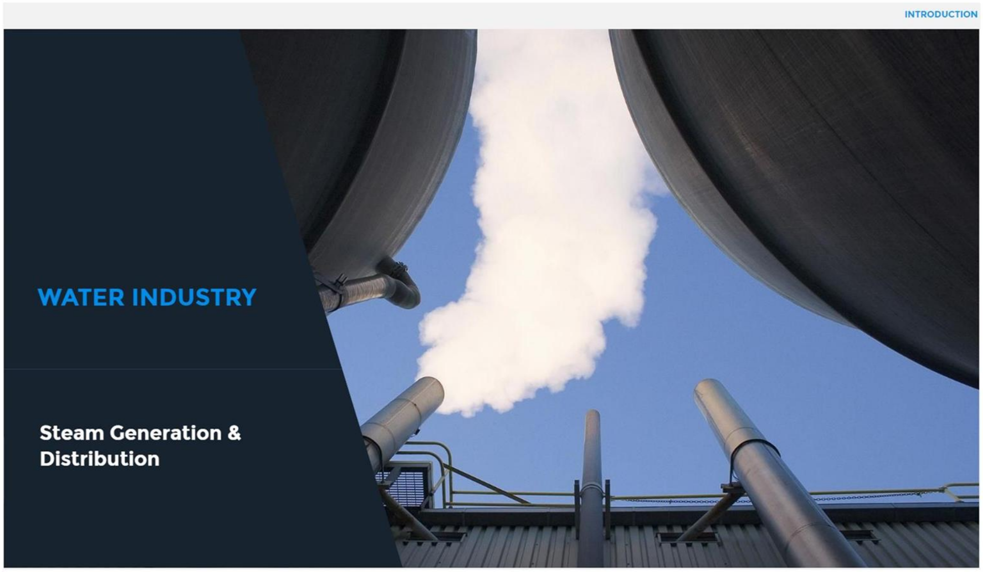
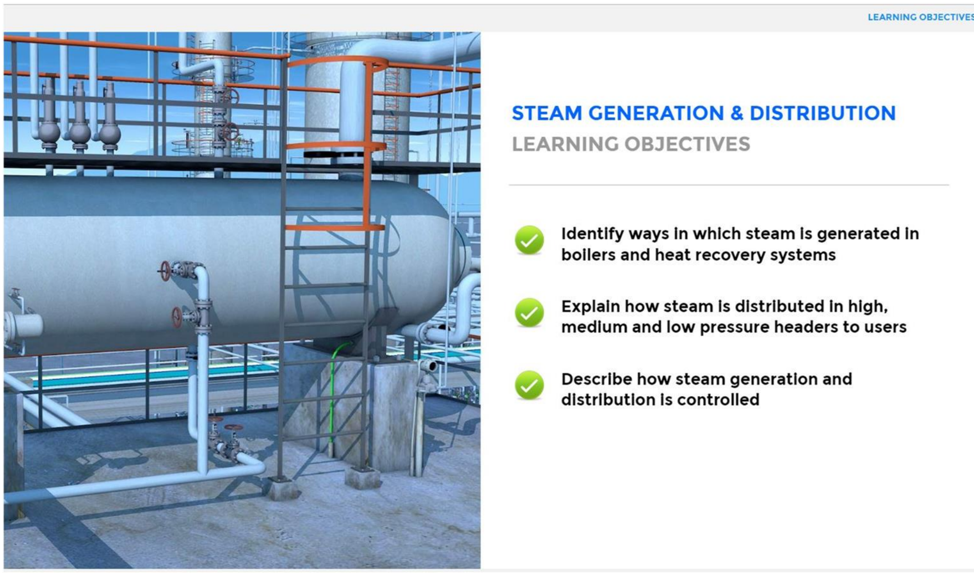
BU MEASUREMENT & ANALYTICS

Water Industry

Steam Generation & Distribution



Welcome! This module is going to explain how continuous manufacturing sites typically generate and distribute steam.

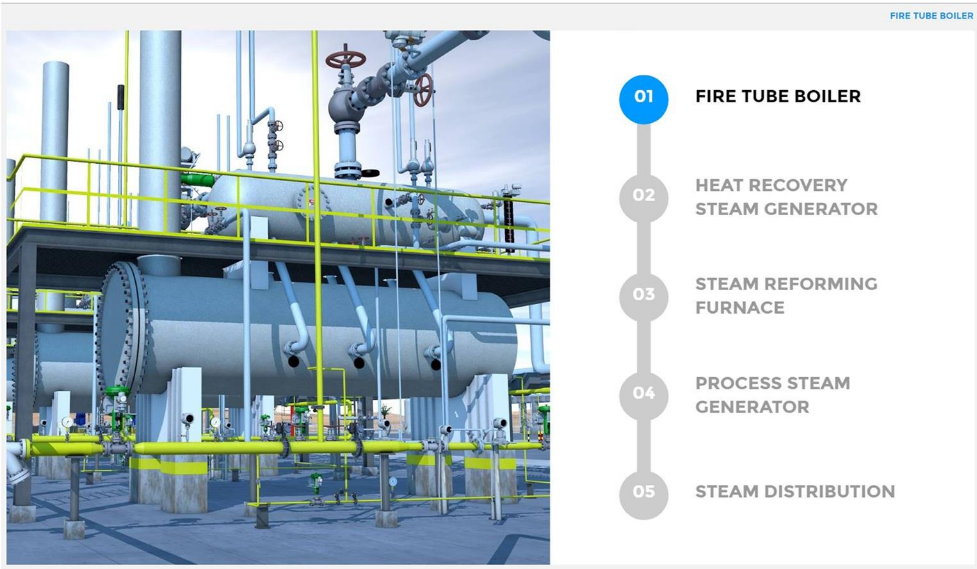


These are your learning objectives. Upon completion of this module, you should be able to:

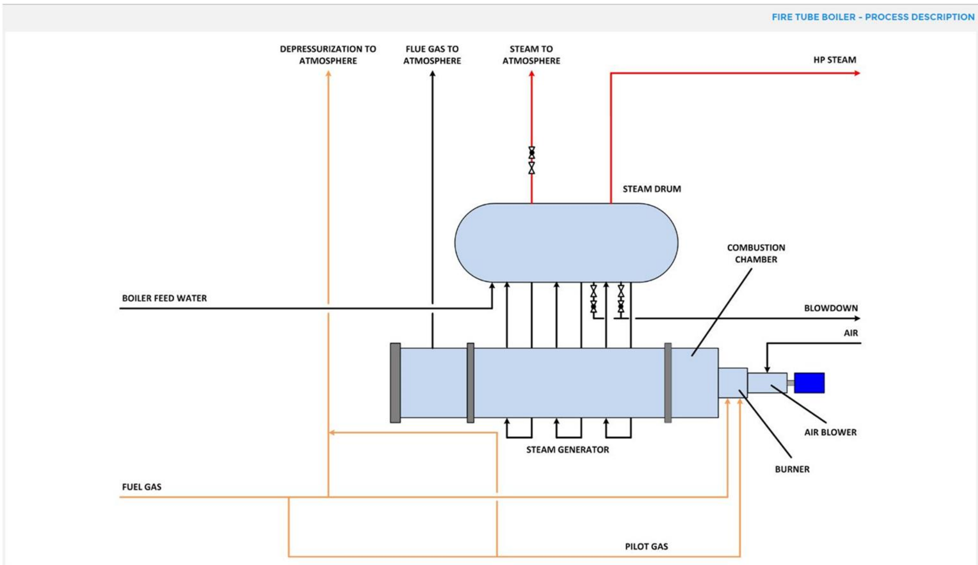
Identify ways in which steam is generated in boilers and heat recovery systems

Explain how steam is distributed in high, medium and low pressure headers to users

Describe how steam generation and distribution is controlled



We'll start with the Fire Tube Boiler.



Fire tube boilers are used to generate steam from boiler feed water. The one shown here is generating saturated steam, i.e.:

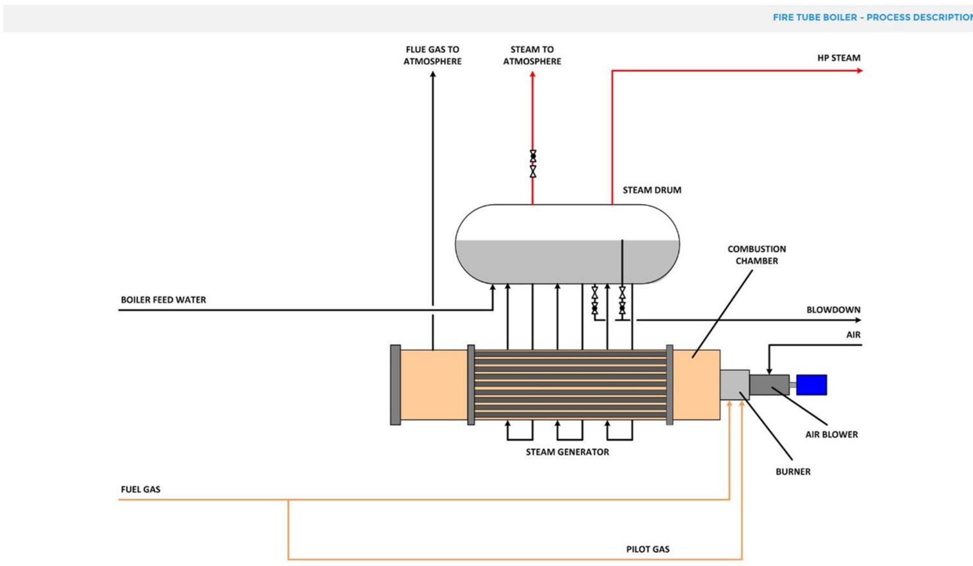
> Saturated steam is produced when water is heated to its boiling point under the prevailing pressure and vaporized
>
> Superheated steam is produced when saturated steam is further heated
>
> Superheating provides additional energy for driving turbines and ensures the steam is less likely to cool and condense in distribution systems

The principal aim of a continuous manufacturing site is to satisfy its steam requirements by generating steam in heat recovery systems.

Fire tube boilers are typically used to supplement steam generated through heat recovery.

To provide operating flexibility, fire tube boilers usually have a relatively small nominal capacity of 1-10 t/h and it’s common to see several of them grouped together with a deaerator.

Water tube boilers are typically used in larger scale steam generation applications, such as co-generated electrical power.



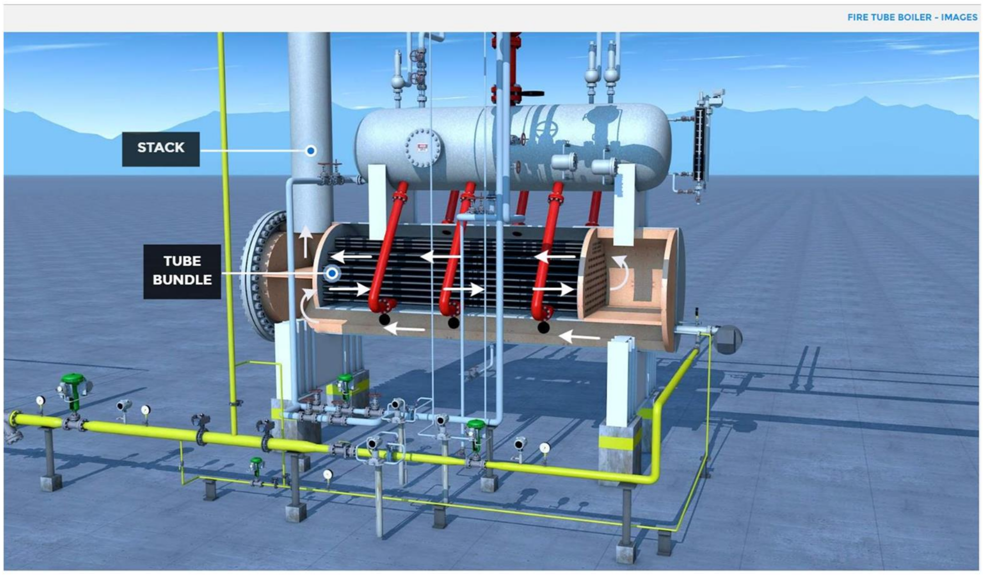
Here, fuel gas is burned in a combustion chamber with air supplied from a blower.

The hot flue gases pass through a tube bundle (called a steam generator), exiting at the far end and passing to atmosphere via a stack.

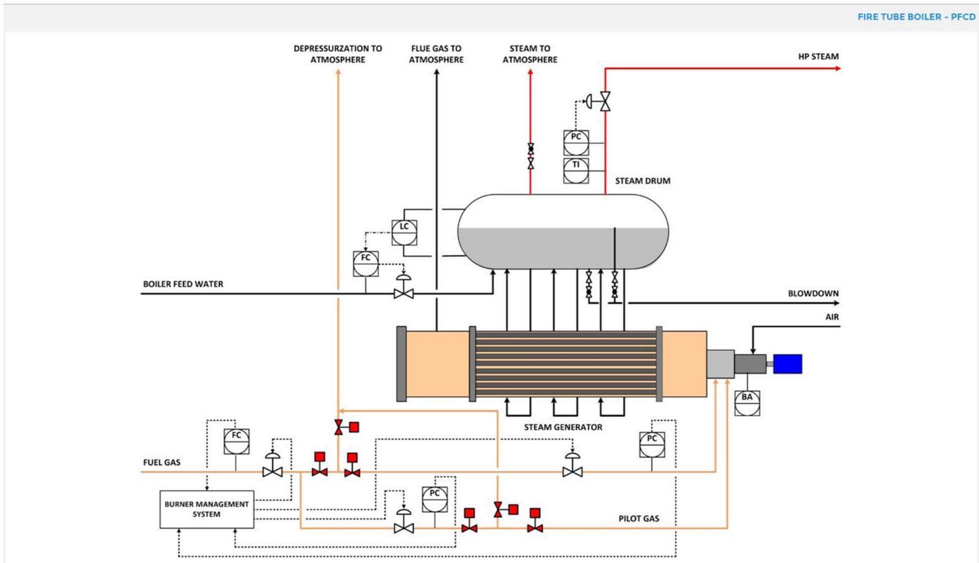
The stack may also have tube bundles for recovering heat from the flue gas before it is vented.

Boiler feed water is passed as makeup to the steam drum where it forms a level.

The boiler feed water circulates over the outer surface of the tubes under a natural, thermosyphon effect, returning to the steam drum where a portion of it flashes to steam which is passed to a steam distribution header.



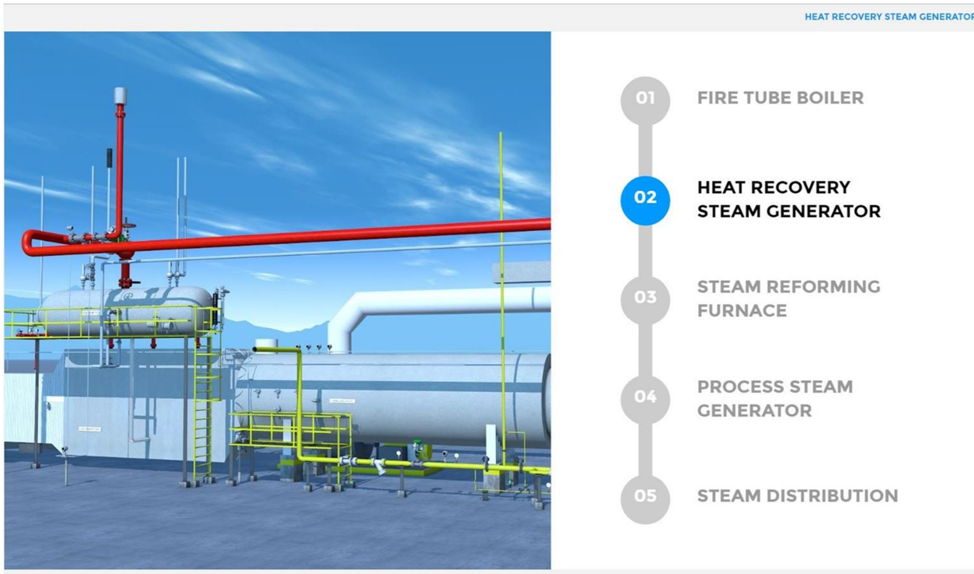
In this application, the burner flame generates hot flue gases that pass beneath the tube bundle, turn at the far end and make two passes through the tubes before exiting to the stack.



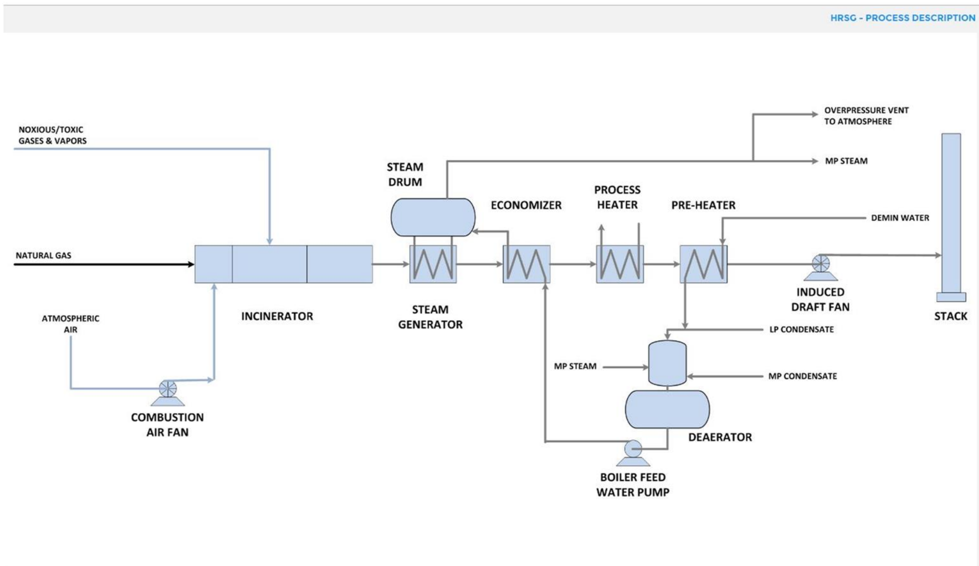
The level in this fire tube boiler is maintained by a level to flow cascade arrangement. Generated steam is passed to a distribution header on pressure control.

The fire side of the boiler is typically monitored and controlled by a burner management system that maintains a continuous pilot flame at the burner and varies the amount of fuel burned to meet the required rate of steam production.

The burner management system also has an automatic shutdown system that trips the fuel source in the event of unstable burner conditions (such as low pressure or a flame-out) that could lead to a firebox explosion or loss of level in the steam drum that could result in overheating and rupture of the tubes.



Next, we'll take a look at a heat recovery steam generator.

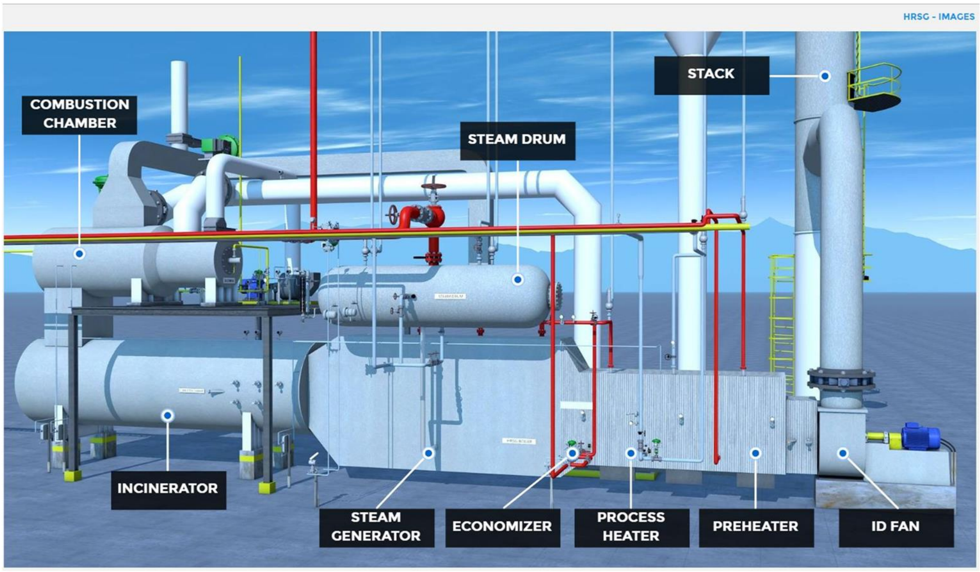


This process flow diagram shows an incinerator that breaks down a mixture of noxious and toxic gases generated in process units by combustion at very high temperature, producing oxides of carbon, sulfur and nitrogen that can be safety vented to atmosphere.

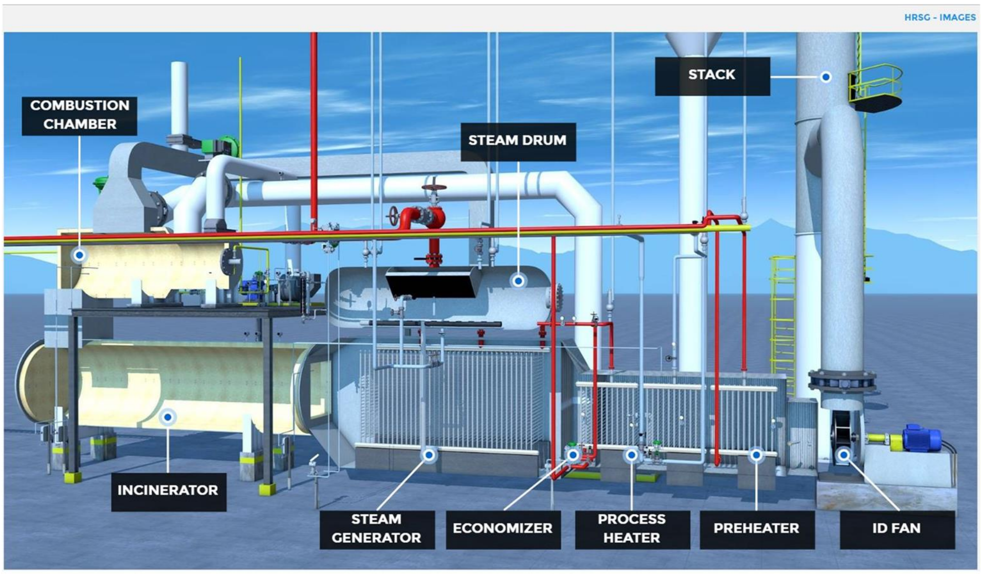
The flue gases exiting the incinerator contain a huge amount of heat that is recovered in a series of tube bundles to generate steam, preheat boiler feed water, heat process water and preheat demineralized water.

Some systems may also have a steam superheater coil located upstream of the steam generator.

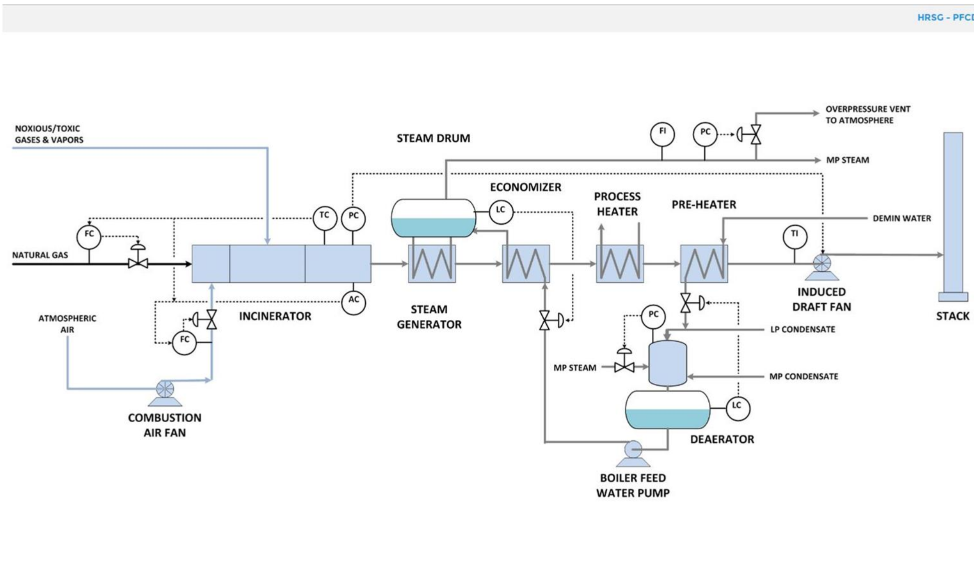
The hot flue gases pass through the shell sides of the heat recovery coils.



This image shows an external view of the incinerator and heat recovery steam generator.



And this cutaway shows the internals.



This process flow control diagram shows typical monitoring and control instrumentation.

On the flue gas side, the incinerator temperature is maintained by a temperature to flow cascade control loop that adjusts the amount of natural gas fuel passed to the burner.

A feed forward signal is passed to a flow controller in the combustion air supply to the burner.

A combined oxygen/combustion analyzer functions as a cascade controller to adjust the flow of combustion air, ensuring there is sufficient excess air for complete combustion and all noxious and toxic compounds are fully combusted.

A pressure controller resets the rotational speed of the induced draft fan.

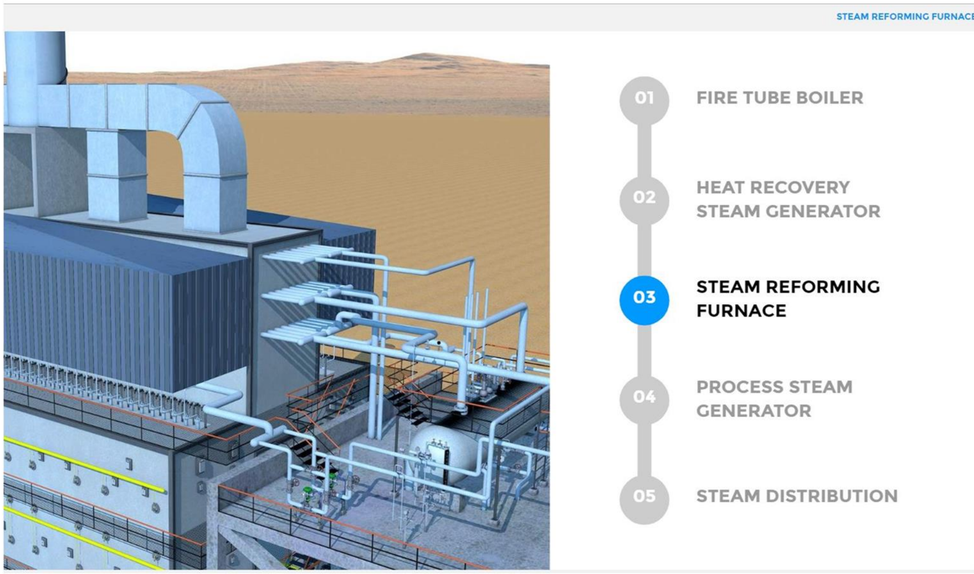
On the water side, preheated makeup demineralized water is drawn into the deaerator on level control.

The stripping section of the deaerator is pressure controlled.

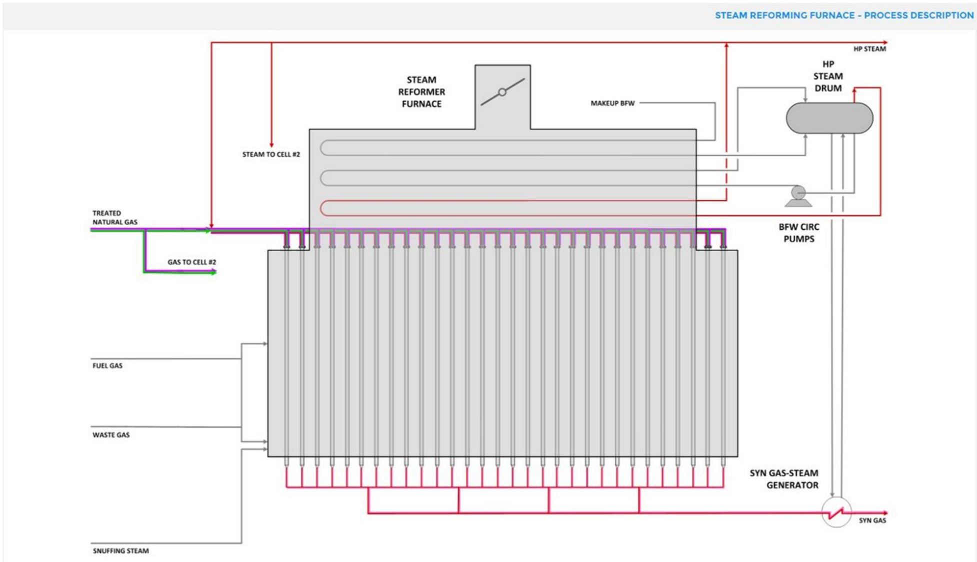
Boiler feed water is drawn into the steam drum on demand by a level controller.

During upset or unstable conditions, an overpressure controller vents any excess steam produced to atmosphere.

This vent is normally closed.



Our next topic is the steam reforming furnace.



The furnace is actually a reactor - the radiant tubes are filled with catalyst. The furnace has two functions:

> To supply the large amount of heat required for the endothermic steam reforming reactions
>
> To generate superheated high pressure steam in-situ, thereby providing one of the steam reforming reactants

Superheated high pressure steam is generated in three coils, located in the convection section:

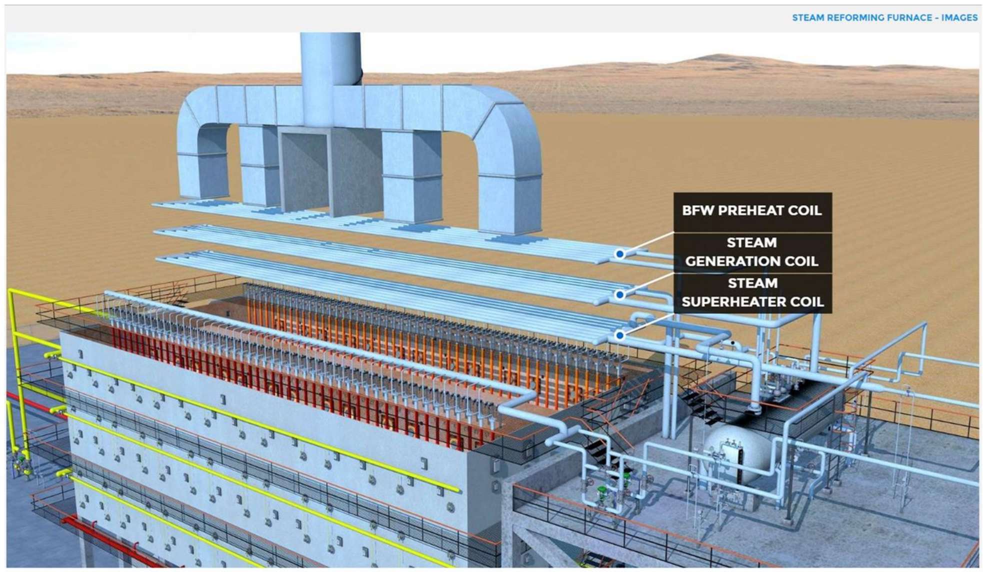
> A boiler feed water preheat coil
>
> A saturated steam generation coil
>
> A steam superheat coil

A synthesis gas steam generator recovers heat from the hot effluent exiting the radiant tubes to generate saturated steam.

So here we have a mix of two boiler classifications:

> In the synthesis gas steam generator, the boiler water circulates through the shell under a natural thermo-syphon effect - like the fire tube boiler you studied earlier

In the convection section steam generation coil, the boiler water flows through the tubes under forced circulation from a pump - this is classified as a water tube boiler

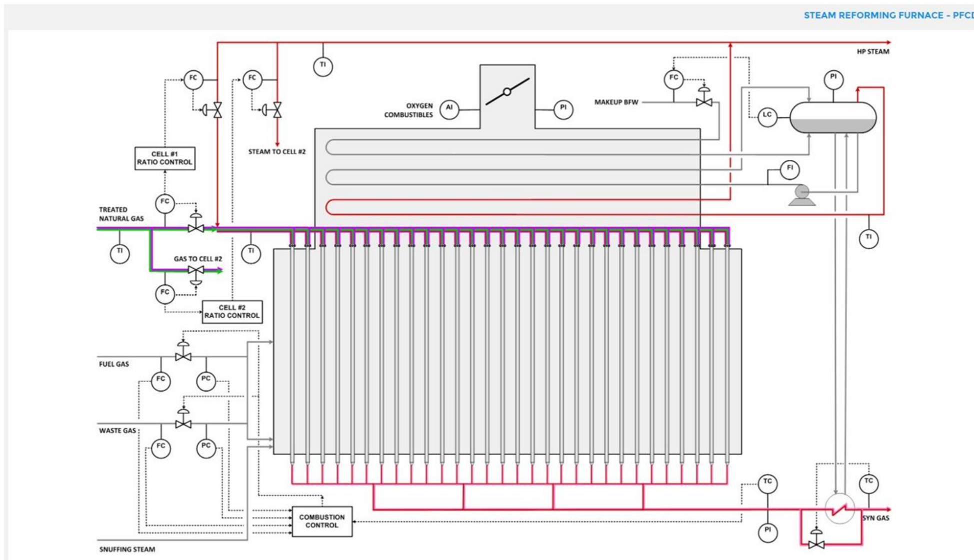


These images show the three convection section coils.

This image shows the natural circulation synthesis gas steam generators.

The forced circulation boiler feed water pumps are shown in the foreground.

This is the high pressure steam drum.



The furnace has three principal control systems:

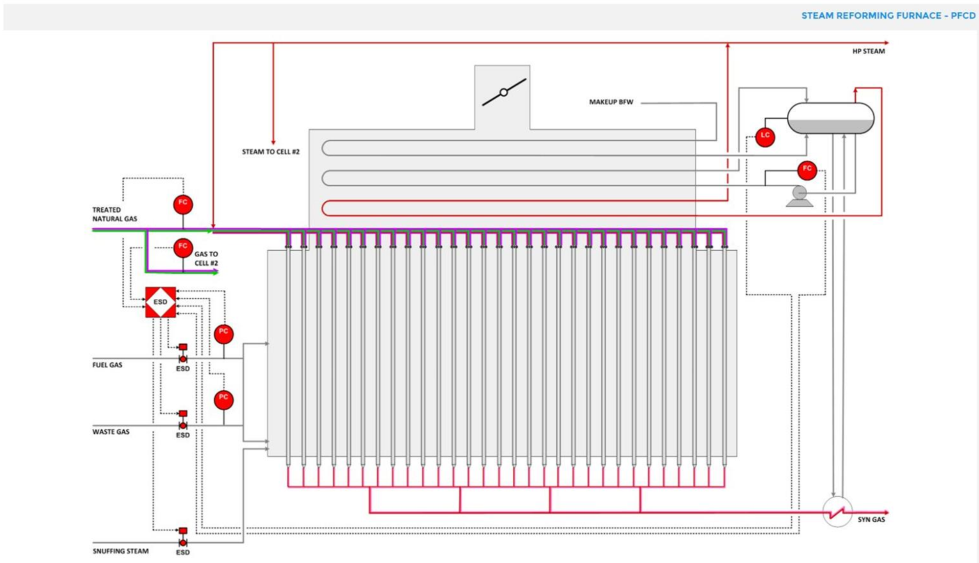
The convection section: A level to flow cascade control loop maintains the level in the steam drum by importing makeup boiler feed water.

The radiant section: The natural gas and steam reactants are flow controlled in a fixed ratio that prevents coke deposition on the catalyst surface.

The temperature of the synthesis gas outlet the synthesis gas steam generator is maintained by adjusting a bypass around the tube side.

The firebox: The burners have two fuels - fuel gas and a waste gas stream from a downstream pressure swing adsorption unit.

The fuels are controlled by a burner management system that maintains the temperature outlet the radiant tubes and with it, the rate of reaction across the catalyst.

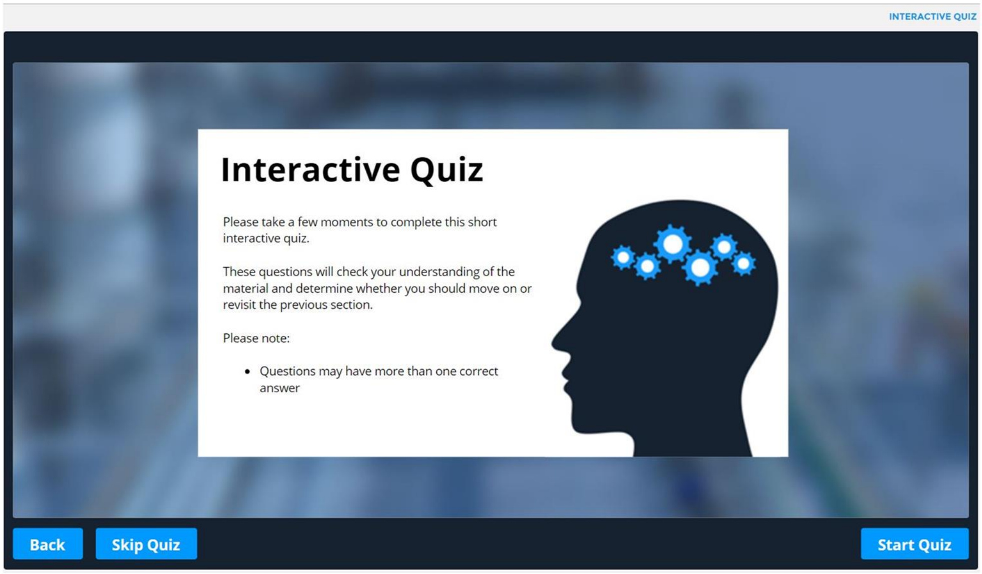


An emergency shutdown system protects the furnace against:

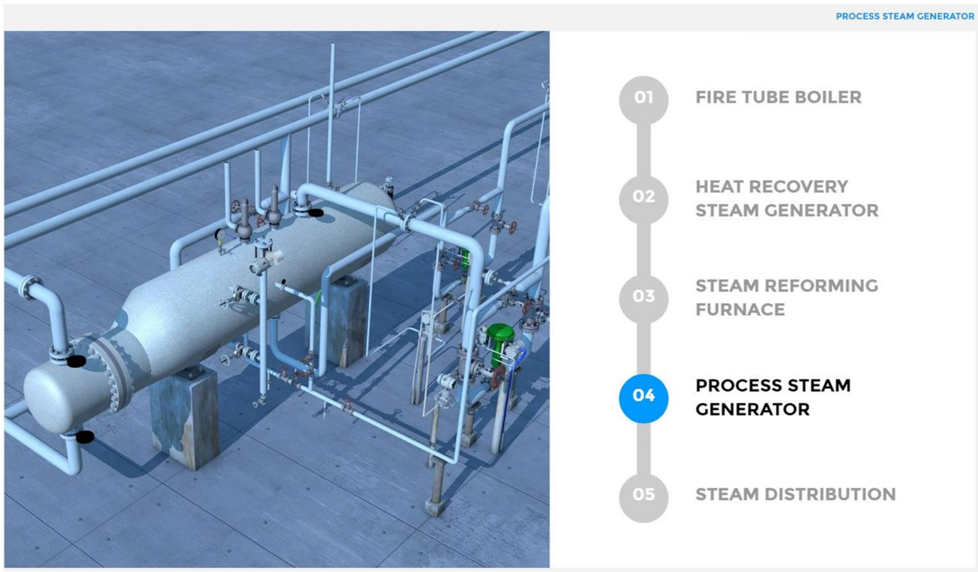
- Loss of flow through the radiant and convection tubes, resulting in overheating
- Loss of level in the steam drum, resulting in pump damage and overheating of the convection tubes
- Loss of burner firing pressure, resulting in burner flame-out and potential firebox explosion

The ESD system isolates the fuels and admits snuffing steam to the firebox.

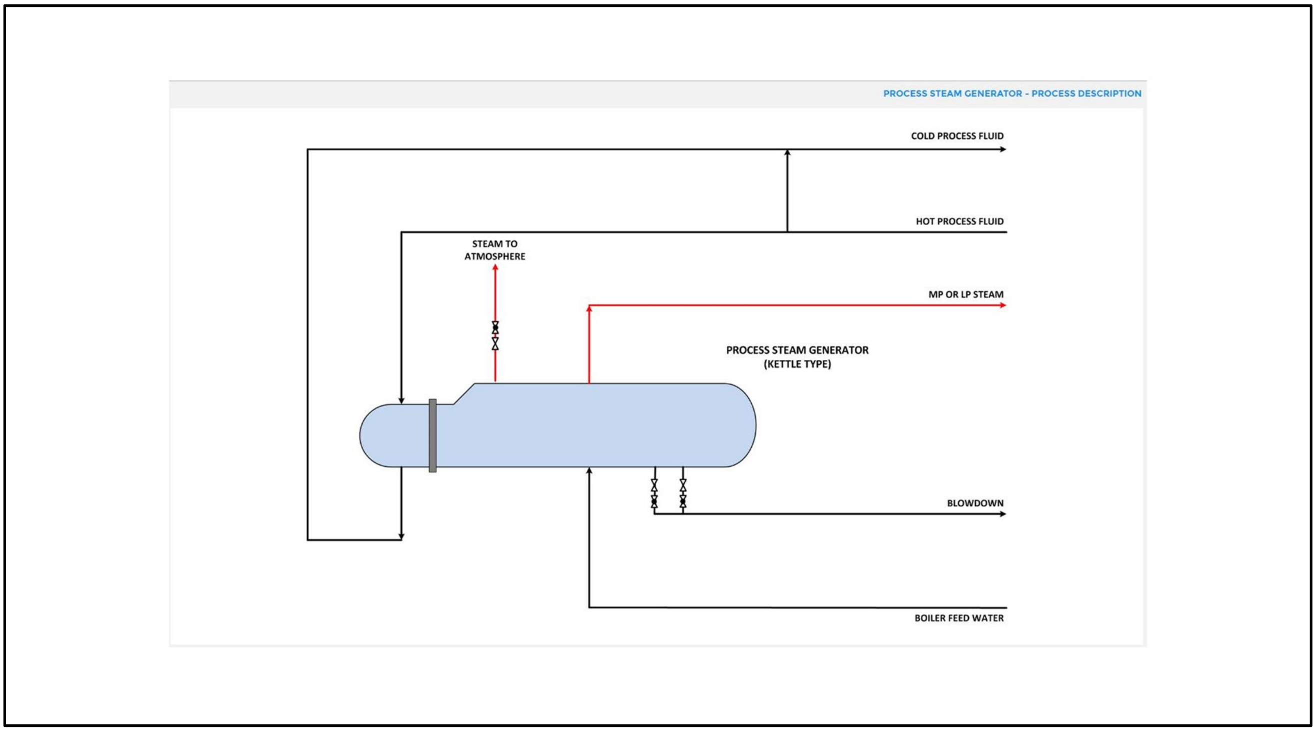
Trip initiators and actuators are shown here.



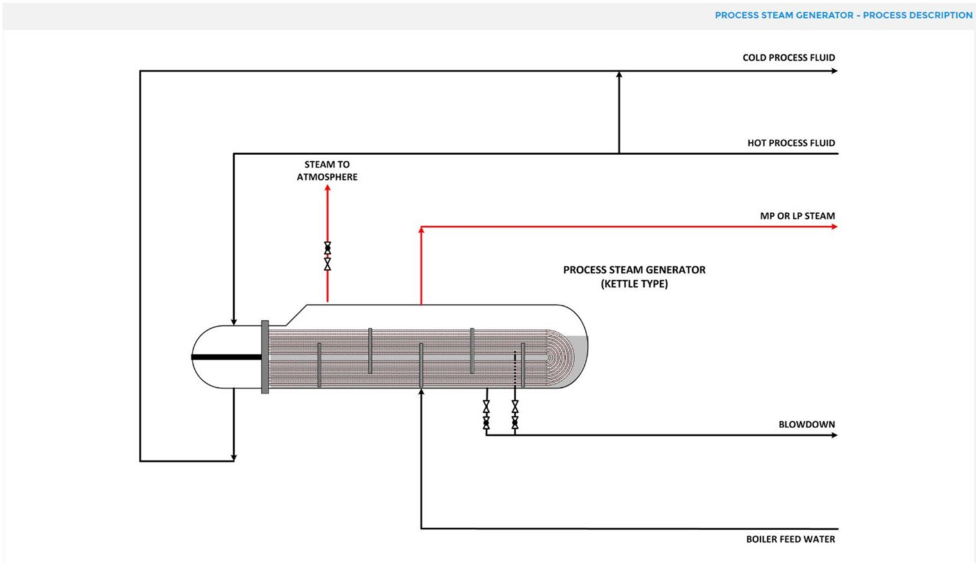
Please take a few moments to complete this short interactive quiz and then click on the 'next' button below when you're ready to move on.



Next, we'll take a look at a process steam generator.



This process flow diagram shows a kettle-type process steam generator that exchanges heat between a hot process fluid and boiler feed water, raising medium or low pressure saturated steam which is passed to a distribution header.

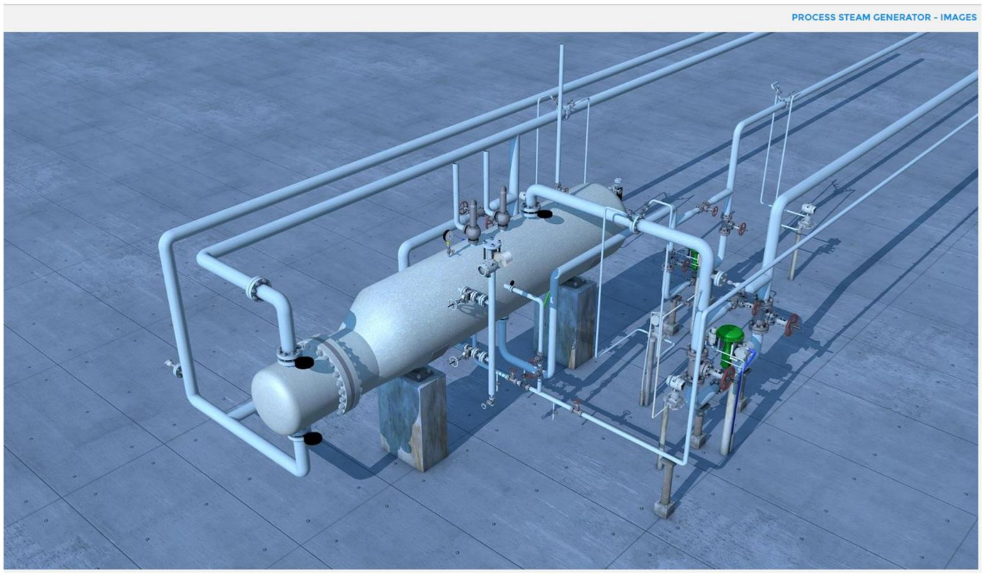


The hot process fluid passes through the tubes, which are immersed in a level of boiler feed water on the shell side. Heat is exchanged and the water boils, producing steam.

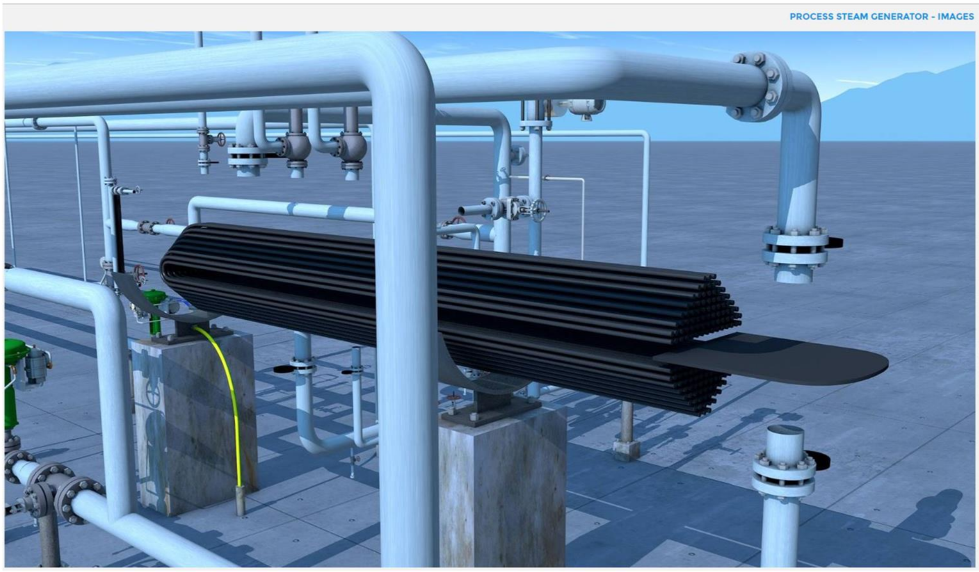
There is an empty space above the water level to allow for steam/water disengagement, avoiding carryover of water into the steam header.

Intermittent and continuous blowdowns are used to control water contaminants.

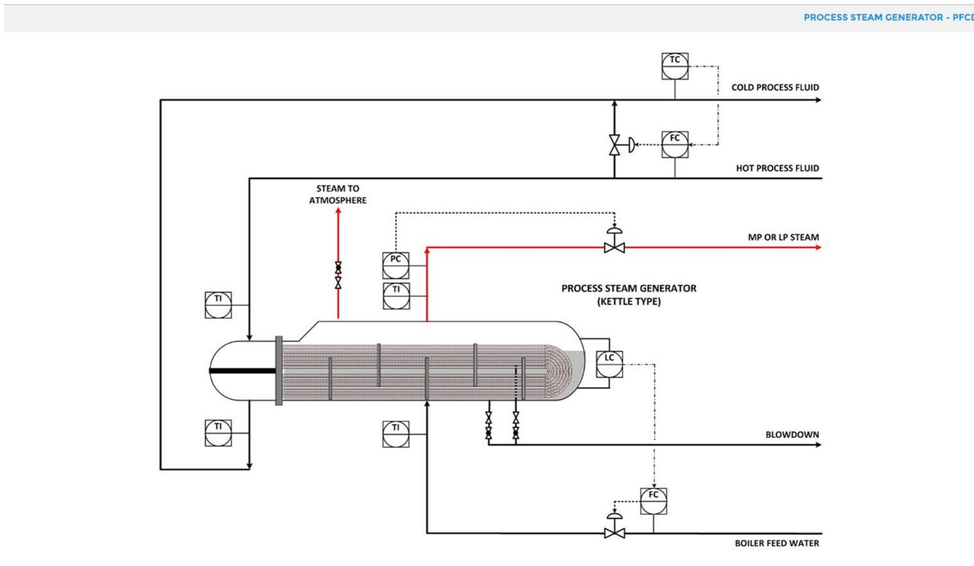
An atmospheric steam vent is used for startup and shutdown operations.



This image shows a typical process steam generator.



This close-up and cutaway show details of the tubes with a horizontal baffle that forces the process fluid to make two passes before exiting.

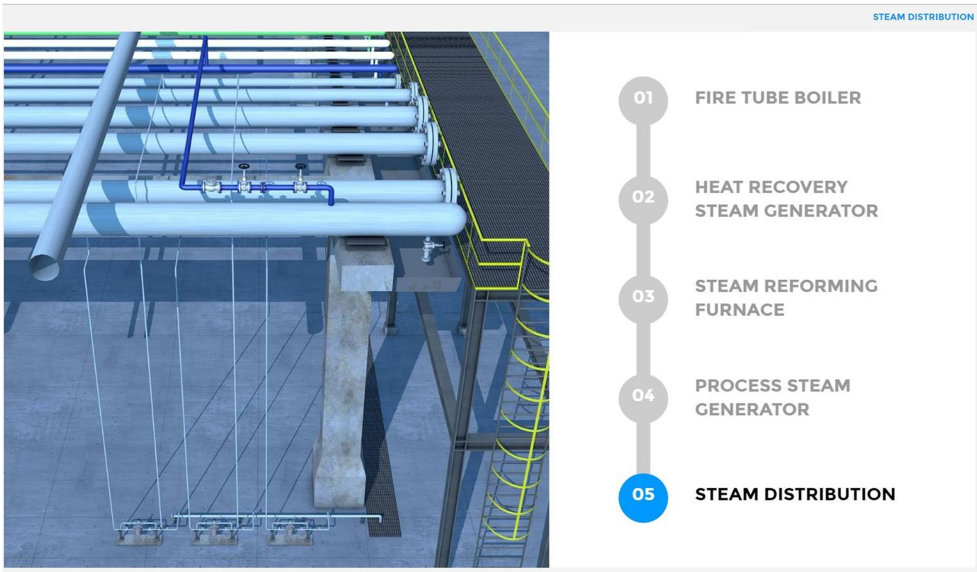


This diagram shows the monitoring and control instrumentation.

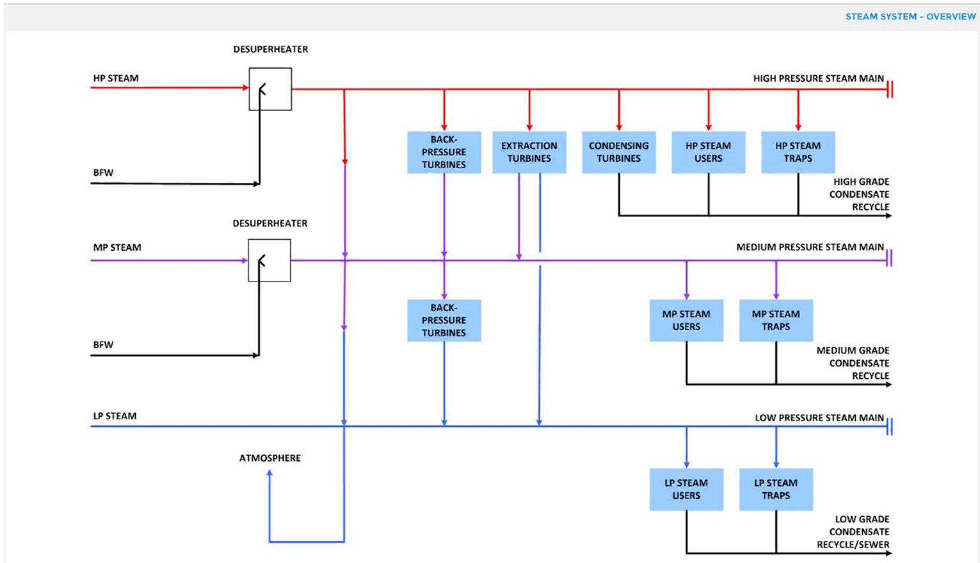
On the tube side, the process fluid outlet temperature is controlled by a temperature to flow cascade loop that adjusts a tube side bypass.

On the shell side, a level to flow cascade loop imports makeup boiler feed water on demand.

The steam generator pressure is maintained by adjusting the amount of steam passed to the distribution header.



In our final topic, we're going to explain how steam that's been generated is distributed to users.



This block flow diagram shows a typical steam distribution system.

There are three steam headers:

High pressure (typically 600 psig or 42 barg)

Medium pressure (usually 200-250 psig or 14-17 barg), and

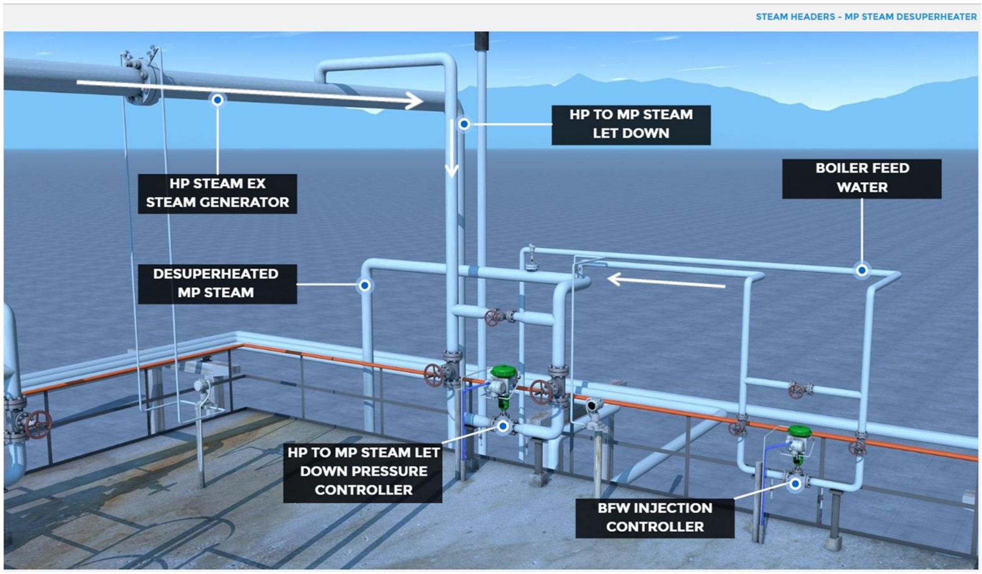
Low pressure steam (which is normally around 100 psig or 7 barg)

High pressure steam is typically superheated, which means it is 120-210ºF or 50-100ºC above its saturated steam temperature.

This is generally good because it reduces the tendency of the steam to cool and condense in distribution headers and steam turbines, resulting in reduced energy efficiency and sometimes mechanical damage.

However, some steam users may place limitations on the maximum supply steam temperature and for this reason some high pressure steam headers have a desuperheating facility where a small amount of cold boiler feed water is injected into the steam to lower its temperature.

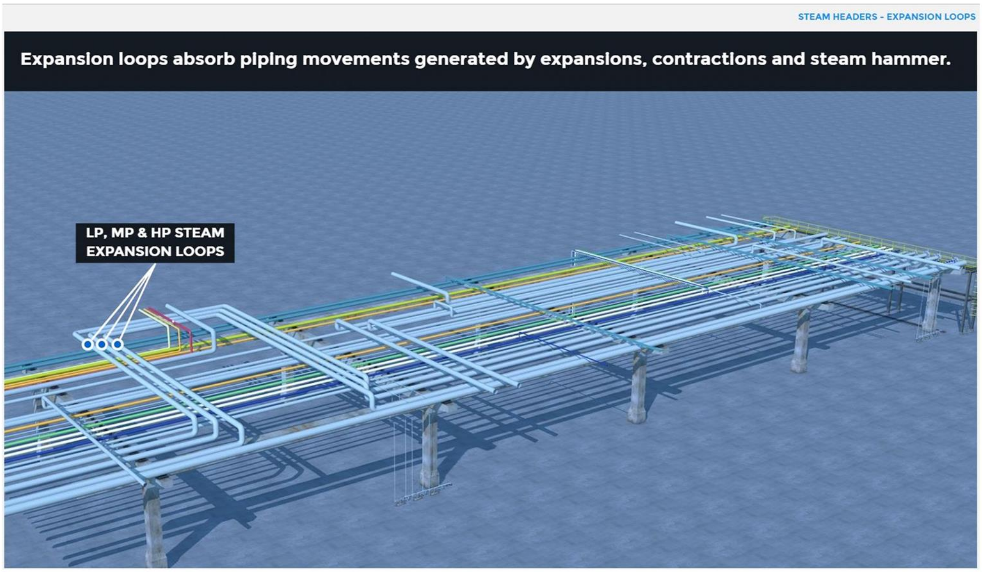
To a lesser extent, medium pressure steam may also have thermal limitations and may also have desuperheating facilities.



This image shows a typical desuperheating facility.

A portion of the high pressure steam generated on this plant is let down in pressure and passed as makeup to the medium pressure steam header.

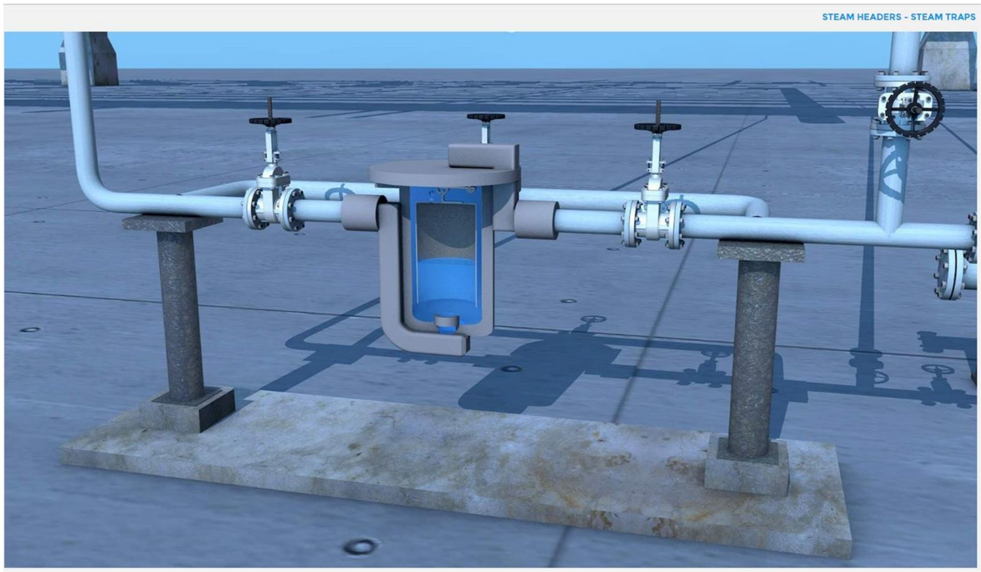
Boiler feed water is injected into the let down high pressure steam to control its temperature.



This section of piperack carries three steam headers - high pressure, medium pressure and low pressure.

Expansion loops are located at intervals along the piperack to absorb piping movements generated by expansions, contractions and steam hammer.

Steam traps are often positioned near to expansion loops as these are often a common location for condensate formation and accumulation. We're going to discuss these next.



Steam traps are devices that remove condensate from steam headers as it is formed, preventing it from accumulating and causing a condition referred to as ‘steam hammer’.

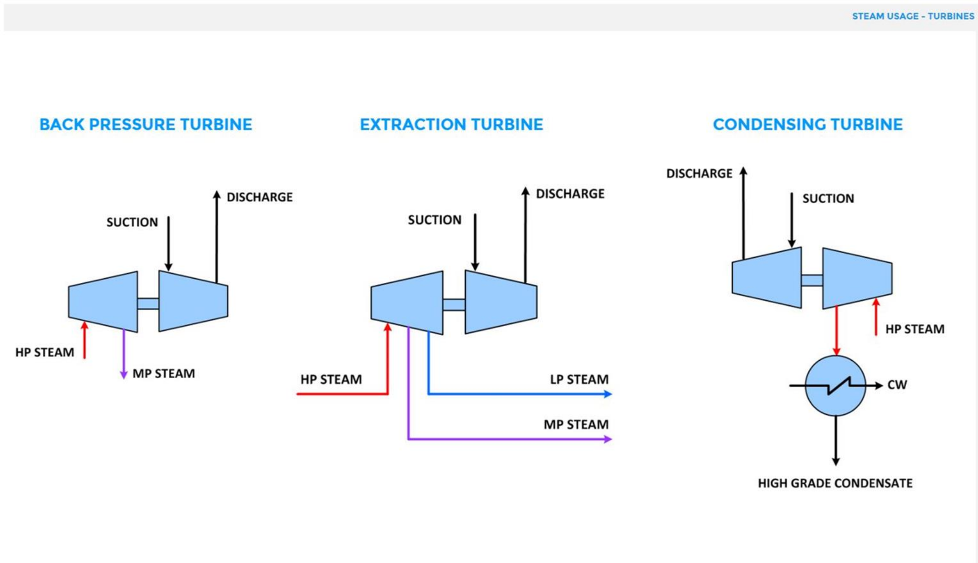
Steam hammer is typically accompanied by loud banging noises caused by the sudden drop in pressure as the steam comes into contact with the condensate and some of the steam condenses.

Steam hammer is a potentially dangerous condition that can cause extreme movement of steam headers, overstressing pipework and fittings - serious cases of steam hammer can result in mechanical damage.

Operators are required to regularly check that steam traps are functioning correctly, particularly if banging noises can be heard in the vicinity of steam headers.

High pressure and medium pressure condensate removed from the respective steam headers by steam traps is typically returned to the deaerator.

Low pressure condensate may also be recovered or if it is contaminated, it may be rejected to the sewer.



Next, we'll take a look at some typical uses for steam, starting with steam turbines.

There are three types of steam turbine commonly in use:

The back-pressure turbine

The extraction turbine

The condensing turbine

We'll use an example of a steam turbine driven centrifugal compressor to illustrate these.

In the back-pressure turbine, the high pressure is used to drive the machine, exhausting into the medium pressure steam main, which then uses some of the energy still remaining in the steam.

The extraction turbine works on the same principle as the back-pressure turbine with an additional feature - a portion of the steam is drawn off (or extracted) before it reaches the final stage.

The extracted steam typically passes to the medium pressure header, where it is used to drive other lower powered turbines.

The exhaust steam passes to the low pressure header where it is used for services such as fire fighting media, low grade heating, cleaning and atomizing fuel oil.

In the condensing turbine, the exhaust steam passes to a vacuum condenser where all remaining low-grade heat is rejected to the cooling water system.

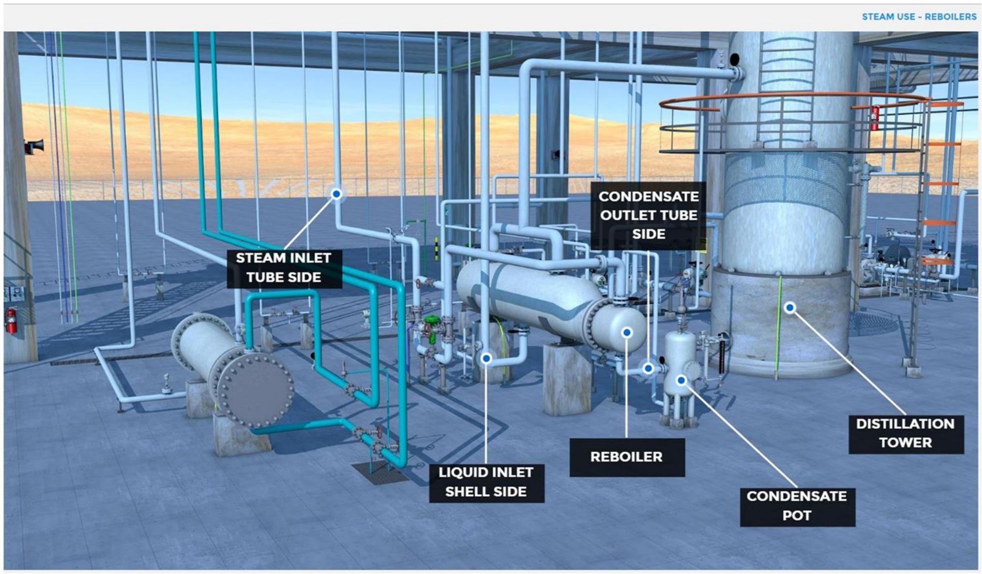
The vacuum allows the turbine to be operated with an extremely low exhaust pressure, thereby maximizing the energy available in the drive steam and making this the most thermally efficient type of steam turbine.

Condensing the exhaust steam enables it to be recovered as high grade condensate that can be re-used for steam generation.

Many manufacturing facilities spread the energy demand between steam and electric power so that they have the ability to respond to a shortage or outage of either.

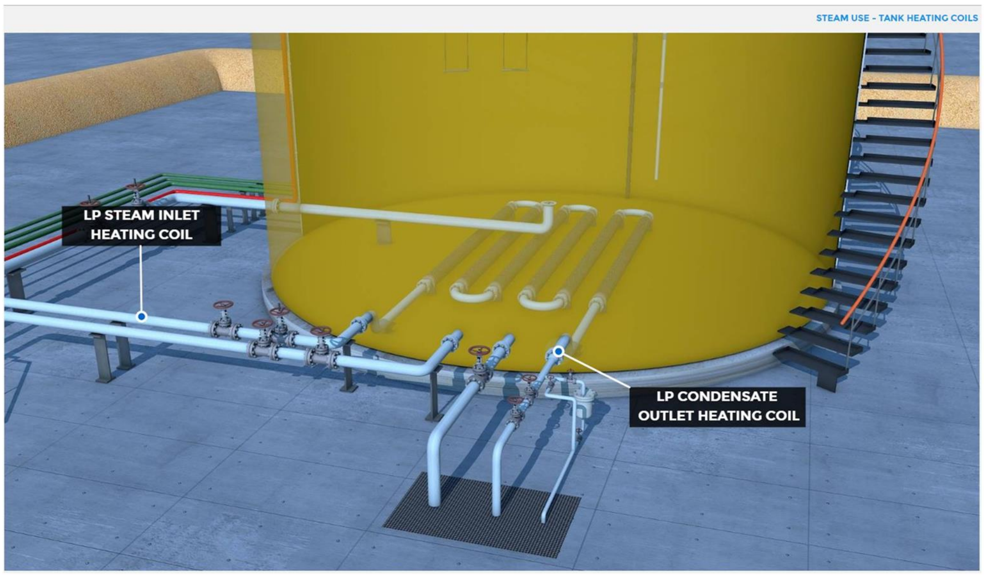
They do this by having a steam turbine and an electric motor driver in each set of pumps (as shown here).

In these images, steam is supplied to a set of three ejectors that are pulling a vacuum on a tower.

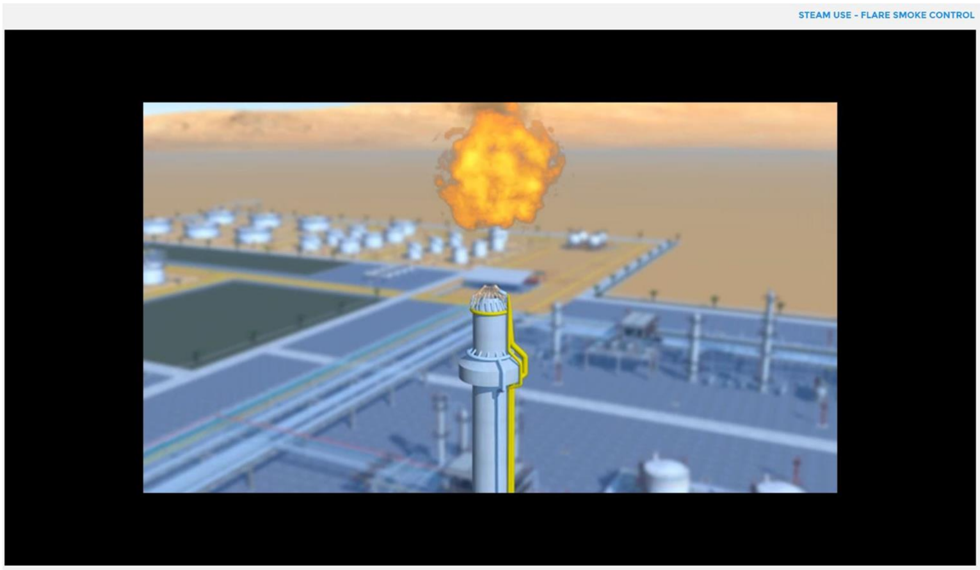


This tower has a thermosyphon reboiler. The heat source is medium pressure steam, which is passed through the tube side where it is condensed - condensate is collected in the condensate pot and returned to the deaerator.

Liquid, drawn from the bottom tray of the tower, passes to the shell side where it is heated by the steam, returning to the underside of the tower's bottom tray as vapor.

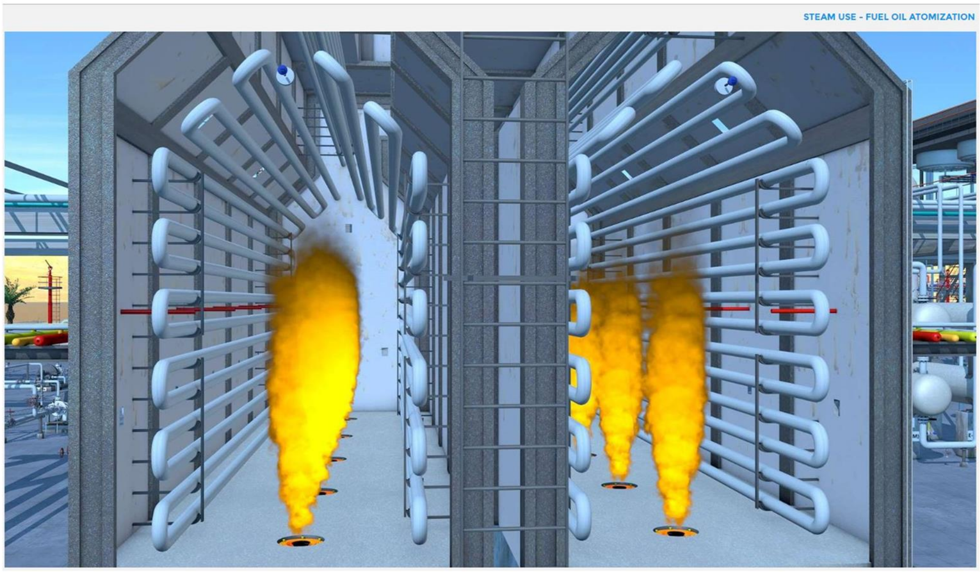


The contents of this tank can solidify if not kept warm. The tank contents are heated by a submerged steam coil. Steam condenses in the coil and is withdrawn by a steam trap.



Here, low pressure steam is being used to atomize liquid droplets as they exit this flare tip.

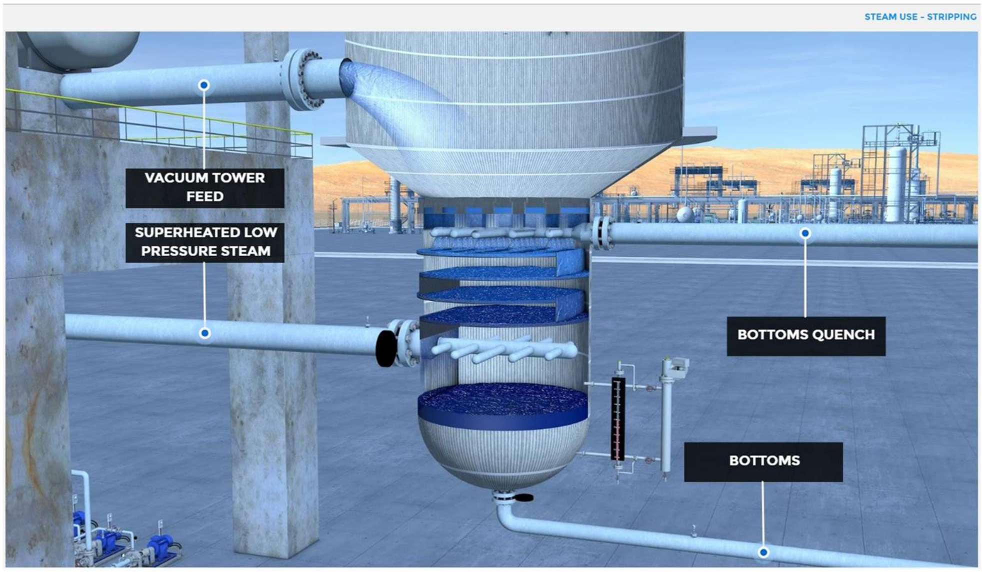
Atomization breaks up the droplets so that they can be burned completely, preventing smoky flames, which are an environmental nuisance.



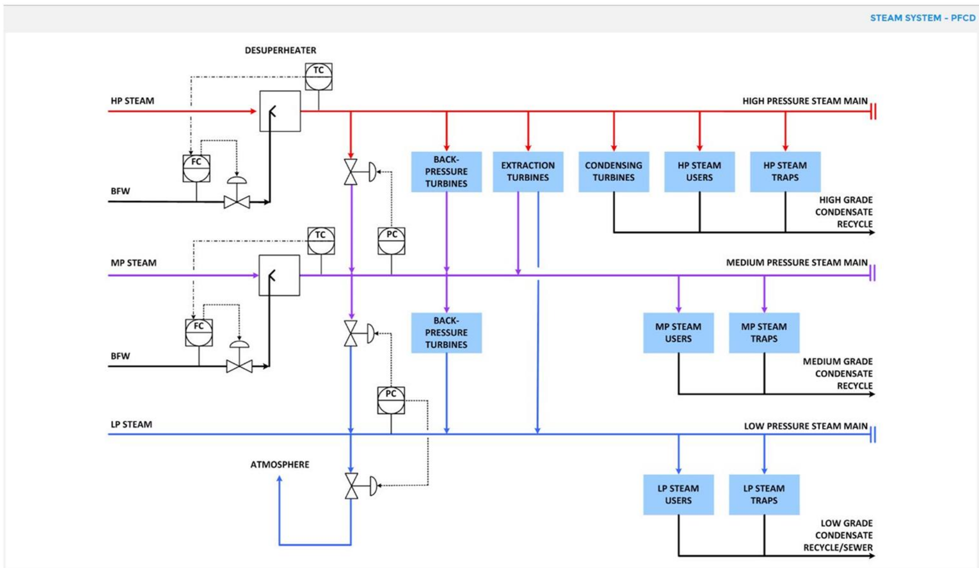
Similarly, the fuel oil being combusted in these burners is being atomized by low pressure steam into small droplets that then vaporize, ensuring smokeless combustion.

In the first image there is insufficient atomizing steam and the flames are smoky.

This is corrected in the second image by increasing the steam.



In this image, the liquid collecting on the lower trays of this vacuum tower is being stripped of light ends by live superheated steam.



This process flow control diagram shows the controls for a typical steam distribution system.

Steam header temperatures are controlled by adjusting the flow of boiler feed water to desuperheaters.

Steam supply is determined by the amount produced by process steam generators with the balance taken up by adjusting the load on package boilers.

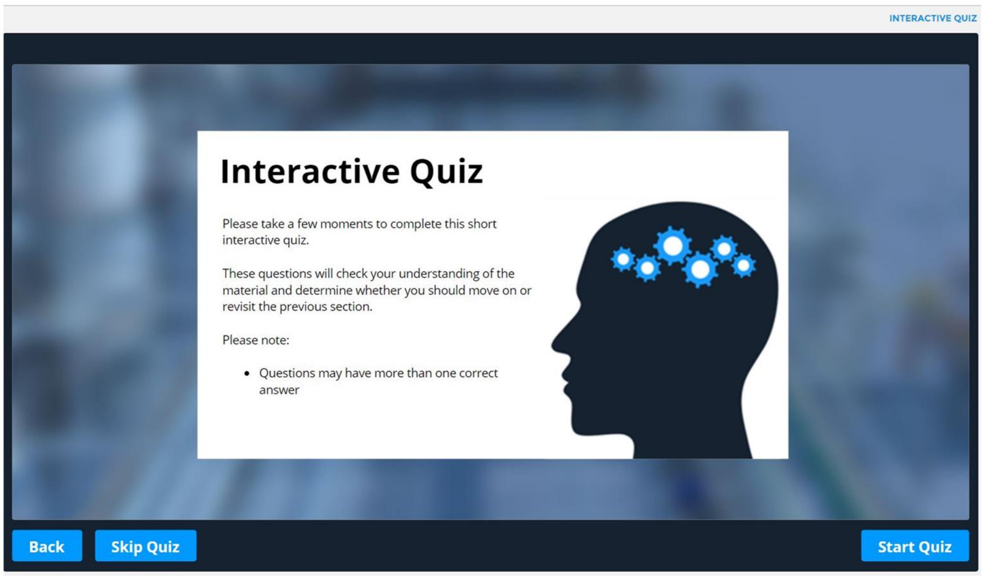
The steam demand is adjusted by placing turbines in service or taking them out of service to match the steam supply.

Small trim adjustments to header pressures are made by pressure controlled letdown between the HP, MP and LP headers.

Excess LP steam is vented to atmosphere short-term while longer term adjustments are made to the supply.

Venting steam to atmosphere is wasteful of energy.

This image shows a typical steam pressure let down station.



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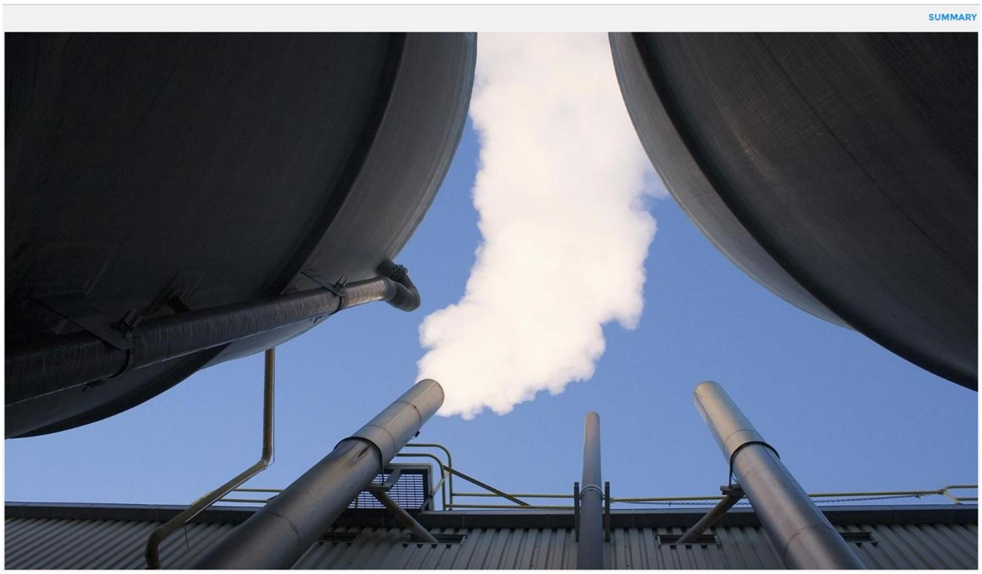


To summarize then:

Steam is generated by recovering waste heat from process streams and hot flue gases in items of equipment such as heat recovery steam generators, steam reforming furnaces and process steam generators.

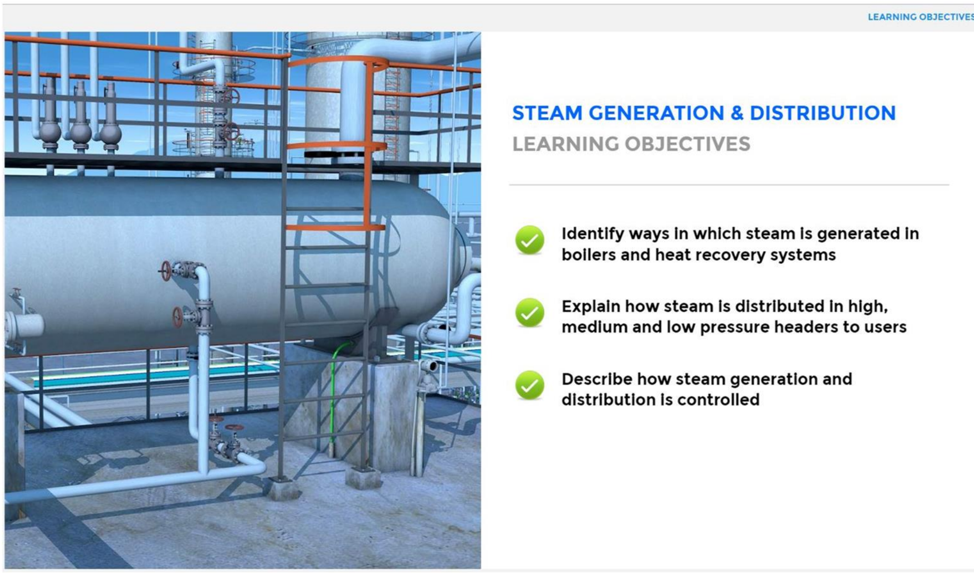
Where steam cannot be raised by heat recovery, it is generated in fire tube or water tube boilers.

Steam is distributed to users by high pressure, medium pressure and low pressure steam headers.

With the possible exception of contaminated low pressure condensate, most condensate is returned to the deaerator.

The steam supply has to meet the steam demand. Adjustments to supply are made by varying the amount of steam generated in fire tube and water tube boilers.

Adjustments to demand are made by switching turbines in or out of service and by letting down steam from HP to MP and LP headers.



And that completes this module. Let's briefly recap your learning objectives. By now, you should be able to:

Identify ways in which steam is generated in boilers and heat recovery systems

Explain how steam is distributed in high, medium and low pressure headers to users

Describe how steam generation and distribution is controlled

You can now close this module.