Understanding Water Hammer

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Agenda

To raise awareness of the causes and potential dangers of water hammer, and to highlight what can be done to minimise and control the phenomenon

- What is water hammer
- Mechanisms and causes of water hammer
- Where these phenomenon can occur
- Possible consequences and risks
- How to avoid water hammer through design, operating and maintenance practices

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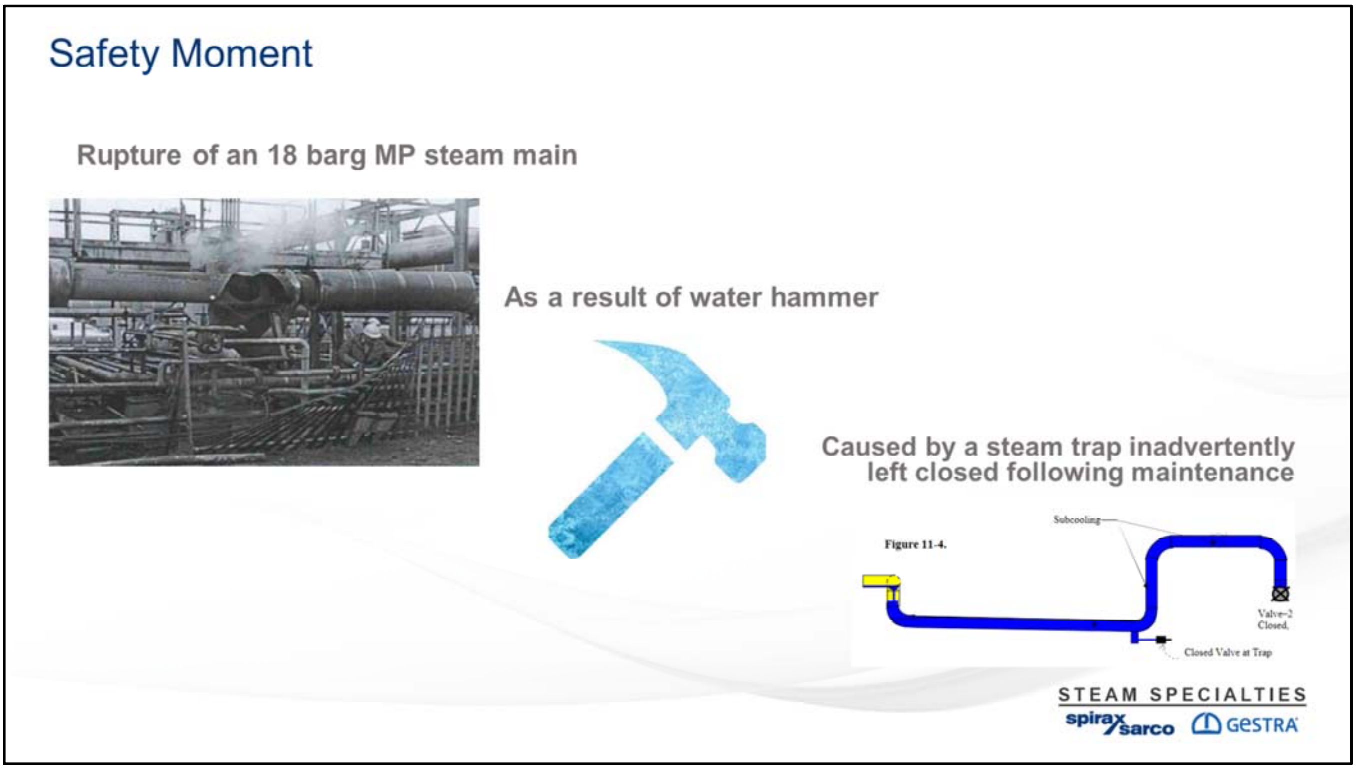


During the period between 29th May and 10th June 2000 three incidents occurred at the Gangemouth Refinery and Petrochemical complex in Scotland. These were: a power distribution failure (29th May), a medium pressure (MP) steam main rupture (7th June), and a Fluidised Catalytic Cracker Unit (FCCU) fire (10th June). Each had the potential to cause fatal injury and environmental impact, although no serious injury occurred, and there was only short term impact on the environment.

MP Steam Main Rupture
An 18 barg medium pressure (MP) steam main located near to the side boundary and a public road ruptured resulting in a significant loss of MP steam directly into the atmosphere. The steam leak damaged fencing immediately adjacent to the ruptured pipework. Debris and steam was blown across the road until the leak was isolated. The leak also caused significant noise disruption to local area. A member of the public walking the dog 300 metres away sustained rib injuries from tripping over the dog. There was significant disruption to the steam supply system for the Complex for approximately one hour until the steam leak could be isolated.

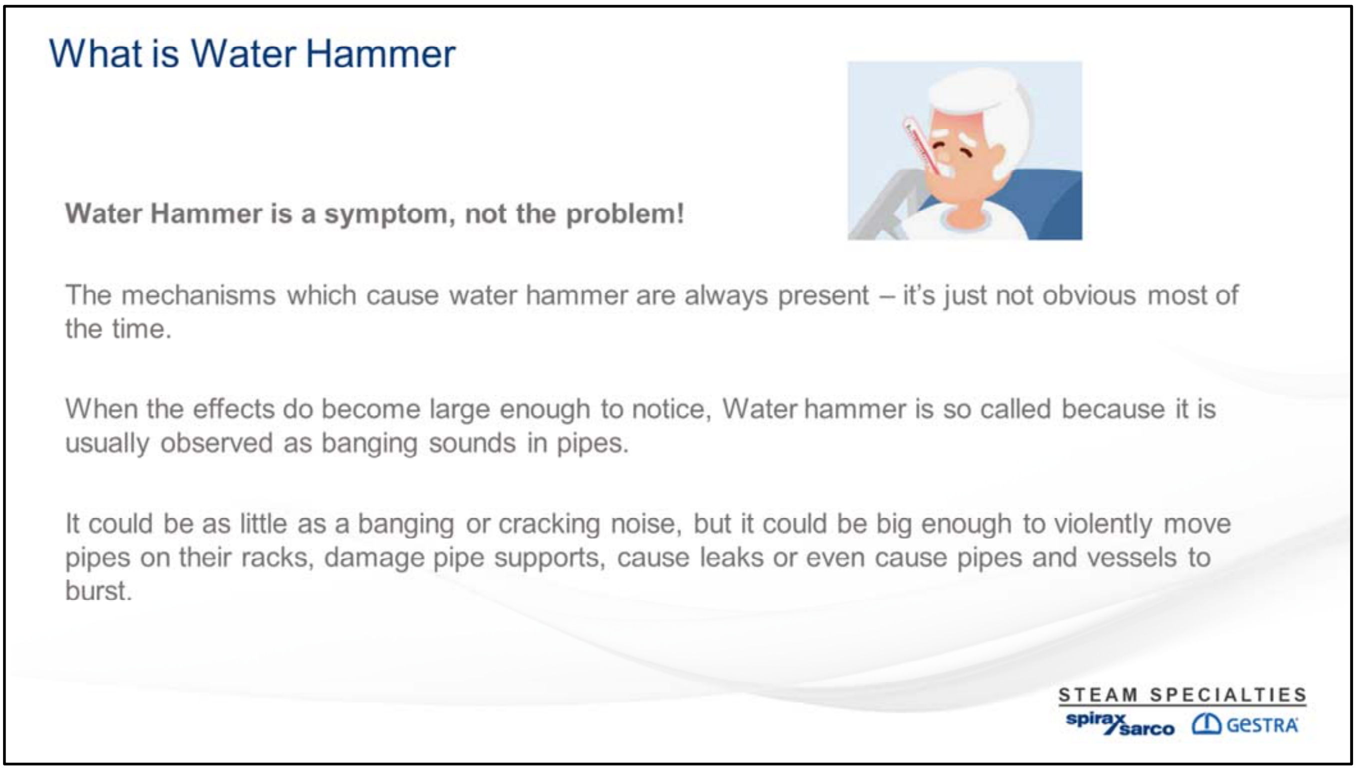
Investigation into the cause found that the water hammer incident was linked to the site wide power distribution failure, the previous week. This had resulted in excess amounts of water being sent to drain, as well as the unavailability of electrical power for drainage pumps. This led to the flooding of culverts (service tunnels) which contained medium pressure (MP) stream distribution lines. While assessing whether the flooding had caused any damage to the pipework a steam trap located in a low point in the section of pipework in the culvert was closed to allow safe access for inspection. The steam trap was subsequently not re-opened and this prevented the removal of condensate from this section of the system. As the liquid condensate level built up in the pipework a quantity of steam (or steam bubbles) was trapped between the hot condensate and closed isolation valves local to the culvert. Eventually collapse of the steam bubble resulted in a phenomenon called condensation induced water hammer which led to a gross overpressure and the subsequent catastrophic failure of the pipeline.

The investigations into the circumstances surrounding all three incidents at the Complex resulted in a number of issues being identified. The UK HSE considered these issues as industry wide lessons, to assist the major hazards industry in reducing the probability of major accident incidents occurring and in reducing the severity of any events which do subsequently occur. The key messages were:

Message 1 - Major hazard industries should ensure that the knowledge available from previous incidents both within their own organisation and externally are incorporated into current safety management systems.

Message 2 - Operators should give increased focus to major accident prevention into order to ensure serious business risk is controlled and to ensure effective governance.

Message 3 - The COMAH safety regime is a living process and should be used as a management tool to assist in process safety management.



The important thing to note is that Water Hammer is a symptom, not the problem!

The term water hammer is used to refer to the noticeable effects which are actually caused by a few quite different phenomena. Water hammer is so called because it is usually observed as banging sounds in pipes.

Water hammer can commonly be seen in domestic settings, caused sometimes by quickly closing a tap. The result is that the pipes or hose can be seen to move due to the pressure waves in the water, and thus might strike floor joists or walls, creating the banging noise. However, due to the short pipe lengths and small flowrates in houses, water hammer in the home is rarely more than an irritation. Industrially however, water hammer can be much more than a minor irritation.

In general water hammer effects occur when the velocity of a fluid suddenly changes and/or flow becomes unsteady or transient (either within a large system or at a very localised point). As such, the mechanisms which cause water hammer are always present to some degree as changes in pressure and fluid properties are required for maintaining and controlling processing conditions. Therefore, any fluid flow and process control actions create pressure changes which result in forces being applied on containing equipment. Normally, these forces are small, such that their presence is not noticed, being well within equipment design parameters. However if the rate of change of pressure is high enough, the forces generated can have noticeable and significant effects, such as violently moving pipes in their racks or even bursting pipe walls.

In the following slides I'll describe how it occurs and hence how it manifests, and consequently how to prevent it or guard against it.

What is Water Hammer

Solve the problem, not the symptom!

The three different mechanisms which result in water hammer effects are:

1. Steam-flow-driven water hammer
2. Condensation induced water hammer
3. Hydraulic Shock or Surge

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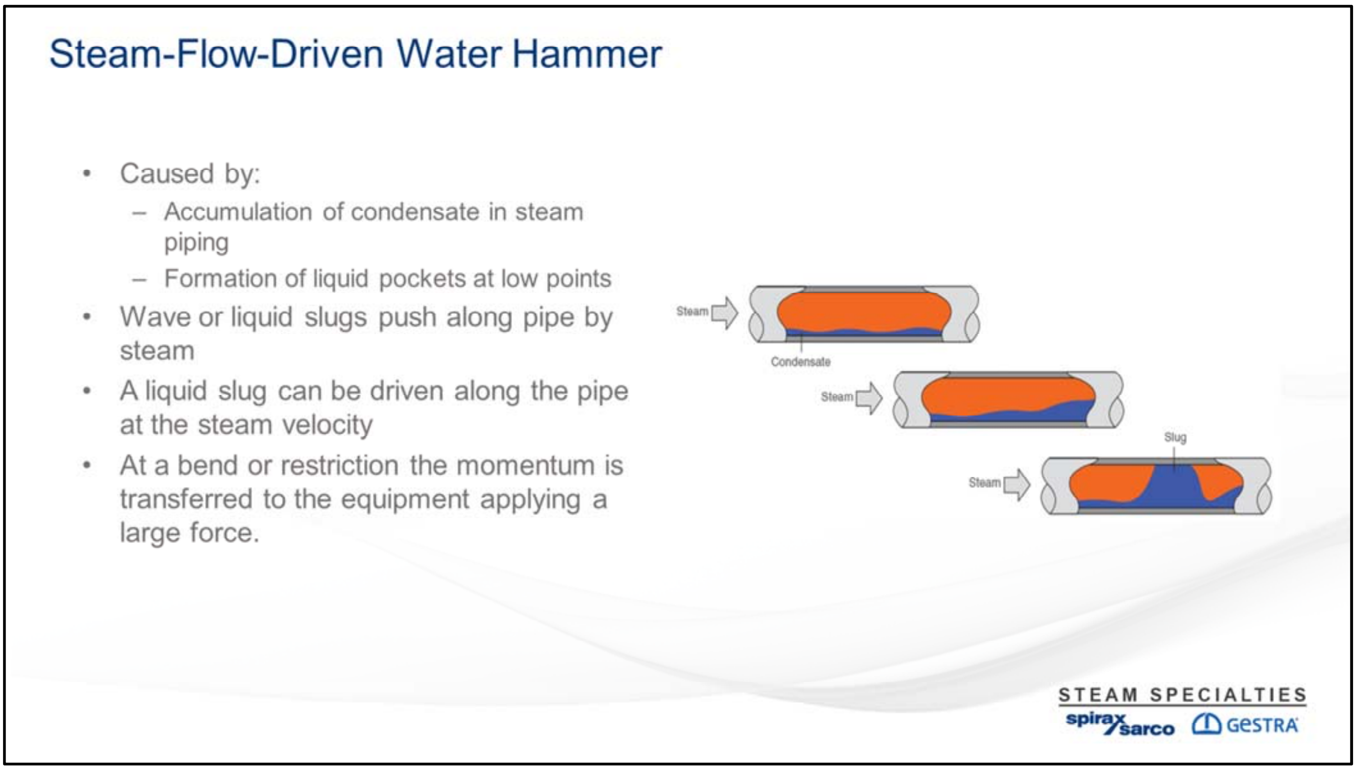
It’s important to identify the correct mechanism involved in order to understand the potential severity and to be able to avoid through good design and operating practices.



There are a couple of ways this can occur, by:

a) Accumulation of condensate in steam piping which results in the formation of waves or slugs of liquid by the action of the steam flowing of over the top of the condensate, in the same way that ocean waves are created;

b) Formation of liquid pockets at low points which are then pushed out by the flow of steam.

The condensate waves or slugs are pushed along the pipe at high velocities by the flowing steam

When these liquid waves or slugs hit a bend or restriction in the piping the momentum is transferred to the equipment applying a large force.

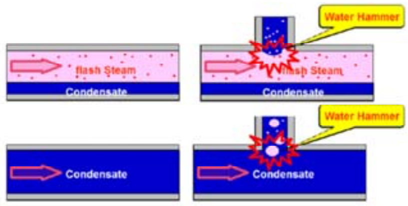
Worse case is the liquid slug completely fills the cross-section of the pipe and is driven along the pipe at the steam velocity

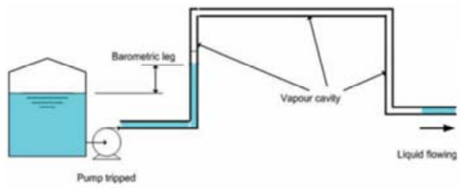
The effects are likely to be greater when there are high steam velocities and longer straight lengths of pipe allowing for the formation and acceleration of larger liquid slugs.

As this mechanism usually results from the accumulation of condensate the effects tend to build over time and therefore act as a warning that something is not right before a major event occurring. NOT ALWAYS THOUGH! Liquid slugs, particularly from pockets during start-up, can occur without prior detection.

Condensation Induced Water Hammer

- This phenomena can occur when:
  - Steam is allowed to enter into a system that contains condensate;
  - Water is injected into a system that contains steam;
  - Vapour pockets exist at high points under certain operating / start-up conditions.
- Rapid condensation of the vapour causes the bubbles / pocket to collapse, with a sudden in-rush of liquid to fill the void (implosion).
- These implosions create very high pressure pulses which impact on equipment imparting high forces.





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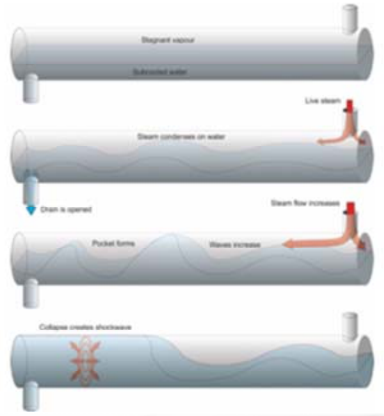
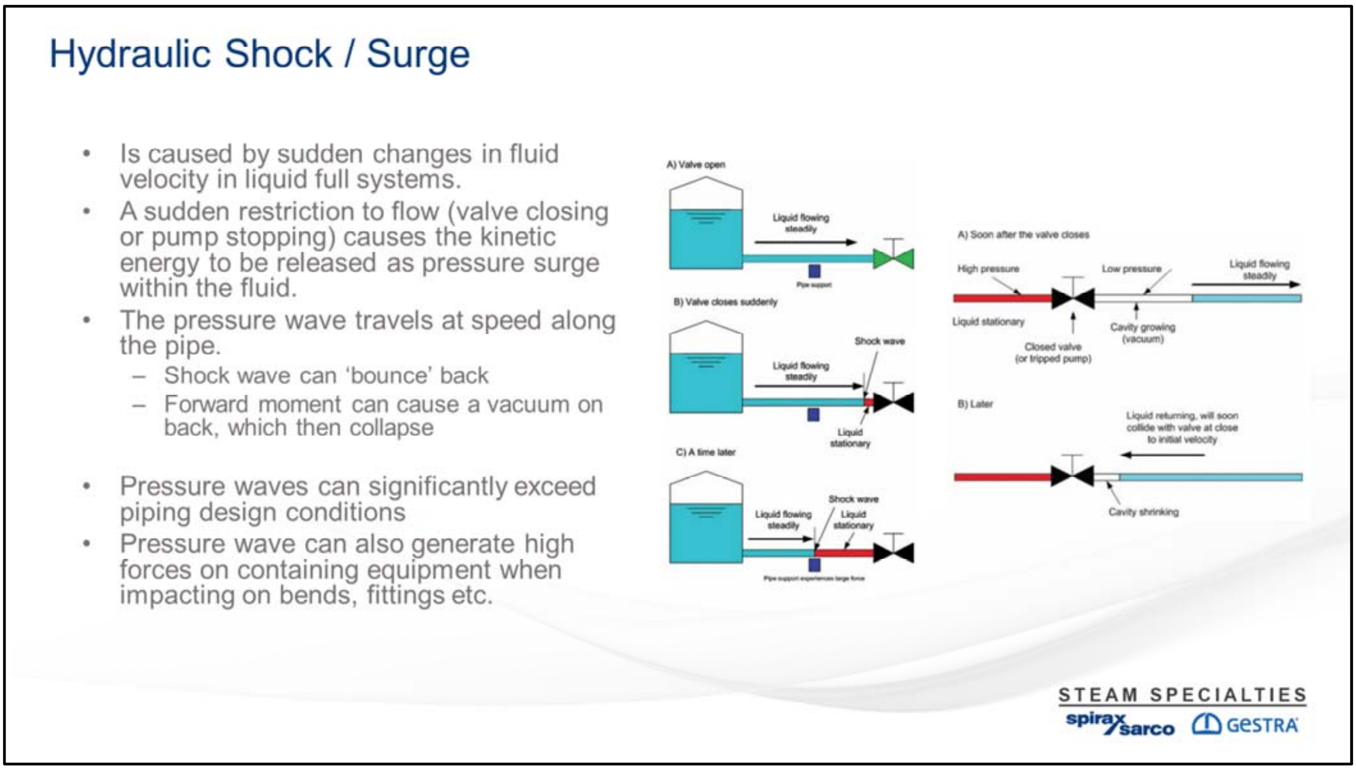
Very sudden!

Steam-Flow and Condensation Induced Water Hammer

The previous two mechanisms can combine to induce water hammer effects:

- The flow of steam over a condensate layer causes waves and liquid slugs to form as per the Steam-Flow-Driven mechanism.
- Steam pockets become trapped between the wave peaks or slugs.
- Cooling of the steam pockets result in rapid condensation and collapse of the steam.
- These implosions create incredible pressure pulses which impact on equipment importing high force loads.





Hydraulic shock, or surge as it is commonly referred to, is a very different mechanism to the previous two. It is caused by sudden changes in bulk fluid velocity in liquid full systems.

Liquids are very slightly compressible. As a result, a sudden restriction to flow (valve closing or pump stopping) does not cause the whole column of liquid to slow down instantaneously. The kinetic energy from the flowing column of liquid is transferred into the fluid by compression of the liquid which results in a pressure shock wave. The pressure wave travels at speed, usually close to the speed of sound, along the pipe, conveying this change of pressure. The greater than rate of change of liquid velocity and the greater than mass of liquid accelerated the higher the resultant peak pressures, particularly where the piping lengths exceeds the pressure wave length.

Shock wave can 'bounce' back from obstacles / restrictions in the piping which can compound pressure spikes

Forward momentum of liquid flowing away from a sudden flow restriction can cause a vacuum on back of the restriction, which then collapses as the liquid surge returns and this often causes the greater pressure shock waves

This pressure wave can significantly exceed piping design conditions causing significant damage and loss of containment

Pressure wave can also generate high forces on containing equipment when impacting on bends, fittings etc.

Where Do These Phenomena Occur?

- Steam-Flow-Driven Water Hammer
  - Steam distribution piping
  - Two-phase condensate return lines
  - Single phase condensate lines with high pressure drop

- Condensate Induced Water Hammer
  - Steam and condensate return headers
  - Condensate return lines immediately downstream of steam consumers and steam traps
  - During start-up / turndown operation

- Hydraulic Shock / Surge:
  - Long liquid filled transfer lines – the longer the length of piping the greater the peak pressures generated.
  - Including condensate return systems

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Having explained the different mechanisms causing water hammer phenomena, it should be apparent that water hammer effects can occur almost anywhere around a plant. However, as the effects are more likely to be noticeable in systems which have higher fluid velocities, greater inventories and greater potential for mixing of steam and condensate, the following are the most common systems in which water hammer is experienced.

Possible Consequences and Risks

- Water hammer can have adverse safety, environment and commercial consequences.
- Severe water hammer can cause:
  - Damage to equipment
  - Loss of containment
  - Personnel injuries or fatalities
  - Environmental damage
  - Consequential production losses and reputation damage
- The likelihood and severity of water hammer can be greatly reduced through appropriate system design.
- Operating and maintenance practices important in maintaining a safe plant conditions as per the design intent.

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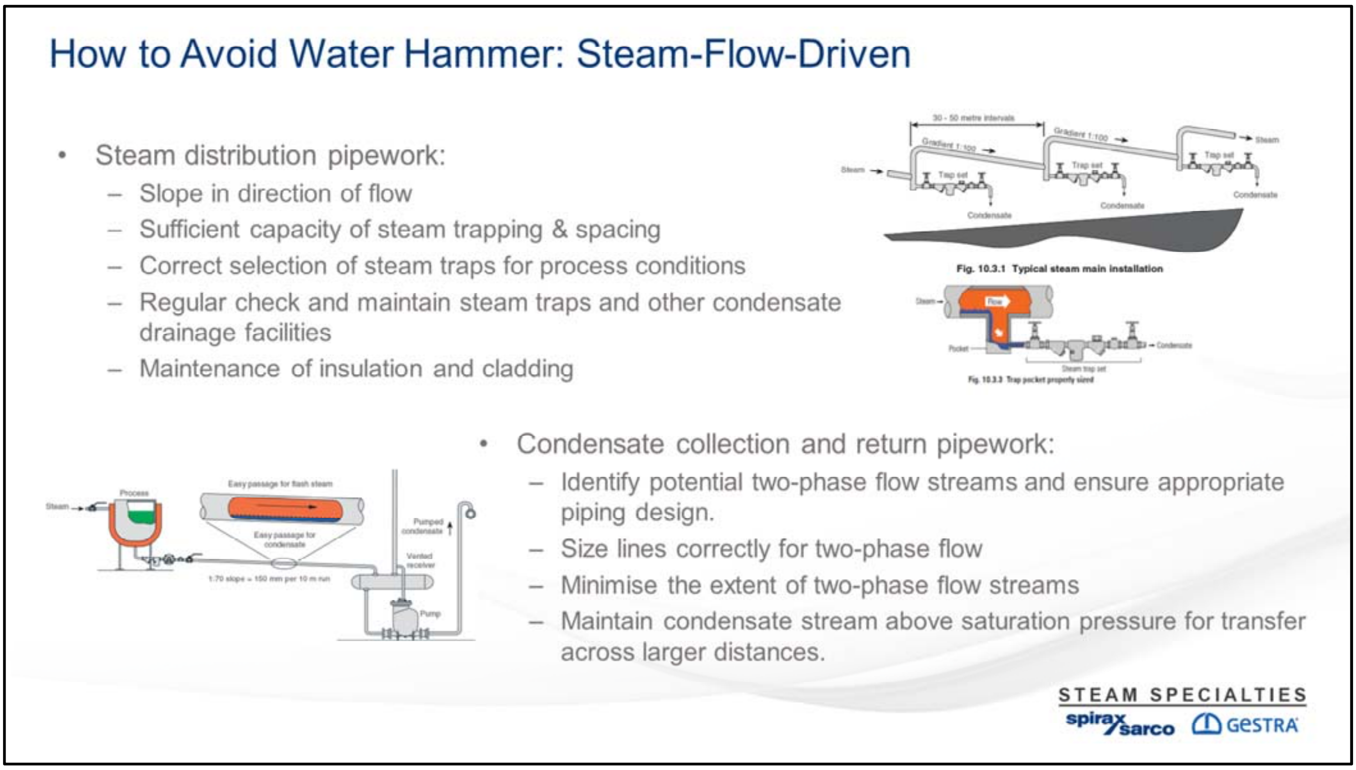


Steam distribution pipework. The aim is to avoid the accumulation of condensate within the system as a whole and in pockets

Slope in direction of flow to aid drainage of condensate to low points

Sufficient capacity of steam trapping to ensure removal of condensate across all operating, start-up and shutdown scenarios.

Correct selection of steam traps for process conditions to ensure reliable operation

Regularly check and maintain steam traps and other condensate drainage facilities

- Steam mains should be drained at **every** low point , at intervals of 30-50m , at the end of mains and branches and before any valves which may close
- Pipes should be installed with a fall in the direction of flow
- Good sized drain pockets should be fitted to ensure condensate can be effectively collected and discharged by a suitably selected steam trap
- Steam trap should be correctly selected in terms of the application and properly sized taking into account of start up conditions
- Eccentric pipe reducers and NOT concentric reducers fittings should be installed. Eccentric design will allow condensate to flow easily to the next drain point
- Steam branches should always be taken from the top of the mains as the steam is at its best quality, off the bottom will produce wet steam reducing heat efficiency and will promote noise and vibration

- Y type strainers on steam should always be fitted on their side and therefore maximising effective screen area and not allowing condensate to collect
- Steam mains should be properly sized, pipes that are undersized will result in high steam velocities which give rise to excessive pressure drop and if steam is in poor condition will create noise, vibration and in worst cases hammer plus potential erosion of valve trim and pipe fitting especially where there is a change in direction

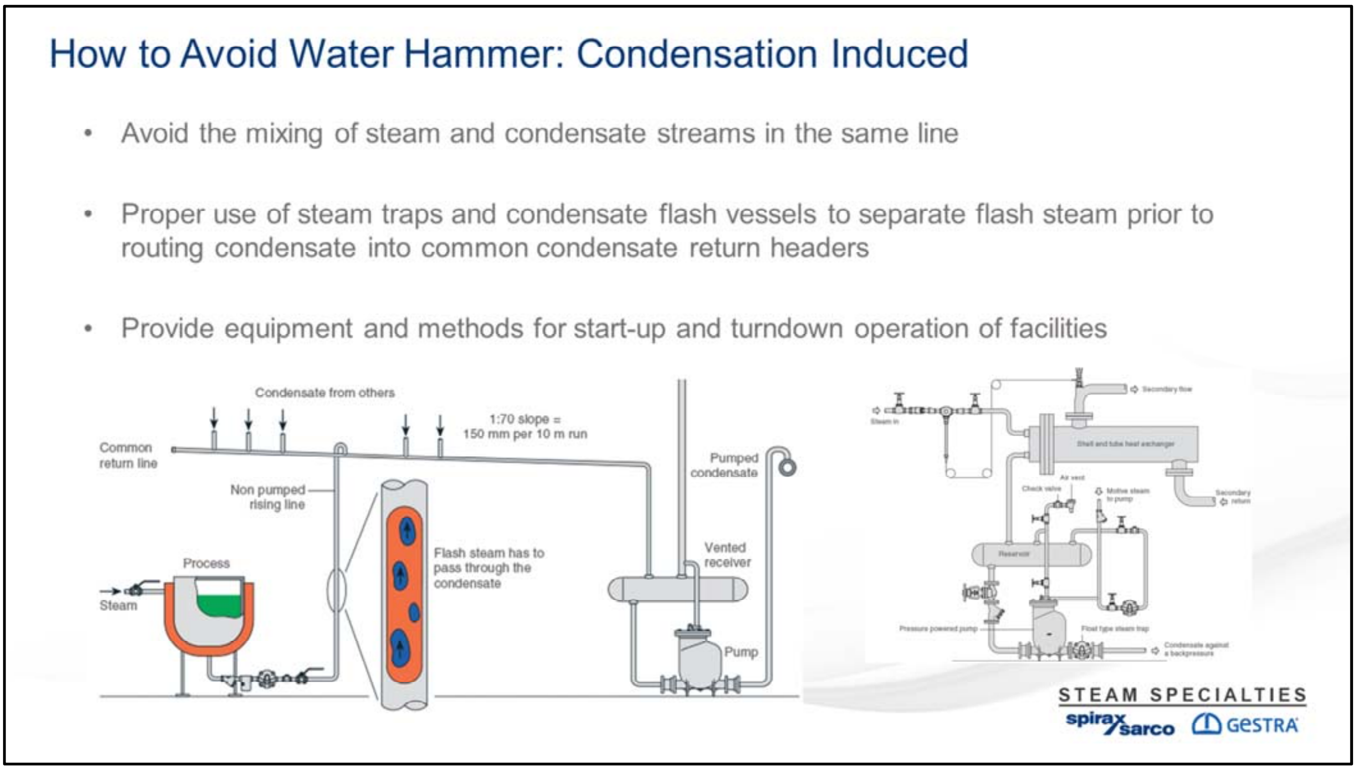
Condensate collection and return pipework: Here the presence of steam and condensate has to be allowed for and the system designed and operated appropriately.

Always identity potential two-phase flow streams on P&IDs and ensure appropriate piping design with respect to supports and stress calculations.

Size lines correctly for two-phase flow where necessary to avoid operating in the region of the wavy or slug flow regimes.

Minimise the extent of two-phase flow by local collection of condensate and separation of flash steam

Maintain condensate stream above saturation pressure for transfer across larger distances.



The measures to avoid Steam Flow Induced water hammer are also applicable to avoiding Condensation Induced water hammer. In addition:

Avoid the mixing of separate steam and condensate streams in the same line.

Separation and independent routing vapour and liquid streams

Minimising the potential for steam break through from control valves and steam traps

Careful selection of control schemes and/or steam trap types (continuous flow type vs on-off for example)

Proper employment of steam traps and condensate flash vessels to letdown and separate flash steam prior to routing condensate into common condensate return headers

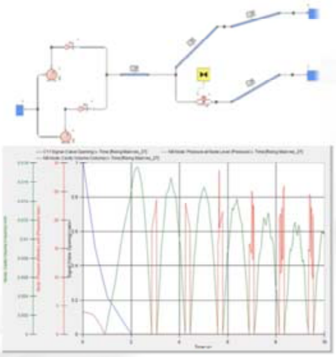
Condensate Induced water hammer can be a particular issue during start-up and other abnormal operation modes when systems are not at normal operating conditions. It’s really important to provide the equipment and methods needed to manage these operations properly when the usual control and equipment may not be suitable and could lead to unsafe conditions.

Steam heat exchangers (reboilers for example). Can become flooded with sub-cooled condensate during start-up. Provide means of removal of condensate

under start-up conditions (e.g. pump trap arrangement)
Ability to vent high point pockets during start-up, or ability to slowly pressurise line to collapse vapour pockets in a controlled manner

How to Avoid Water Hammer: Hydraulic Shock / Surge

- Undertake surge screening and piping analysis to if determine peak overpressures are acceptable or not.
- Dynamic simulation could be utilised for particularly complex or high risk situations
- Mitigation steps can be:
  - Increase line size to reduce fluid velocities
  - Break long transfer lines down into smaller, separate stages
  - Use of slow closing valves
  - Avoid use of quarter turn valves. Use of equal percentage valve trims
  - Use of surge buffer vessels
  - Increasing pressure rating of pipework



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Any Questions?

Many thanks for your attention. Please contact me or my colleagues at Spirax Sarco require any further information or support in the future.

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