



Best Management Practice

**Prevention of Condensate
Induced Water Hammer in
Steam Distribution Pipeline
Systems**

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1 Introduction

1.1 Purpose

The purpose of this guide is to provide a background as well as preventative measures to reduce the damage and injuries caused by water hammer in thermal operations, otherwise known as Condensate Induced Water Hammer (CIWH).

1.2 Overview

Thermal operations use steam to heat oil in the reservoir to assist in reducing the viscosity to enable flow. The steam is transported to the wells using above ground steam distribution pipelines that rest on supports. The steam is normally saturated steam and coexists with condensate at steam saturation temperatures.

The risk of “Condensate Induced Water Hammer” (CIWH) exists whenever condensate is present in the system, but only if specific conditions are present. Where these conditions are present, the risk of condensate induced water hammer can lead to rupture of the steam distribution line leading to devastating effects.

Steam distribution systems must be designed, operated, and maintained to allow for both an understanding of the steam and condensate conditions and means to manage the condensate during start-up or transient conditions.

Operating procedures must be established, and operators trained to prevent water hammer. Properly designed steam injection facilities can benefit operators by providing the right tools to detect the threat of water hammer conditions and prevent it from occurring. This paper discusses a variety of considerations when designing steam distribution systems to provide operators with the necessary tools to prevent condensate induced water hammer.

1.3 Scope

This guide applies to thermal operations where the use of steam co-existing with condensate increases the risk of water hammer.

2 Water Hammer in Thermal Operations

2.1 Steam, Condensate, and Thermal Operations

Thermal operations use steam to heat oil in the reservoir to help reduce the viscosity to enable flow.

The steam is transported to the wells using above-ground steam distribution pipelines that rest on supports. The steam is normally saturated steam and coexists with condensate at steam saturation temperatures.

In SAGD or cyclic steam production the steam is generated using once-through steam generators or heat-recovery steam generators. The steam produced is considered wet steam as it contains as high as 20 per cent condensate, making the steam as low as 80 per cent steam quality. Most operators target 99 per cent steam quality but may reduce steam quality into the

steam distribution pipeline to lower quality due to carryover of concentrated blowdown from the high-pressure steam separators.

Above-ground pipelines that distribute steam to well pads are susceptible to such threats as flow-assisted corrosion, erosion corrosion, cavitation, steam-driven slug flow, and CIWH due to water and flow regime effects.

There are two types of water hammer encountered in thermal operations:

- Steam-driven slug flow hammer
- Condensate-induced water hammer (CIWH)

Of the two, CIWH is the more powerful and dangerous.

2.2 Cause And Effects of Steam-Driven Slug Flow Hammer

With steam-driven slug flow hammer the causes are more dependent on start-up and transient conditions.

With steam-driven slug flow the cause is primarily due to the accumulation of condensate at low-lying areas that can be propelled at high velocity through the line as a single slug. The cause is due to a high differential pressure across the slug, causing it to propel like a cannon through the line. Most above ground pipelines are designed to handle some slugging events at directional changes in the line, however, in some cases, pipelines are knocked off their supports and damage can occur if not properly anchored.

A steam-flow-driven water hammer is an impact event, where a slug of rapidly moving water strikes a stationary object. The exchange of momentum creates impact forces that can cause shaking and moving at the location of direction changes.

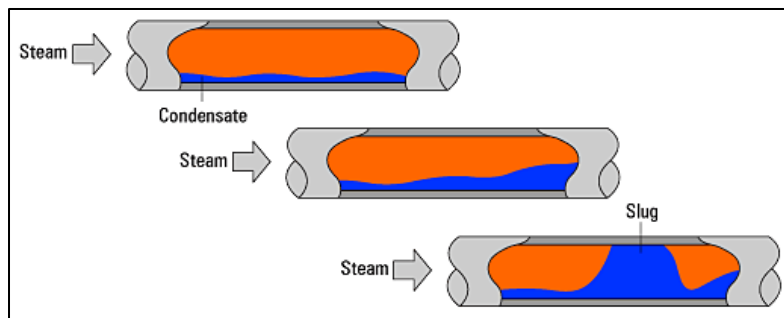


Figure 1: Steam Driven Slug Flow

2.3 Cause And Effects of Condensate Induced Water Hammer (CIWH)

With CIWH, the cause and effects are much different. CIWH occurs when steam collapses (condenses) to a liquid state due to a rapid loss of energy from contact with subcooled condensate and while collapsing, creates a void that draws water from either side at high velocity and the collision of the liquid, causing a severe transient pressure.

A CIWH is the more powerful of the two types.

Depending on the pressures and temperatures involved, the reduction in volume may be by a factor of several hundred to well over a thousand, and the resulting low-pressure void allows the pressurized surrounding condensate to rush in, resulting in a tremendous collision. This in turn generates severe over-pressurization. Gaskets, fittings and valves – virtually any piping component – are susceptible to failure, often with tragic consequences.

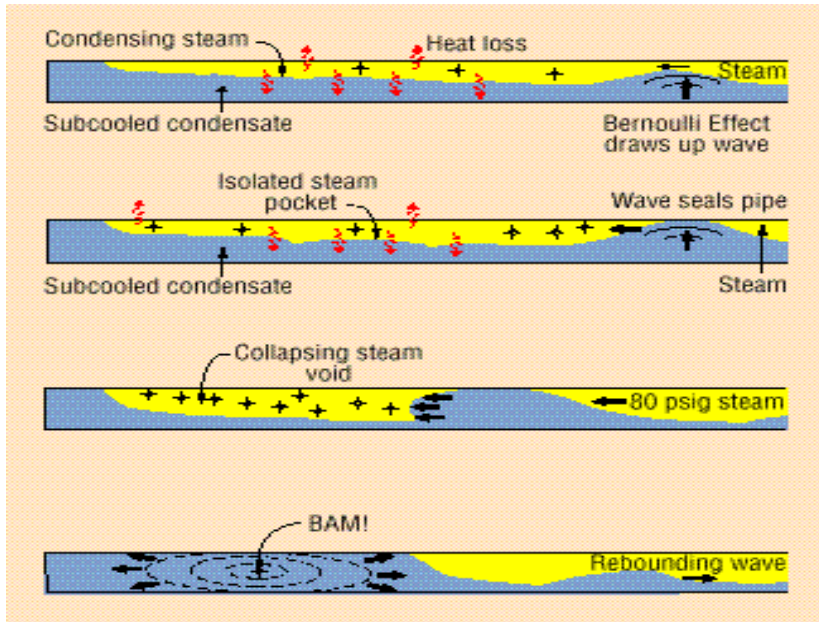


Figure 2: Condensate Induced Water Hammer

With steam-driven slug flow, the design can accommodate for a reasonable slug impact in terms of anchoring and managing this energy- with CIWH, it cannot.

The energy created by a CIWH depends on several factors, including the mass flow rate and temperature of the steam, the steam pressure, the volume of condensate in the pipeline, pipeline slope, and the sub-cool temperature difference. A small amount of sub cool condensate may cause only a fraction of the steam to collapse through the limited energy transfer. A large volume of condensate that may be sitting at a low point in a line that suddenly has a high rate of flow of steam that contacts the condensate with a temperature greater than a set range (e.g. 10°C or 15°C) below the temperature of the steam can cause a massive volume of steam to collapse, creating a massive CIWH incident at the point of the collision of condensate. The greater the subcool, the more intense the collapse.

In addition, the severity of steam condensation can increase with an increase in specific volume of the liquid phase, corresponding to a decrease in specific volume of the vapour phase of the steam-condensate mixture.

“High-mass flow plus high volume of condensate plus high temperature difference disaster. In sub-cooled conditions, any temperature difference that causes steam collapse is a problem. The higher the mass flow of steam in combination with the volume of sub-cooled condensate determines the magnitude of the hammer.”

During initial startup, low points will have and/or collect condensate/ice due to:

- Ambient conditions
- Last shutdown (bottled-up versus drained hot)
- Initial cold pipe wall temperatures
- Improper draining of the condensate
- Plugged drain lines
- Improper warm-up time
- Improper valve operation

2.4 Design Considerations

Mainline valves should have bypass piping and a system that enables throttling of steam around the main block valve.

Valves placed at low points must have a drain upstream and in proximity of the valve to enable drainage of condensate during start up. Steam distribution systems should have processes in place to manage the presence of subcooled condensate.

Valves that are isolated while operating can sometimes leak and result in condensate collected on the other side of the valve. There must be a method of removal of these fluids prior to introducing steam to the downstream of any valve.

Efforts should be made, where economically and logistically feasible, to determine the temperature of condensate through temperature transmitters and indicators.

Low point drains are required at significant low areas where the condensate can pool to form significant amounts of condensate. The span between supports should consider sag and the volume of water that can be left present during shutdown.

Note: In all cases, liquid removal must be as close to the lowest point as practical in the system. If the line slopes toward the plant, the drain point must be on the downstream side of the plant isolation valve. If the line slopes toward the pad, ensure that the drainage is on the upstream side of the isolation valve near the pad.

Always ensure that liquid removal of a main steam distribution pipeline that relies on other pads has provisions for liquid removal when that pad is not operable.

2.4.1 Key Design Considerations

- Adequate number and placement of system low-point drains.
- Adequate number of system bypass/equalizing valves.
- Adequate drainage collection of condensate.
- Proper component labeling.
- Sloping pipe with steam traps/collection vessels at low points.
- For systems with steam traps, sizing appropriate for the application, and heat trace should be considered.
- Proper support design with adequate distances to prevent pooling.

- Proper condensate sizing of lines, drains, tanks, valves to ensure proper operation of the steam system. Improperly sized equipment can be a significant contributor to water hammer.
- Installation standards for steam components.
- Ensure piping systems are installed as per the design.
- Review piping systems to make sure that there are no low points that cannot be drained during startup and in operation. Road crossings where the steam line needs to pass underground with a local low point utilizing risers should have additional considerations in place to address difficulties in condensate drainage from lack of adequate pressure. Pipelines should be sloped where possible to avoid these types of low points.
- Ensure that the piping supports are installed as per design.
- Be aware of and monitor possible changes in ground elevation (sinking and upheaval, especially in muskeg or steam chamber heaving).
- Insulation systems on steam pipelines and piping should be designed to minimize heat loss and maintain safe surface temperatures. High-temperature insulation materials should be selected based on their thermal rating and compatibility with the system's operating temperature. Insulation thickness should be determined according to pipe diameter, operating temperatures, and the level of heat retention or personnel protection required.
- Correct any occurrences of piping sagging and missing, wet or damaged insulation that could cause condensate accumulation that cause high levels of condensation that exceeds steam trap capabilities.
- Addition of drains will support removal of large volumes of condensate.
- Design in high point vents for blowing off steam and ensure adequate height of the vent to create safe distance from the operator and adequate support for safety.
- Consider provision of temperature indication at all locations where condensate becomes trapped during shutdown or ensure effective liquid removal instead.

2.5 Operating Considerations

In most thermal oil sands operations, the most significant threat is in relation to condensate induced water hammer. The procedures used in relation to condensate induced water hammer prevention are considered critical procedures and specific scenario-based training for operators is required. All steam distribution systems must have current diagrams showing condensate removal systems and procedures developed for each operating or start up case that may result in a water hammer.

The key to preventing CIWH is to remove condensate through condensate-removal systems while operating (steam-driven slug flow). Provided condensate is at saturation temperature, steam can coexist safely. If sub-cool conditions exist, such as after shutdown and during restart where steam contacts subcooled condensate or in an area where condensate collects a distance

away from the steam and the temperature drops to subcool, conditions (e.g., shut in laterals) will present a significant risk of condensate induced water hammer.

The key to managing this threat is to avoid contact of steam with subcooled condensate.

Always slowly blend steam using a globe valve around the main block valve until the pipe on the other side reaches a temperature close to that of the steam (generally within 10°C but can vary based on the system). The mainline valve should not be opened until the low point drains are set back to a minimum opening percentage and there is no liquid condensate coming out of them. Drains downstream of the main block valve should be open to remove steam condensate until the system is warmed up. Any system that could have condensate present at subcool conditions should be drained completely prior to introducing the steam. A slow warmup of a line allows the system slowly to balance in temperature between the steam and the condensate, especially considering progressive condensing will occur during startup.

Usually during start-up, noises can be heard from small hammers occurring as condensate builds ahead of the steam and the steam contacts small pockets of subcooled condensate as the system warms up. Provided that a build-up of subcool condensate is not present ahead of the front of steam, a steady and progressive ramp-up of steam flow will keep the steam front and the condensate close in temperature and prevent the difference in temperature to build in combination with a collection of condensate of significant size. Drainage and slow ramp up support safe startup.

Deadheading steam at the pad will result in a slow but progressive accumulation of condensate in the pipeline. The lower the ambient temperature the faster condensation will occur. If the pipeline slopes away from the steam distribution header, condensate will collect at the blocked-in point downstream. Over time as more condensate accumulates in the line, the steam front will move back from the isolation point as condensate replaces it. As the steam front recedes, the condensate volume builds. The longer the duration the deadhead is held, the more the mass of condensate will be and the greater the subcool conditions that will form away from the steam. This situation results in both a large mass of condensate and a significant temperature difference between the condensate at the far end and the condensate near the steam phase. It should always be assumed that sub-cooled conditions exist, and the condensate should be removed very slowly so as not to cause steam flow toward the sub-cooled condensate. In some cases, the rate of condensation exceeds the ability to remove the condensate and full system shut down and draining is required.

Modelling of condensate formation should be considered as a part of startup scenarios in cold weather. A general relation between operating pressure and subcool on the maximum spike pressure of the steam-condensate system can be estimated from the unsteady Bernoulli or acoustic relation in compressible flow:

$$P = \rho \Delta V a$$

Where P is the transient spike in pressure, ρ denotes the fluid density, ΔV is the change in flow velocity, and a is the sonic velocity. A relation between subcool temperature, operating pressure, and transient spike pressure can be developed once the aforementioned parameters are determined.

Always ensure that insulation is maintained in good condition to conserve energy to reduce condensate formation.

2.5.1 Key Operational Considerations

- Ensure that there are standard operating procedures for:
 - Startup in various ambient conditions
 - Hot standby
 - Shutdown
 - Low steam flows
 - Maintenance of steam traps/valves
 - Shutdown- it is good practice to open vents at the highest location on the pressurized pipe to relieve pressure, not a drain. Operating a drain may initiate a water hammer. However, if the steam system is showing evidence of good thermal performance and there are no indications of the presence of subcooled condensate, low point drains are sufficient to use for shutdown.
- Define system startup procedures as critical procedures, with defined training and retraining requirements. Never let a junior person perform startup of a steam distribution pipeline.
- Perform pre-job/task analysis.
- Perform verification of system status prior to initiating work.
- Establish effective control room to field communications (i.e. Supervisor/operator).
- Ensure all condensate is drained before startup.
- Monitor pipe temperatures as per procedures.
- Monitor pipe temperature and growth during startup.
- Do not operate and/or maintain a “hot” piping system without adequate flow. Minimum operating parameters should be established for safe operations. and provided to Operations personnel.
- Future system development should be designed to ensure existing infrastructure shall operate above the minimum operating parameters for safe operations.
- Consider installing thermocouples at strategic locations for monitoring startups and shutdowns through the DCS.
- Warm up valves on steam line isolation valves should be sufficiently sized to allow for controlled, limited flow of steam without slamming the main valve with a large amount of high-pressure steam. Do not “crack open” large steam isolation valves with the hope of avoiding condensation-induced water hammer. This will not guarantee safe operation.
- Always gravity drain away from the process applications with a modulating control valve.
- Condensate can be drained into a pressurized condensate return line or in the steam piping downstream of a control valve only if proper differential is maintained.
- Properly label the steam and condensate lines.

- Perform startup and piping warm up as per standard operating procedures, documenting all conditions.
- Ensure safe access to truck out and drains.
- Review safety issue with Operators close to live steam opening/closing valves.
- Ensure all heat tracing is functioning properly.
- Remove abandoned steam and condensate lines from the system.
- Establish lockout/tagout procedures and practices.
- Monitor the operation of the steam system, especially with respect to proper steam trap functions.
- Manage steam velocities during operations, as the higher the velocity, the higher the force of impact during a steam driven slug flow event.
- Management of change processes need to be implemented when operating conditions change. For example, if a pad that is being used for removal of condensate along the route of a main steam distribution pipeline is inoperable it can create a significant risk of steam driven slug flow. Any pad required for condensate removal must maintain function even if the pad is isolated from steam feed and production gathering.

2.5.2 Steam traps

- Steam traps can be used to remove condensate from the steam piping system but can come with their own inherent risks which could create CIWH.
- There are various steam trap designs available, each with the proper application.
- On the Flowline Pad Edge steam traps, most are an inverted bucket design to allow the proper collection of condensate in an accumulator and then discharge the condensate to downstream of the valve.
- Steam traps must be inspected and tested to ensure they fully function.
- Steam traps are critical to ensure that condensate does not significantly accumulate in the steam piping. The steam trap preventative maintenance program should be identified and completed. Any time a critical steam trap is out of service, the operators should be aware of it and monitor the piping until the trap is returned to service. Operators should ask:
 - What type of monitoring is available to determine if steam traps are functioning properly?
 - How often is the monitoring done?
 - What is the action taken if a critical steam trap is not properly functioning?

2.5.3 Maintenance

Considerations for maintenance programs can include:

- Blocked steam traps

- Deadlegs
- Trapped water
- Damaged or missing insulation or heat trace
- Leaking valves allowing for steam by-pass during isolation

2.5.4 Post Event Management

In the event of a water hammer occurrence, there is still a risk of pipe movement due to thermal contraction if the pipeline is shut down for investigation. A pipeline right-of-way (ROW) inspection should occur to assess the condition of the aboveground pipeline, supports and shoes.

Should the pipeline come off the racks, be aware that the pipeline will thermally contract when shut down, and shoes not on supports can become caught and may tear. Prior to shutting in a line that is not on the rack an inspection to determine this risk should occur.

It is recommended to avoid the use of welded shoes in areas of directional change, except at anchors. Clamp-on shoes are generally preferred as they allow rotation during an event and permit axial movement during post-event contraction. Welded shoes restrict movement and may increase the likelihood of pressure boundary failure if the shoe becomes engaged with a structural support.

2.5.5 Quality inspection and benchmarking

System checks should occur to confirm placement of traps. Pipelines should be surveyed to establish a benchmark prior to startup with follow-up surveys at a reasonable frequency

Pipe supports should be marked to establish a benchmark for thermal growth.

All low points should be inspected to ensure that drainage systems are in place to support startup, and reasonable liquid collection systems should be in place. Where permanent systems are not feasible, a mobile condensate-collection system can be used.

2.5.6 Integrity Management and Inspection:

In SAGD operations, the downhole steam chamber can heave and subside due to the pressure in the reservoir. Monitoring of elevation profile maybe required to understand if low points have been created that at one time were not a low point.

3 Reference Studies

3.1 Scenario One

Deadheaded steam at 10 MPa during winter conditions to support repair of a main block valve to a pad. Over time condensate formed at the low end of the line near the pad and progressively filled the line progressively toward the plant. Over the 24-hr period of isolation the lower topography near the pad reduced in temperature to subcooled conditions, whereas at the front of steam the temperature was near steam saturation temperature. When the repairs at the pad were complete the start-up procedure was not followed and instead of draining the condensate from the system to the point where only saturated condensate was present and

instead of throttling the bypass line to slowly introduce steam the main block valve was used. The main block valve cannot control the steam flow to the rate that would be necessary to prevent a surge of steam that would contact the subcooled condensate. The main block valve bounced to a higher open position than was called for through the system allowing a surge of steam. A globe valve that is throttle would be able to but still a threat of water hammer exists while the subcooled condensate still exists in the system.

How to prevent: To remove the threat the subcooled condensate must be removed. In this case it was not, and a condensate induced water hammer resulted.

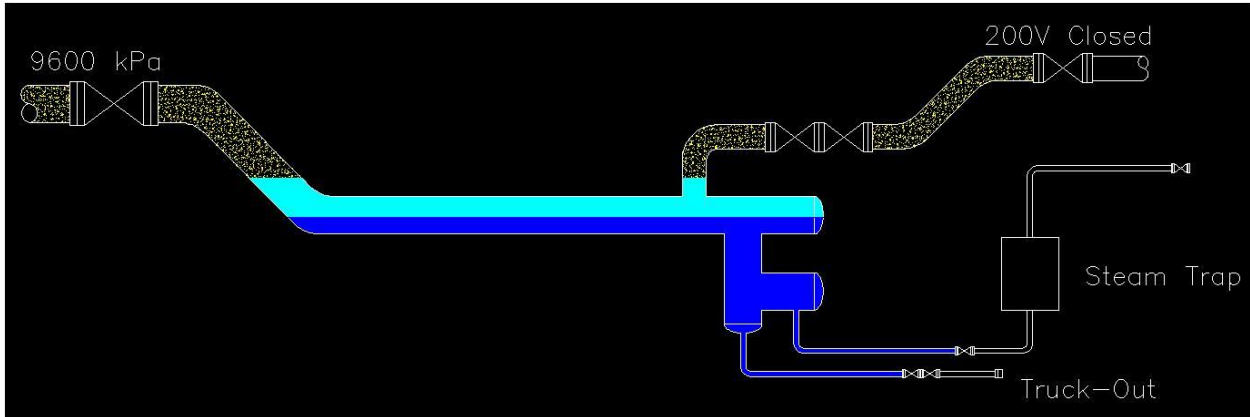


Figure 3: Subcooled Condensate Exists Below Condensate at Saturated Temperature

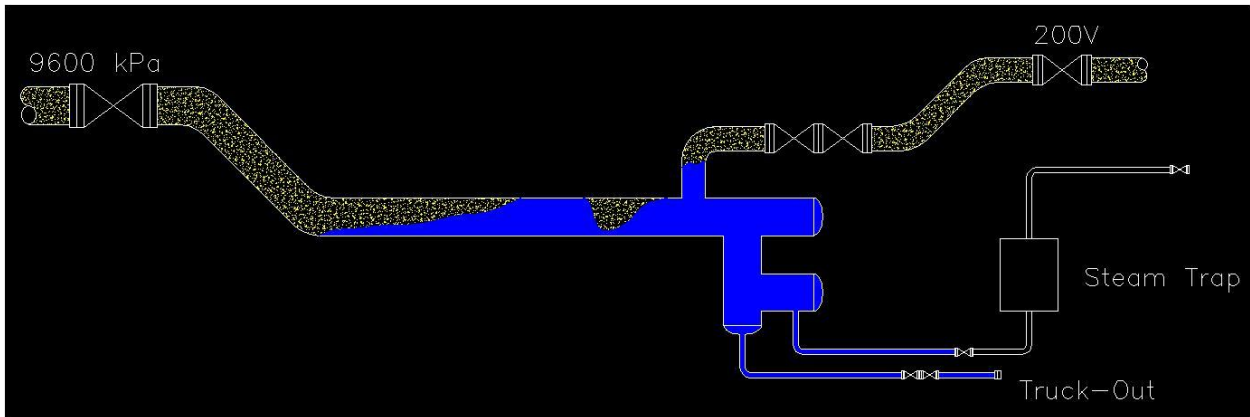


Figure 4: Steam in Contact with Subcooled Condensate

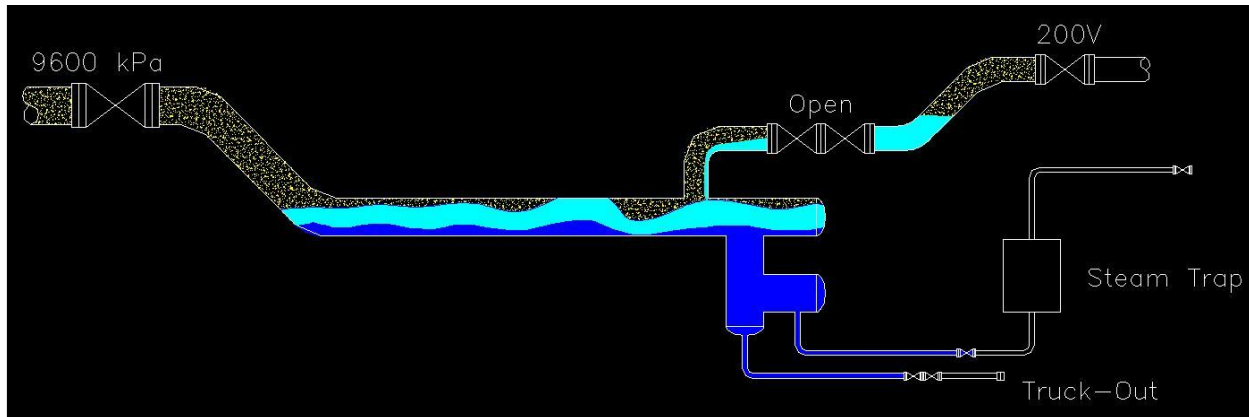


Figure 5: Subcooled Condensate Exists Below Condensate at Saturated Temperature

3.2 Scenario Two

A Heat Recovery Steam Generator had a header system that distributed steam to multiple pads. One line was isolated from the header while the others were in operation. The isolation valve was not properly isolating, and steam was leaking and condensing on the other side of the valve. The condensate pooled at a low point in the piping system that was not designed to drain. A requirement for steam to other pads was required and the block valve isolating the line was opened to introduce steam to the line under the assumption that no condensate was present. The main block valve from the HRSG was used to introduce steam and was a remotely operated valve. The steam contacted the condensate at subcooled temperatures, and a condensate induced water hammer resulted.

How to prevent: Ensure that the system is sloped to drain and no water holdup points exist in the system. If water hold up locations exists ensure that they are fully drained prior to start-up.

4 References

- Kirsner.org is a good reference for condensate induced water hammer that contains bulletins, training, and several case studies. <https://www.kirsner.org/>
- Kevin Dorma Consulting. "Using data science to quantify CIWH and the suppression effect of air." www.kevindorma.ca/2021/03/17/using-data-science-to-quantify-ciwh-and-the-suppression-effect-of-air/
- ABSA Condensate Induced Water Hammer Safety Principles. AB-603 2002-05. www.absa.ca/media/1490/ab-503_waterhammer_card.pdf