The Nature of Water Hammers

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Water hammer is the unexpected release and associated shock wave of high-pressure steam/condensate, or the shock waves created by colliding water. Water Hammers can cause extensive property damage, severe injury, and death.

Many employees who work near high-pressure steam/condensate systems do not realize the hazards associated with water hammers. Even experienced operators who know the dangers involved with the systems do not fully understand the causes of water hammer.

Incidents

- Seven workers at a commercial nuclear power plant were injured when a reheater drain line ruptured because of a water hammer. All seven workers suffered serious steam burns and steam inhalation injuries. (NRC Event No. 31053)

- On June 7, 1993, a water hammer event at Hanford, in a DOE facility, resulting from opening a valve to an undrained line, caused a valve rupture, subsequently filling a space with 120 psi steam killing the Hanford site power operator who opened the valve. The valve that failed was constructed of gray cast iron with less than the expected tensile strength. Cast steel is the preferred material for such components. (ORPS Reports RL--WHC-WHC300EM-1993-0022).

- On October 10, 1986, a condensate-induced water hammer at the Brookhaven National Laboratory resulted in two fatalities and two severe injuries. The Accident Investigation Board determined the direct cause was the use of an in-line gate valve to remove condensate instead of drains that had been installed for that purpose.

The typical misconception of water hammer is of water carried by steam slugging into a pipe wall. If the condensate is not forced to compress on itself in a collision, then the collision will not technically result in a water hammer. Generally, water slugs are of insufficient magnitude to rupture piping, although insulation or pipe supports could shift and experience some damage. Not to be dismissed, water slugs can wreck steam turbines as inducted water is roughly 1,400 times denser than steam.

The water hammers that plant operators hear when warming up steam lines are condensate induced water hammers, the result of mixing steam with subcooled condensate. Operators commonly see steam pipes moving, or “kicking”, from these water hammers. These hammers are actually transient shock waves within the system piping that frequently exceed the system working pressure, commonly leading to rupture of compromised piping and ductile fittings.

Contrary to old operating practices to drain and warm up steam lines, "Cracking Open" valves in lines to bleed condensate under steam pressure is NOT safe and has resulted in numerous reported water hammer fatalities.

Before admitting steam to any line, the condensate must be removed. Condensate should be assumed to be in all low points and dead legs until proven otherwise by verification of drain or steam trap position and operation. Pressurized dead legs without functioning traps or periodic manual blowdowns will have condensate present. The affected section of piping should be isolated, depressurized and drained before restoring steam to the system.

A condensation-induced water hammer requires the condensate be subcooled more than 40°F below the saturated steam temperature. Maintaining pipe insulation prevents condensate from cooling, subsequently preventing formation of water hammers.

Water hammers also occur when starting and stopping boiler feed pumps, usually when check valves are leaking past, allowing steam to enter the feed water piping

Steam bubble collapse in subcooled water is the dominant cause of water hammer events in nuclear power plants. Water hammer due to steam bubble collapse occurs when a water slug forms in stratified horizontal flow conditions, or when a steam bubble is trapped at the end of the pipe. This commonly occurs when admitting cold water into pipes filled with steam.

Water Hammers in water piping systems without steam occur when there is a sudden change of direction or velocity of the water. Fast acting valves are often applied for quick safety shut-down of pipelines for liquids in power plants. The fast deceleration of the liquid, leads to water hammer upstream of the valve and to cavitational hammer downstream.

On large systems, as in hydro-electric power plants, where you have penstocks full of water driving the turbine/generators, water hammers can be extremely dangerous. A sudden load rejection will cause valves and wicket gates to close to avoid generator overspeed. In this condition the water flow will be stopped in a very short time. Due to the inertia and volume of water, its kinetic energy is transferred to the penstock walls and upstream through the water column. Penstocks are designed accordingly to withstand the huge energy surges and in addition, energy dissipaters are installed upstream in the penstocks. These could be breathing pipes or air accumulators/dissipaters (surge tanks and pressure-regulating valves).

There is another destructive condition, where negative pressure, developed by opening flow control valves, may go below the vapor pressure of water, allowing the water to vaporize, leading to column separation. Cavitation is the formation of the vapor phase in a liquid flow when the hydrodynamic pressure falls below the vapor pressure of the liquid for that temperature. Water will boil out but not for the addition of heat but because the pressure drops below this value. The extreme vacuum may collapse the penstocks and other conveyance facilities. Then when pressure returns to normal values, the water vapor will return to liquid state, creating a powerful wave with devastating consequences. The collision of the water will reverberate back and forth until friction losses diminish the wave force. There have been numerous cases of steel and concrete penstocks being destroyed by this wave action. Pump power failures also cause water hammers by creating a rapid change in flow, which causes a pressure upsurge on the suction side and a pressure down surge on the discharge side. The down surge is usually the

major problem because the pressure on the discharge side reaches vapor pressure, resulting in column separation.

The US Department of Energy focused on the more dangerous condensate induced water hammers and developed a list of primary and contributing causes that may lead to water hammers.

I. Primary Causes

A. Condensation in lines containing both steam and condensate
B. Condensate entrainment in steam-filled lines
C. Voiding of normally condensate-filled lines
D. Rapid valve action (e.g., check valve closing, relief valve opening, control valve instability, and personnel error)

II. Contributing Causes

A. Design

1. Inadequate number and placement of system low-point drains
2. Inadequate number of system bypass/equalizing valves
3. Inadequate drainage of condensate
4. Improper component labeling

B. Maintenance

1. Blocked steam traps (by corrosion products or other defects)
2. Age-related problems
   a. Material strength concerns (e.g., pipes, valves, fittings, rupture discs, gaskets, boiler tubes)
   b. Abandoned in-place components/sub-systems and portions of systems
   c Corrosion (due to lack of water treatment, wrong materials, etc.)
   d. Out-of-date equipment
   e. Inadequate preventive maintenance
3. Incomplete preventive maintenance programs

C. Procedures

1. Inadequate system startup procedures
2. Inadequate pre-job/task analysis
3. Inadequate communications (i.e., supervisor/operator)
4. Inadequate lockout/tagout procedures and practices
5. Inadequate verification of system status prior to initiating work
6. Inadequate protective clothing and equipment
7. Inadequate announcements about potentially hazardous operations, tests, or maintenance in general access areas
8. Deficient emergency planning; no specification of "kill" switch location

D. Management Controls

1. Inadequately trained/qualified system operators
2. Inability to verify a worker's knowledge and qualifications adequately
3. Inadequate as-built versus design documentation and drawings

When water hammer occurs, the system's ability to withstand the resulting pressure surge(s) is influenced by the strength of the system's components/materials. Materials used in older steam/condensate systems that are not recommended for today's systems include:

1. Gray cast iron valves
2. "bondstrand" fiberglass pipes
3. PVC (polyvinylchloride) unions
4. Teflon gaskets

Piping systems can also be significantly weakened by poor water chemistry control.

DOE's Office of Environment, Safety and Health conducted workshops at Hanford to help prevent additional water hammer incidents from occurring, focusing on the condensate induced water hammer safety principle that "steam and water cannot be safely mixed in a piping system without risking condensate-induced water hammer." The following recommendations presented at the workshop were based on lessons learned from previous water hammer incidents.

1. Review and inspect all steam systems to ensure proper distribution and sizing of cold traps for startup and operation and to verify that all low points have steam traps. Give maintenance the highest priority.

2. Frequently inspect all steam traps to ensure that they operate properly and that no condensate accumulates. Immediately repair or replace erratic steam traps. Use thermocouples where feasible to locate condensate accumulation.

3. Do not "CRACK OPEN" valves to avoid condensation-induced water hammer. This will not guarantee safe operation. The formation of a condensation-induced water slug can occur at very low condensate flow conditions.

4. Valves in pipe lines that lack properly positioned steam traps should remain open at all times or, preferably, should be removed from the piping system.

5. Before opening valves in steam lines, check for adequate placement of steam traps. Verify that the steam traps operate properly and fully open the bleed valves using reduced system pressure to remove any remaining condensate.

6. Where feasible, operate the valves remotely using mechanical extension linkage, reach rods, or adequately controllable power-operated valves.

7. Inspect the piping system for sagging. Where necessary, install steam traps or repair the sagging.

8. Check or repair the piping insulation. It will save energy and reduce accumulation of condensate in the piping system.

9. Activation of cold steam piping should be performed slowly at reduced pressure and with trap bleed valves continuously open.

10. The above list of recommendations should be followed regardless of piping size. Do not exclude small pipe sizes without appropriate analysis.

11. All isolation valves must have bypass systems. However, bypass operation will not prevent water hammer if condensate is present.

12. Placement of blowdown valves before and after a vertical rise (such as over-the-road) is required to prevent possible condensate accumulation.

13. Improperly designed steam/water systems should not have the incorrect features overcome by operational methods. Systems must have incorrect features corrected.

References:

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3. "EH-95-1 Averting Water Hammers and Other Steam/Condensate System Incidents" U S Department of Environment, Safety & Health, Safety Bulletin DOE/EH -0437

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