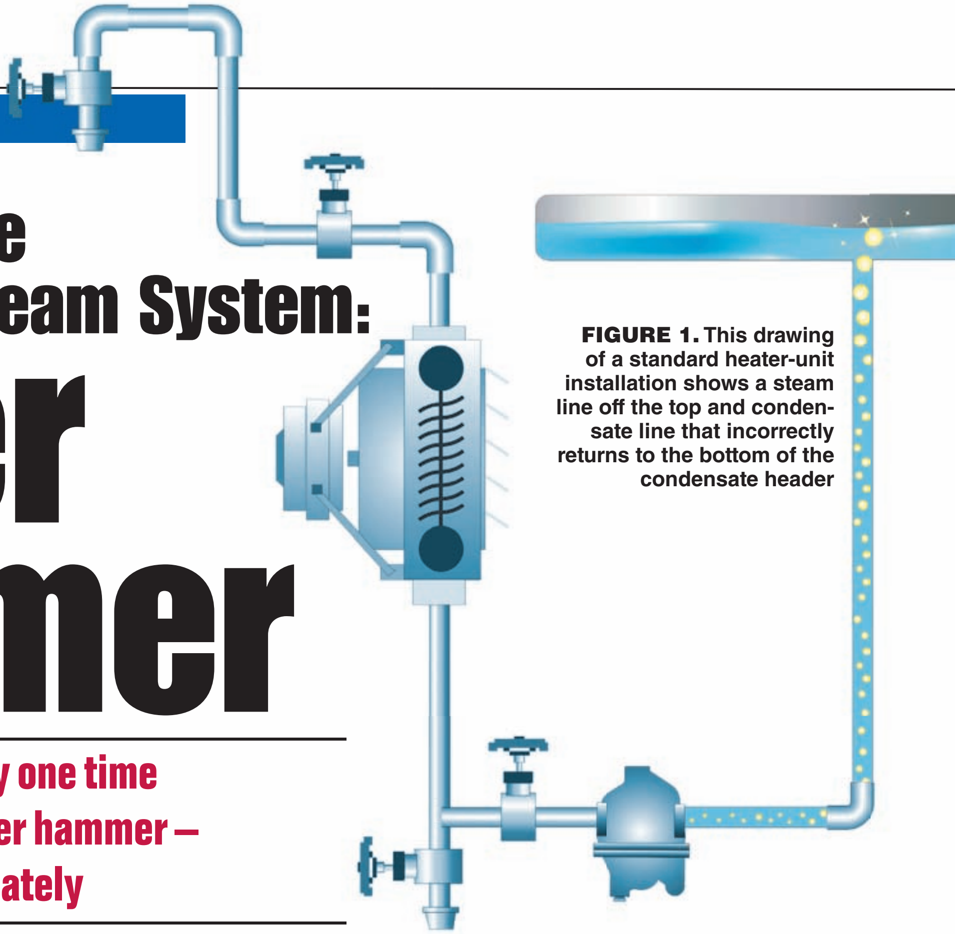

FIGURE 1. This drawing of a standard heater-unit installation shows a steam line off the top and condensate line that incorrectly returns to the bottom of the condensate header

Water hammer — a high pressure surge or wave created by the kinetic energy of the moving liquid — is not only a system issue, but primarily a safety concern. Understanding the nature and severity of water hammer in a steam-and-condensate system will allow prevention of its destructive forces. A better understanding will also help with the introduction of preventative measures into system designs, steam system startups, maintenance and installations, which can contribute to personnel safety, reduce maintenance costs, and reduce system downtime.

In its most severe form, water hammer can cause injuries or even fatalities. Unfortunately, 82% of the steam systems in North America are experiencing some type of water hammer. Many mistakenly believe that water hammer is an unavoidable and natural part of steam-and-condensate systems; this is entirely false. Water hammer is never normal, it is abnormal. If the system is properly designed and correctly operated, water hammer will not occur. It is possible for high-pressure steam systems to function without water hammer over a long operational life.

Water hammer can occur in any steam or condensate line. Its effects can be more pronounced in heterogeneous or condensate bi-phase systems. Condensate bi-phase systems contain two states, the liquid (condensate) and a vapor (flash or generated steam). This bi-phase condition is found in steam systems where condensate coexists with generated steam or flash steam. Typical examples include heat exchangers, tracer lines, steam mains, condensate-return lines and sometimes pump-discharge lines.

A common example of water hammer occurs during the startup or energizing of a steam system. If the steam line is energized too quickly without proper warm-up time and the condensate created during the startup is not properly removed, water hammer will be the result.

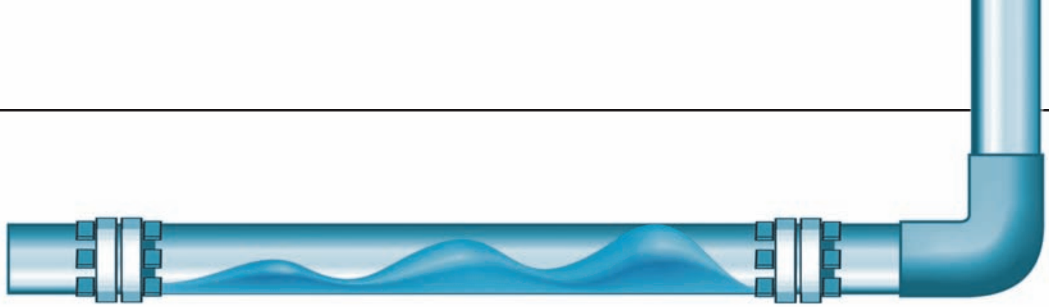

FIGURE 3. As steam rushes accros this cold pipe, a large wave of high velocity condensate is formed, creating a water hammer effect on the elbow fitting

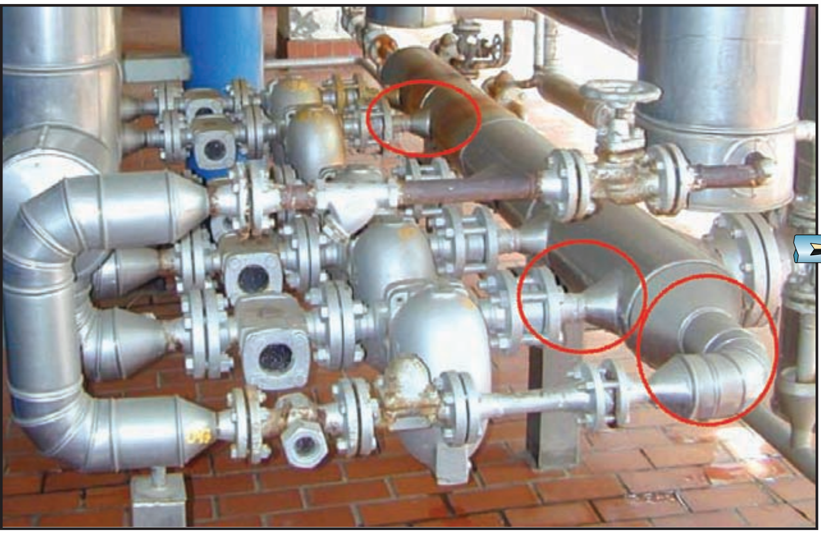

FIGURE 2. Red circles show improper connection to the condensate header. Instead of connecting into the side of the condensate header, the returns should enter in the top of the manifold (condensate header)

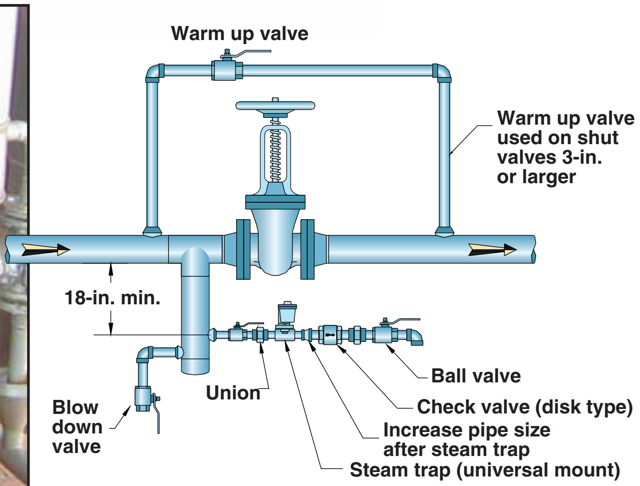

FIGURE 4. This AutoCAD print shows the standard installation of an isolation valve in a steam system. Two main points are the warm-up valve and the drip leg pocket with a steam trap ahead of the isolation valve. This installation will prevent water hammer during startup, but it will also promote long valve life

Effects of water hammer

The effect of water hammer cannot be underestimated. Its forces have been documented to result in the collapse of elements within all designs of steam traps including the cracking of steam trap bodies. Water hammer can overstress pressure gauges, bend internal system mechanisms and otherwise impair inline analytical equipment. Ruptured piping systems and pipe fittings, broken pipe welds, as well as valve, pipe support, and heat-exchanger-equipment tube failures can all occur with prolonged exposure to water hammer's effects. When severe, it can result in not only damage to equipment, but also significant injury to plant personnel.

Water hammer may be occurring and yet remain silent to personnel. This means that water hammer is not always accompanied by audible noise. For example, a steam bubble may be small in size and yet the collapsing bubble creates a "thermal shock" that is not heard by the human ear. However, damage to steam and condensate components is still occurring.

The continuing banging and other audible sound that may accompany water hammer should be interpreted as the way the steam system is trying to communicate with plant personnel. This audible noise should be an alarm meaning "fix the water hammer problem" or "damage will occur". This water-hammer sound means something in the system is wrong and needs to be corrected.

Evidence gathered while conducting root-cause analysis on steam-component failure suggested that water hammer causes 67% of premature component failures.

Causes of water hammer

The following four conditions have been identified as causes of the violent reactions known as water hammer:

- Hydraulic shock
- Thermal shock
- Flow shock
- Differential shock

The following is a description of each of these causes.

Hydraulic shock. A small percentage of the water-hammer problems found in steam systems are caused by hydraulic shock. This condition can be easily described by using the example of a household faucet. When the faucet in a home opens, a uniform mass of water moves through the pipes from the point where it enters the house to the outlet of the faucet. This could be a 200-lb quantity of water moving at 10 ft/s or about 7 mph.

When the faucet is suddenly shut, it could be compared to a 200-lb hammer coming to a stop. There is a noticeable "bang" heard in the system when the faucet is closed. This shockwave sound is similar to a hammer hitting a piece of steel. The shock pressure wave of about 300 psi is reflected back and forth from end to end until the energy is dissipated in the piping system.

This is the same action that can take place in the suction or discharge piping in a steam and condensate system. Pumps are often installed with check valves. As the pump starts and stops, hydraulic shock can occur as the flow rapidly stops and the check valves restrict the flow in one direction. Slow closure of the valve, just like slow closure of a faucet, is the solution to this problem. When a column of water is slowed before it is stopped, its momentum is reduced gradually and, therefore, damaging water hammer will not be produced.

Thermal shock. One pound of steam at 0 psig occupies 1,600 times the volume of a pound of water at atmospheric conditions. This ratio drops proportionately as the condensate line pressure increases. When the steam collapses, water is accelerated into the resulting vacuum from all directions with great speeds.

In bi-phase condensate systems, steam bubbles may be introduced below the level of condensate in a condensate line. For example, a branch line from a steam trap may be piped to the bottom or side of a condensate main header (Figures 1 and 2). The pressure in the condensate line is lower than the flash steam temperature (lower pressure yields lower temperature). The condensate cools the flash steam bubble and the steam bubble collapses immediately. While collapsing, a void is created in the volume of the pipe and condensate rushes to fill this void, thus causing an audible pinging sound.

Flow shock. Flow shock is most commonly caused by lack of proper drainage ahead of a steam-line-isolation valve or steam control valve. For example, consider a steam-line-isolation valve (typically used with pipe of 3-in. dia. or larger) opened without the use of a warm-up. When the large valve is opened, steam rushes down a cold pipe producing a large quantity of condensate at high velocity. This condensate will continue to build in mass as it travels along the pipe and a large wave of condensate is created (Figure 3). The wave will travel at a high velocity until there is a sudden change in direction, possibly an elbow or valve in the line. When the condensate changes direction, the sudden stop will generate water hammer.

When a steam control valve opens, a slug of condensate enters the equipment at a high velocity. Water hammer is produced when the condensate impinges on the heat exchanger tubes or walls. Additionally, water hammer from thermal shock will result from the mixing of steam and condensate that follows the relatively cooler condensate.

Differential shock. Differential shock, like flow shock, occurs in bi-phase systems. It occurs whenever steam and condensate flow in the same line, but at different velocities. This is commonly seen in condensate-return lines.

In bi-phase systems, the velocity of the steam is often 10 times that of the liquid. If condensate waves rise and fill a pipe, a seal is formed temporarily between the upstream and downstream side of the condensate wave. Since the steam cannot flow through the condensate seal, pressure drops on the downstream side. The pressure differential then drives the condensate seal at a high velocity downstream accelerating it like a piston. As it is driven downstream, the wave of condensate picks up more liquid, which adds to the existing mass of the slug and the velocity increases.

Just as in the example above, the slug of condensate gains high momentum and will be forced to change direction due to a tee, elbow or valve in the line. The result is usually great damage when the condensate slug pounds into the wall of a valve or fitting while changing direction.

Since having a bi-phase mixture is possible in most condensate return lines, correctly sizing condensate return lines becomes essential.

Condensate normally flows at the bottom of a return line with the assistance of gravity. Condensate flows naturally because of the pitch in the pipe and also because the higher velocity flash steam above it, pulls it along. The flash steam moves at a higher-velocity because it moves by differential pressure.

Flash steam occurs in return lines when condensate discharges into these lines that are operating at a lower pressure. The lower pressure causes a percentage of the condensate to flash back to steam at the given saturation pressure. If the lines are also undersized, additional pressure is created in the line. This pressure pushes the flash steam at relatively higher velocities toward the condensate receiver, where it is vented to atmosphere. Heat loss of the flash steam while moving in the line causes some of the flash steam to condense, which contributes to this pressure difference and amplifies the velocity. Because the flash steam moves faster than the condensate, it makes waves. As long as these waves are not high enough to touch the top of the pipe and do not close off the flash steam's passageway, there is not a problem. This is why larger-sized condensate return lines are preferred.

To control differential shock, the condensate seal must be prevented from forming in a bi-phase system. Steam mains must be properly trapped and condensate lines must be properly sized. The length of horizontal lines to the trap's inlet should be minimized.

Steam-main drainage is one of the most common applications for steam traps. It is important that water is removed from steam mains as quickly as possible, for reasons of safety and to permit greater plant efficiency. A build-up of water can lead to water hammer, and as we have already discussed, the water hammer can have any number of adverse effects on the steam and condensate components of a system.

Prevention or resolution

There are a variety of design or system changes that can be implemented to prevent or eliminate water hammer.

Proper training and well-documented, standard operation procedures (SOP's) should be provided to plant personnel for steam system startups, shut downs, maintenance and general operation. Maintenance programs, in particular, should be designed to take a pro-active approach on water hammer. Pipe insulation, for instance, should be regularly checked and repaired as needed. Doing this will save energy and reduce accumulation of condensate in the piping system.

Installation standards for steam components should be implemented and rigorously enforced to ensure correct steam and condensate design. For steam traps, these standards should include their proper sizing and general suitability for each application. Steam-line-drip steam traps must be properly specified and placed on the steam system (Figure 4). Warm-up valves should be included on steam-line-isolation valves that are 2-in. dia. or larger. Do not "crack open" large steam-line-isolation valves with the hope of avoiding condensation-induced water hammer. This will not guarantee safe operation.

Condensate line-sizing is crucial to insure proper operation of the steam system as under-sizing condensate lines is one of the largest contributors to water hammer. To be correct, condensate connections of branch lines to the main condensate line should enter only through the top (Figure 5).

Systems that have a modulating control valve should have a dripleg-trap (Figure 6) upstream of the valve to remove condensate during a closed condition for the valve. Always gravity drain away from process applications with a modulating control valve. The condensate can be drained into a pressurized-condensate-return line only if a proper differential is maintained.

Finally, be sure to properly label the steam and condensate lines and to remove abandoned steam and condensate lines from the system. Adherence to these basic heuristics will provide a suitable foundation for the reduction of water hammer and water-hammer-related losses in most industrial steam systems. ■

Edited by Matthew Phelan

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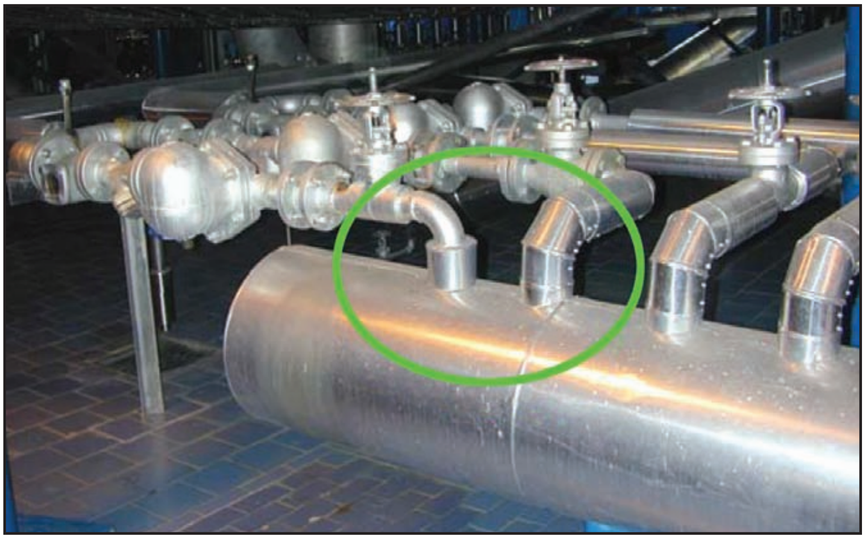
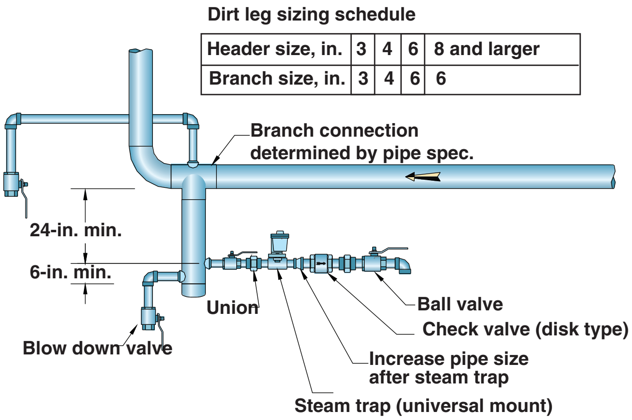


FIGURE 5. The green circle indicates the proper connections to the main condensate header



Dirt leg sizing schedule

Header size, in.	3	4	6	8 and larger
Branch size, in.	3	4	6	6

FIGURE 6. This drawing depicts a standard dripleg-trap installation