Steam System Piping

Mechanical Systems - Multifamily

Key Terminology

"A" dimension

"B" dimension

Boiler feed tank

Carryover

Cavitation

Concentric reducer

Condensate

Condensate receiver tank

Counterflow

Dry return

Dry steam

Eccentric reducer

Equalizer

Gravity return

Hartford Loop

Header

Low-water cutoff

Near-boiler piping

Normal Water Line (NWL)

Parallel flow

Pounds per square inch (psi)

Pressure drop

Pump return

Reducing elbow (also reducing fitting)

Riser

Steam main

Water hammer

Wet return

Wet steam

Section Transition

Learning Objectives (Slide #2)

By attending this session, participants will understand:

- Near-boiler piping, on both the supply and return sides, and its functions.
- The importance of proper header design.
- How steam and condensate flow through a building.
- The differences between dry and wet returns.
- How gravity and pumped returns work.
- Some causes of water hammer and their solutions.

This section contains a great deal of detail on steam systems piping. Most buildings with steam heating are very old and the piping is rarely labeled. It's important that auditors be able to tell which pipes are which, what purpose they are serving, and whether they are pitched properly.

Near-boiler Piping: Supply Side (Slide #3)

This graphic depicts ***near-boiler piping*** on the supply side of a steam boiler. The system contains the following components:

- ***Risers***, which are the vertical pipes attached to the boiler.
- The ***steam main***, which delivers steam to the building.
- The ***header***, which is the horizontal piece connecting the risers to the steam mains and the return-side piping.

It is important that the piping near the boiler be installed exactly as the boiler manufacturer recommends. This piping is just as essential to system performance as the burner and controls.

Riser and Header (Slide #4)

In a steam heating system, we want only steam to go into the pipes. Liquid water should stay in the boiler. The near-boiler piping design is key to preventing boiler water from entering the supply pipes.

- The boiler fires, heating the water. As the water changes into gas, it rises to the surface. When enough pressure builds, the steam exits through the risers at the top of the boiler.
- Note in the graphic that the steam leaving the boiler does not go directly to the main supply to the building. Instead, a riser carries the steam from the boiler to the header, a large-diameter horizontal pipe. There may be one or more risers; this graphic shows a boiler with two risers.
- Steam moves more slowly through a larger pipe than a smaller one. The more slowly the steam travels through these pipes, the more time the water droplets in the steam have to drop out and return to the boiler. This means a drier steam will enter the building distribution system.
    - ***Dry steam***, which has few or no water droplets in it, leads to better heat transfer and fewer distribution problems.

- The temperature of the header piping fluctuates with the boiler firing schedule, and it expands and contracts accordingly. The horizontal piping and elbows have swing joints to compensate for this movement. Without this flexibility, cast iron boiler sections can crack and steel boiler welds can fail.

The steam system supply pipe is located between the boiler ***equalizer*** and the last riser. This piping layout acts as a mechanical separator. The relatively heavy water drops can't turn as easily as the steam can, so they keep moving forward when the steam turns to enter the supply piping. The water then drops into the equalizer. This process of separating the water from the steam is one of the header's most important functions.

Incorrect Steam Supply Piping (Slide #5)

This graphic shows what happens when the steam supply pipe is located between two risers instead of after the last one.

- In this situation, the steam and water droplets rushing up from the risers collide below the center supply. There is no chance for the water droplets to separate from the steam and return to the boiler.
- This means that the water droplets will be carried into the supply pipe and out to the building. This is known as ***carryover***.
- Carryover is bad for two main reasons:
  - It sends ***wet steam***, which carries a lot of water droplets, out to the building. Wet steam transfers less heat than dry steam and can damage the system.
  - If water leaves the boiler too quickly, the boiler may take on more make-up water than is necessary, which can lead to boiler flooding.
- The steam supply piping should be located between the equalizer and the last riser to avoid carryover.

Impact of Wet Steam (Slide #6)

- As discussed in the "Steam Basics" section of this curriculum, gaseous steam contains more heat than liquid water. Therefore, wet steam contains less heat than dry steam and is less efficient at transferring heat to a building.
- The water droplets in wet steam can lead to ***water hammer***. Steam often travels through a system's piping at speeds close to 60 miles per hour. When those water droplets slam into a pipe or a fitting at that speed, they make a loud noise. When they hit an elbow, air vent, or steam trap at that speed, they can damage those components, leading to breakage.
- The photo shows an air vent damaged by water hammer. You can tell by the wet, darker sections that water has recently been spitting out of the vent. Air vents are supposed to release only air.

What's wrong with this picture? (Slide #7)

- This slide shows a boiler with only one riser instead of the two the manufacturer recommends. The imbalance causes a sloped water line, which can damage the boiler and even cause failure. In a cast-iron sectional boiler, a sloped water line like this would leave some of the back sections above the water line, where they could overheat and crack.
- While omitting the second riser may have saved some money during installation, it could lead to more costly repairs!

Good Steam Header Design (Slide #8)

- These headers were designed to remove the water droplets from steam, sending dry steam up to the building.
- Notice in each photo that the water droplets follow a pathway that returns them to the boiler. The steam can head into the building and leave the water droplets behind.

Bad Steam Header Design (Slide #9)

- These headers were designed by someone unfamiliar with proper steam header design. There is no place to separate the water droplets from the steam, so these buildings likely suffer from a lot of water hammer.
- In the photo on the left, the water droplets cannot make that sharp turn, so they will be carried into the building with the steam.
- In the photo on the right, there is no place for the water droplets to separate and fall back into the boiler. They will go into the building with the steam.

Parallel Flow (Slide #10)

Now that we've reviewed how steam leaves the boiler through the risers and gets into the header, let's discuss the ways that steam and the ***condensate*** that it eventually becomes flow through the piping.

- This slide shows an example of a ***parallel flow*** setup, in which steam and condensate flow in the same direction in the same piping. In this case, both the steam and condensate are flowing from right to left in the header.
- For the condensate to flow properly, all horizontal steam mains with parallel flow must be pitched downward at least ¼" for every 10' in the direction of the steam and condensate flow.

Counterflow (Slide #11)

This slide shows an example of a ***counterflow*** setup, in which steam and condensate flow in opposite directions in the same piping. The piping in a counterflow setup should be one size larger than in a parallel flow setup to allow sufficient space for the steam and condensate to flow freely past each other.

In this setup, there is no need for separate return piping. The condensate flows down the sloped steam main and returns to the boiler. The counterflow steam mains must be pitched at least 1” for every 10’ in the direction of the boiler for this downward flow to occur.

Branching of Steam Mains (Slide #12)

These illustrations depict two ways for the steam mains to connect to the steam header.

The drawing on the left shows a 90° elbow, which is acceptable, but not as good as the one on the right, which shows a 45° bend. Not only does the 45° bend have a lower ***pressure drop*** than the 90° elbow, it also reduces the chance that condensate will drop directly onto the steam that is rushing up.

Near-boiler Piping: Return Side (Slide #13)

Near-boiler piping on the return side of the system includes the following:

- Equalizer.
- ***Hartford Loop.***
- “A” dimension or “B” dimension.
- Return piping, either dry or wet.

Equalizer (Slide #14)

- The equalizer is a section of vertical piping off the steam header.
- The equalizer balances the pressure between the boiler’s steam outlet and condensate return inlet so that the boiler water level stays within optimal and safe levels.
    - The equalizer uses a ***reducing elbow*** or ***reducing fitting*** to connect two pipes of different sizes.

Before the Hartford Loop #1 (Slide #15)

The Hartford Loop is an essential safety feature that must be part of every boiler’s return piping.

- Boiler explosions were common in the late 1800s and early 1900s before the Hartford Loop was invented.
- How did these boiler explosions occur?
    - As the steam pressure built in the boiler, it pushed down on the boiler’s water line.
    - The water backed out of the boiler.
    - The boiler water line dropped to an unsafe level.
    - The boiler itself was unable to stay cool and its surface got hot.
    - Fresh water replaced the missing water. The fresh water instantly flashed to steam when it contacted the hot boiler surface.
    - Steam takes up 1,700 times as much space as water, and this flashed steam had no place to go. The pressure in the boiler quickly rose to a dangerous level.

    - Once the steam pressure exceeded the boiler rating, the boiler exploded.
- This graphic shows a boiler without a Hartford Loop. You can see how easily the water can back up into the return as the steam pressure builds up in the boiler. It does this because the pressure above the return is lower than the pressure in the boiler.

Before the Hartford Loop #2 (Slide #16)

Before the Hartford Loop was invented, leaking return lines could also lead to boiler explosions. As water leaked out of the return line, it drained the water from the boiler. When the boiler tried to fire without enough water inside, it exploded.

The Hartford Loop #1 (Slide #17)

In 1919, the Hartford Steam Boiler Insurance and Inspection Company improved piping with the Hartford Loop design, shown here.

With a Hartford Loop in place, the pressure in the boiler is the same as the pressure where the equalizer and the Hartford Loop join. This prevents the water in the boiler from dropping below the top of the Hartford Loop. It also prevents the water level in the boiler from dropping below that horizontal connection, even if the return line is leaking. It essentially acts as a check valve.

The Hartford loop is for 1-pipe and 2-pipe systems without feed water pumps.

The Hartford Loop #2 (Slide #18)

This photo shows a Hartford loop on a sectional boiler.

The Hartford Loop #3 (Slide #19)

This slide shows the two graphics side by side for comparison. On the right, you can see what a difference the Hartford Loop makes in keeping the water at a safe level.

Wet Return (Slide #20)

The return piping carries the condensate back to the boiler from the terminal units.

The location of the return pipe determines the type of return: wet or dry. This slide shows a ***wet return***. Everything below the dashed line is full of water.

- Steam boilers contain a sight glass that shows the water level in the boiler. All the system piping below that water level will be full of water. The return pipe shown here is below the water line.
- We call the return piping below the water level a wet return because it is full of water all the time.

Dry Return (Slide #21)

This slide shows the ***dry return***, which is the piping located above the water level. It is called a dry return because it is not full of water all the time. Again, everything below the dashed line is full of water.

"A" Dimension (Slide #22)

- The ***"A" dimension*** is the vertical distance between the boiler water level and the lowest steam-carrying pipe in a one-pipe steam system.
- When the boiler is off, the water level in the vertical pipe connecting the steam main to the wet return should be at the same level as the boiler water. When the burner fires and steam forms in the boiler, the pressure inside the boiler increases. As the steam flows through the main, it experiences a drop in pressure due to friction in the pipe. This pressure drop can be as much as 0.5 ***pounds per square inch (psi)***. As a result, the steam pressure at the end of the main is less than the pressure inside the boiler, and the condensate in the return line cannot return to the boiler without additional pressure. That additional pressure comes from the "A" dimension.
- The condensate will back up inside the vertical pipe until its weight creates enough additional pressure to overcome the full steam pressure and return to the boiler.
- The "A" dimension must be at least 28" (equivalent to 1 psi) to provide enough room for water to rise and force the condensate back into the boiler. This 1 psi compensates for the reduction in steam pressure along the steam main, the pressure drop caused by the return piping and any sediment that may be in the lines, and the initial rush of condensate that occurs when the system starts up with cold piping.
- It is often useful to measure the "A" dimension in a system from the ceiling down instead of from the floor up as ceilings in building basements are typically more level than floors.
- If the system's "A" dimension is not large enough, the condensate may stay in the return piping and not make it back to the boiler. This could lead to water hammer.

"B" Dimension (Slide #23)

- The ***"B" dimension*** is similar to the "A" dimension, but the "B" dimension is used solely for two-pipe steam systems with ***gravity returns***.
- Both the "A" and "B" dimensions measure the same thing. he distance from the boiler water level to the lowest steam-carrying main, but the "B" dimension is a little greater than the "A" dimension for each psi of steam pressure. The "B" dimension requires at least 30" per psi of steam in the system, rather than 28". For a system operating at 2 psi, the "B" dimension would have to be at least 60", or 5'.
- As most basements do not have room for such a tall system, two-pipe steam systems often use pumped returns instead.

It is important to note that the pressures discussed above usually correspond to low rise, i.e., 2- or 3-story buildings. Boilers in mid and high rise multifamily buildings are likely 15psi systems, although they can operate to pressures as low as 3 to 5 psi. Boilers for campus-style buildings – two or more buildings on a loop – also generally operate at higher pressures.

Parallel Flow – Dry Return (Slide #24)

This slide shows a parallel flow system with a dry return. The large arrow indicates the lowest point of return piping, from where you would measure the "A" dimension.

Parallel Flow – Wet Return (Slide #25)

This slide shows a parallel flow system with a wet return. The large arrow indicates the lowest point of the steam main, from where you would measure the "A" dimension. Notice how much more room is available for the "A" dimension in a wet return layout.

Counterflow – Dry Return (Slide #26)

This slide shows a counterflow system with a dry return. The large arrow indicates the lowest point in the steam main, from where you would measure the "A" dimension.

Quiz (Slide #27)

The next three slides are a pop quiz!

Name the Type of Flow and Return #1 (Slide #28)

Name the type of flow and return shown here.

- Is the flow parallel or counter?
- Is the return wet or dry?

This slide shows a parallel flow system with a wet return.

Name the Type of Flow and Return #2 (Slide #29)

Name the type of flow and return shown here.

- Is the flow parallel or counter?
- Is the return wet or dry?

This slide shows a counterflow system with a dry return.

Name the Type of Flow and Return #3 (Slide #30)

Name the type of flow and return shown here.

- Is the flow parallel or counter?
- Is the return wet or dry?

This slide shows a parallel flow system with a dry return.

Returning Condensate to the Boiler (Slide #31)

There are two ways to return condensate to the boiler: with a gravity return or a ***pump return***.

- Systems with gravity returns use gravity to return condensate to the boiler. “A” or “B” dimensions are needed for these systems to function properly.
- If there is not enough room for gravity to push the condensate back to the boiler, a pump return must be used instead. In a pump return system, the condensate collects in a tank, from which it is pumped back into the boiler.

Condensate Receiver Tank (Slide #32)

- The ***condensate receiver tank*** must be located to allow condensate to flow into it by gravity.
- A receiver tank does not communicate with the boiler. Instead, as soon as the tank fills to a certain level, the pumps push water from the tank into the boiler. Unfortunately, this can flood the boiler.

Boiler Feed Tank (Slide #33)

- Instead of using a condensate receiver tank, which operates independently of the water line in the boiler, a better solution is to install a ***boiler feed tank***.
- Boiler feed tanks are sized based on the rate at which the boiler produces steam and the time it takes for the condensate to return to the boiler.
- The water in a boiler feed tank is not meant to replace all the water in the boiler, only the amount between the ***normal water line (NWL)*** and the ***low-water cutoff*** level.
- Boiler feed tanks are bigger than condensate receiver tanks because they must hold the condensate until the control on the boiler calls for more water.
- The pumps attached to boiler feed tanks are typically controlled by pump controllers. A common line is McDonnell & Miller's pump controllers, such as the No. 150, which is piped into the boiler near the low-water cutoff.

Water Hammer: Not Just a Header Problem (Slide #34)

Earlier, we discussed how an improperly designed header can cause water hammer. However, water hammer occurs whenever water droplets slam into the piping, and this can occur anyplace where steam and water are flowing in the same pipe.

Water hammer is caused by:

- Collapsing of steam when it comes in contact with colder condensate or
- Slugging or entraining condensate along with the faster moving steam when it strikes piping at changes in direction.

Water Hammer: Sagging or Improper Pitch (Slide #35)

- Condensate pooling, which leads to hammer, is caused by poor piping pitch, incorrectly functioning steam traps, collection points at debris strainers and other connections, concentric reducers, etc.
- One of the most common causes of water hammer is piping not sloped sufficiently and therefore does not allow water to drain correctly. Piping that dips, like in the example shown in the top drawing, is a prime suspect.
- Most buildings with steam systems are old and many have settled over time. Settling can cause piping to sag, which means it may no longer be sloped properly.

Water Hammer: Sagging Pipe (Slide #36)

- This photo shows a sagging pipe. This one is at the beginning of a riser that is supposed to provide steam to one line of apartments.
- The condensate returning from the riser will collect in the low spot indicated by the arrow, where it will interfere with the passage of steam. Once the water level rises to the dotted line, it will block the pipe. Steam will not be able to pass without pushing water out of its way.
- This sagging pipe will cause water hammer and could prevent steam from reaching a riser, which will lead to complaints of inadequate heat.

Water Hammer: Low Points (Slide #37)

- An improper pipe fitting can create a low point in the system where condensate collects, which can cause water hammer.
- This slide shows two types of reducing fittings for steam piping.
    - The top fitting is called a ***concentric reducer*** because the larger and smaller ends are concentric; that is, they have the same center point. As water can’t travel uphill on its own, it will be trapped on the large diameter side and won’t be able to flow properly through the rest of the piping. This collected water can be a source of water hammer.

- The bottom fitting is called an ***eccentric reducer*** because the larger and smaller ends do not have the same center point; they have the same bottom point, creating a smooth bottom. This type of fitting allows condensate to flow through the system properly.

- If you're in a building with water hammer issues, check the reducers. Recommend replacing concentric reducers with eccentric reducers.

Water Hammer: Not Enough Drainage (Slide #38)

- Water hammer can also be caused by insufficient drainage for the condensate.
- In pipe sections where the water level is too high, the steam rushing over it will create waves. These waves can create pockets that trap the steam, causing ***cavitation***. Once the steam is surrounded by the relatively cooler condensate, it will immediately condense and create a vacuum. Water is sucked upward to fill that vacuum, causing water droplets to slam into the piping.
- This kind of water hammer can indicate that some of the piping is clogged, preventing condensate from easily returning to the boiler. Check that all strainers and traps in the system are open and clear of debris to allow the free flow of condensate.
- If all the piping is clear, then piping may need to be added to some low sections to remove the condensate. Remember that the condensate will always be at the lowest level inside the pipe, so this new piping must connect to the bottom of the existing piping to be effective.

Preventing Water Hammer (Slide #39)

Let's review the ways to prevent water hammer in a steam system:

- First, check that the steam header provides a way to separate the water droplets from the steam. This will help ensure that dry steam is going in the steam main and out to the rest of the building.
- Check that the piping is properly pitched to allow the condensate to drain back to the boiler. Remember that the pitch in counterflow systems is different than the pitch in parallel flow systems. Fix any sagging piping to restore the proper pitch.
- Make sure the reducers are eccentric, not concentric, to allow condensate to flow smoothly downward.
- Check that all strainers, traps, and other fittings aren't clogged and preventing condensate from flowing through them.

Summary (Slide #40)

- Near-boiler piping is essential to the proper functioning of the system.
  - On the supply side, a properly designed header separates water droplets from the steam so that only dry steam enters the building piping. This helps reduce water hammer.
  - On the return side, the Hartford Loop is critical to preventing the water from emptying out of the boiler and causing an explosion.

- In parallel flow systems, the steam and condensate flow in the same direction. In counterflow systems, the steam and condensate flow in opposite directions.
- Dry returns are located above the normal boiler water line and should contain only steam. Wet returns are located below the water line and are full of water all the time.
- In gravity return systems for one-pipe steam, the “A” dimension is needed to get the condensate back to the boiler. In gravity return systems for two-pipe steam, the “B” dimension is needed to get the condensate back to the boiler. In pumped-return systems, the condensate flows into a tank and is returned to the boiler through a pump.
- Not only is water hammer loud and annoying, it also damages the piping and system components, causing premature failure. Fix any low points, sagging, or clogged piping to resolve water hammer issues.