Water Hammer in Steam System by USA DOE

EH-95-1 Averting Water Hammers and Other Steam/Condensate System Incidents

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Averting Water Hammers and Other Steam/Condensate System Incidents

Water hammer, the unexpected release and associated shock wave of high-pressure steam/condensate, can cause death, severe injury, and extensive property damage. In one such case, a water hammer filled a confined space with 120 psi steam on June 7, 1993, killing the Hanford site power operator who opened the valve. Although direct clean-up costs totaled only $34,000, the costs necessary to upgrade systems including inspection, component replacement, procedure revision, labeling, and drawing and to implement adequate conduct of operations, exceeded $5 million.

Unfortunately, not all employees who work near high-pressure steam/condensate systems realize the hazards associated with such systems.

In fact, employees who operate and know the dangers involved in the systems often do not understand the causes of water hammer. This Bulletin describes the primary and contributing causes leading to water hammers and other steam/condensate system incidents and provides recommendations on how to avert similar incidents in the future.

The Department of Energy (DOE) and its contractors are taking aggressive steps to strengthen programs that protect employees who work on or near steam systems. These efforts include conducting lessons-learned workshops and producing at-a-glance employee reference tools in conjunction with the Hanford and Savannah River sites.
Water Hammer and General Steam/Condensate Incidents

DOE developed improved employee protection measures based on a review of water hammer and other steam/condensate incidents reported to DOE’s Safety Performance Measurement System (SPMS) and Occurrence Reporting and Processing System (ORPS). Incidents were reviewed if they resulted in, or had the potential to cause, employee injury due to a breach in a steam or condensate system. Many findings listed in the Hanford Type A Accident Investigation Report (DOE/EH-0335P) parallel those of the incidents reviewed. While the Hanford report focuses on steam system operations, the report pointed to other types of systems that have the potential to affect employees involved with them similarly.

Review of the SPMS and ORPS reports generated a list of primary and contributing causes that may lead to water hammers and other general steam/condensate incidents. Both primary and contributing causes are listed below. Here, the contributing causes are organized into four categories: design, maintenance, procedures, and management controls.

Primary Causes

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

Contributing Causes

Design

* Inadequate number and placement of system low-point drains
* Inadequate number of system bypass/equalizing valves
* Inadequate drainage of condensate
* Improper component labeling

Maintenance

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

Procedures

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

Management Controls

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

Factors Compromising System Integrity

When water hammer occurs, the system's ability to withstand the resulting pressure surge(s) is influenced primarily by the strength of the system's components/materials. Older systems may contain components/materials incapable of containing pressure surges, particularly when temperatures and pressures have increased instantaneously beyond their design tolerance.

For example, the valve that failed at the Hanford incident was constructed of gray cast iron with less than the expected tensile strength. Cast steel is the referred material for such components. Similarly, materials such as bondstrand" fiberglass pipes, PVC (polyvinylchloride) unions, and teflon gaskets which have been used in other steam/condensate systems re not recommended for today's systems. In addition, some systems are compromised further by not being subject to water chemistry control requirements during their early years and by inattention to routine maintenance.

Working on steam/condensate components usually requires that these systems be shut down, blown down, or adequately locked out/tagged out. Several incidents were identified in which employees who were repairing or replacing valves assumed that the valves were isolated; however, in fact, a blockage of rust or debris prevented the
component from feeling "hot to the touch." When these blockages broke loose, live steam flowed from the valve. Although no one was seriously injured in these incidents, there was potential for serious injury or property damage.

Any special devices (such as a rupture disc) that release steam inside a building represent special hazards to those who may be in the immediate area during system failure. Likewise, pressure tests may release steam/condensate. These tests should be conducted under special controls and after all nonessential personnel have left the area.

Lessons Learned Workshops

DOE's Office of Environment, Safety and Health has conducted two workshops at Hanford to help prevent additional water hammer incidents from occurring. These workshops help managers and employees

(1) Improve recognition of water hammer risks;
(2) Assess the adequacy of system design, operation, and maintenance; and
(3) maximize effectiveness of operator and manager training.

Ongoing reviews and evaluations incorporate new lessons learned continually, providing attendees with the most up-to-date information available.

Water Hammer Safety Principle

The workshop focused on the following condensate-induced water hammer safety principle.

"Steam and water cannot be safely mixed in a piping system without risking condensate-induced water hammer. Do not mix steam with water either by injecting water into a steam system or steam into a system that includes water (condensate). Condensate should be assumed to be in all low points and dead legs until proven otherwise."

Workshop Recommendations

The following recommendations presented at the workshop are 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.

Helpful Publications

Occupational Safety and Health Administration standard 29 CFR 1910.147, "The Control of Hazardous Energy (Lockout/Tagout)," provides excellent safety guidance for workers.
maintaining/repairing steam/condensate systems. However, there is little guidance specific to the safe operation necessary to minimize the likelihood of water hammer. Operators are expected to have the expertise required to operate systems safely. Management can influence operator actions through required training, job hazard analyses, pre-job briefings, standard operating procedures, and direct supervision, as required by DOE Order 5480.19, "Conduct of Operations for DOE Facilities."

Steam plant operation and water hammer information can be found in the McGraw-Hill publication, "Steam-Plant Operation," by E.B. Woodruff and H.B. Lammers (at PSE Book Store, www.plantsupport.com); and in a Nuclear Regulatory Commission (NRC) publication, "Evaluation of Water Hammer Occurrences in Nuclear Power Plants," NUREG-0927. Specifics from these documents should be considered for inclusion into site/facility procedures and training. To obtain copies of the NRC publication, contact the NRC Public Document Room at 202-634-3273 or the National Technical Information Services at 703-487-4650.