A basic introduction to steam

steam

FOR HOT, COLD, MOIST AND DRY, FOUR CHAMPIONS FIERCE. STRIVE HERE FOR MASTERY

steam

Milton 1666

Steam Wonderful Steam

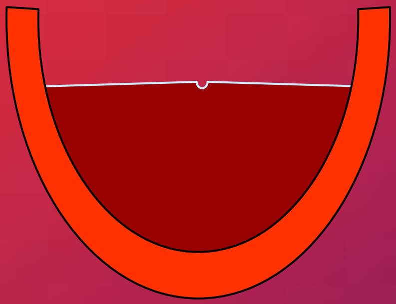
- Very high heat content
- Recyclable
- Clean, non toxic
- Biodegradable
- Easy to distribute
- Easy to control

Steam Wonderful Steam

The magic of steam is that pressure and temperature are directly related, it is therefore easy to control temperature by controlling pressure.

It is the ideal way to provide exactly the right temperature and thus deliver the right amount of energy for a wide number of applications.

Steam Wonderful Steam



An application demands a precise temperature throughout the process.

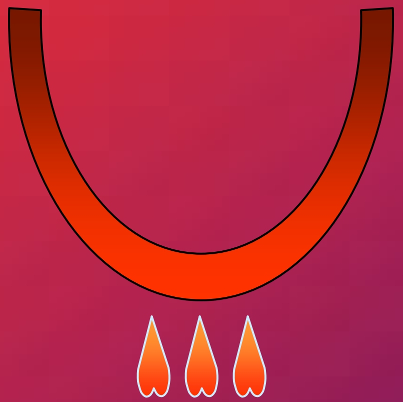
An example might be cooking toffee in a cooking pan.

Too cool and the toffee isn't cooked.

Too hot and the sugar will burn.

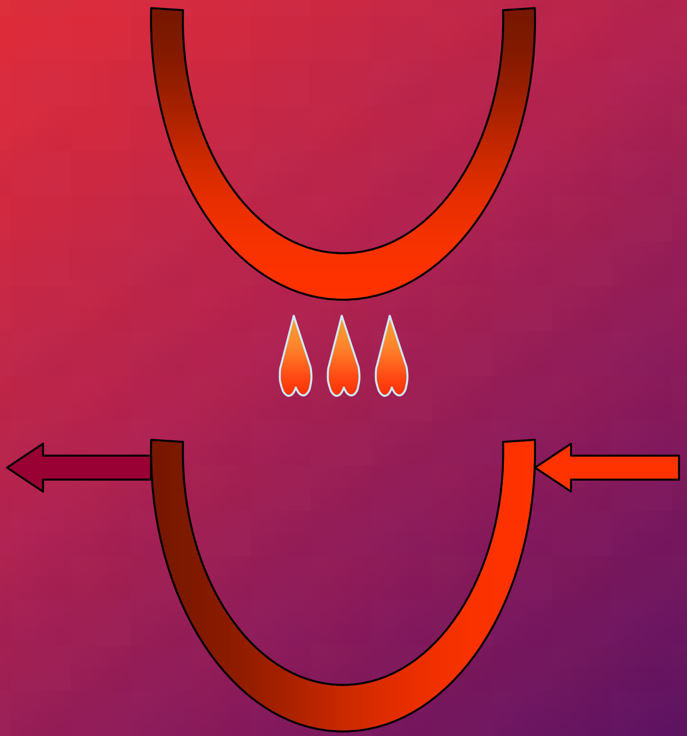
Steam Wonderful Steam

A direct source of heat such as a gas flame would create hot spots.



Steam Wonderful Steam

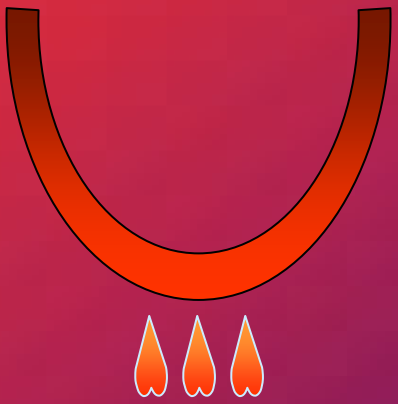
A direct source of heat such as a gas flame would create hot spots.



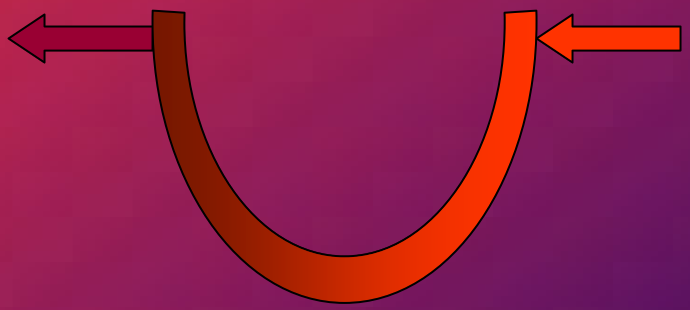
With a thermal fluid, oil, or hot water, a temperature gradient would exist across a heat exchanger as the temperature was given up.

Steam Wonderful Steam

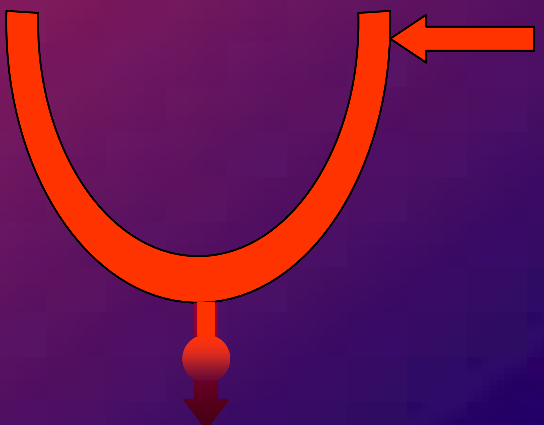
A direct source of heat such as a gas flame would create hot spots.



With a thermal fluid, oil, or hot water, a temperature gradient would exist across a heat exchanger as the temperature was given up.



Steam provides the answer. If the process requires a precise temperature, all that is required is to control the pressure accurately.

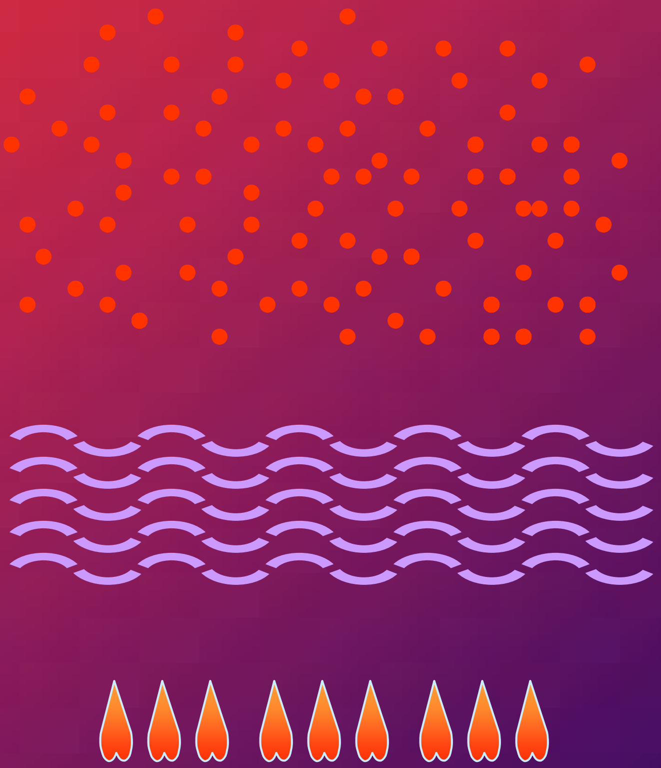


Sensible Heat & Latent Heat

To understand this relationship between temperature and pressure, one needs to understand the concept of ‘Sensible heat’ and ‘Latent heat’

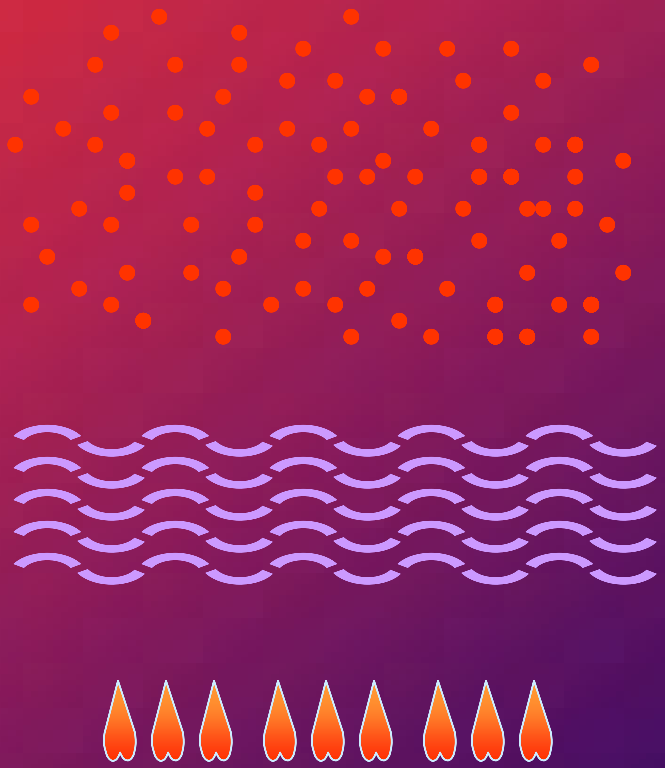
Sensible heat can be defined as the energy required to raise a given mass of a liquid to it’s boiling point.

Latent heat is the amount of energy required to change that same mass of liquid to a vapour.



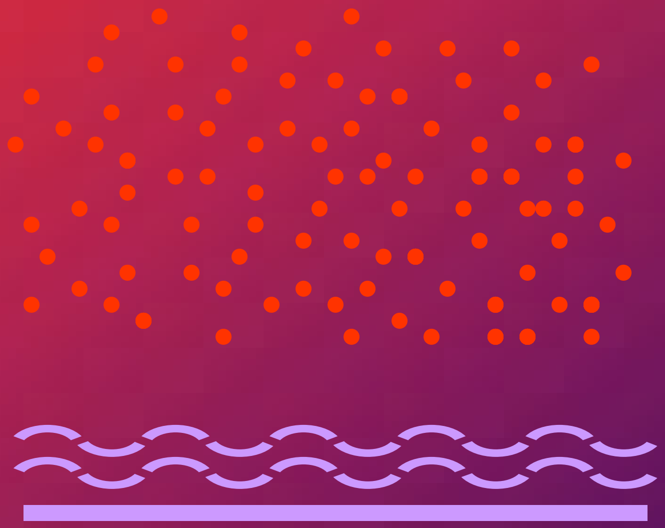
Sensible Heat & Latent Heat

In simple terms, latent heat is the energy required make the molecules of water overcome the mutual attraction that kept them together as a liquid.



Sensible Heat & Latent Heat

The liberated molecules retain this added latent energy only giving the latent energy up as the molecules come together as water again.



Sensible Heat & Latent Heat

Water boils at 100 Celsius at atmospheric pressure

The ‘sensible’ energy in the water at 100 Celsius at atmospheric pressure is 419 kilo Joules per kilogram.

Sensible Heat & Latent Heat

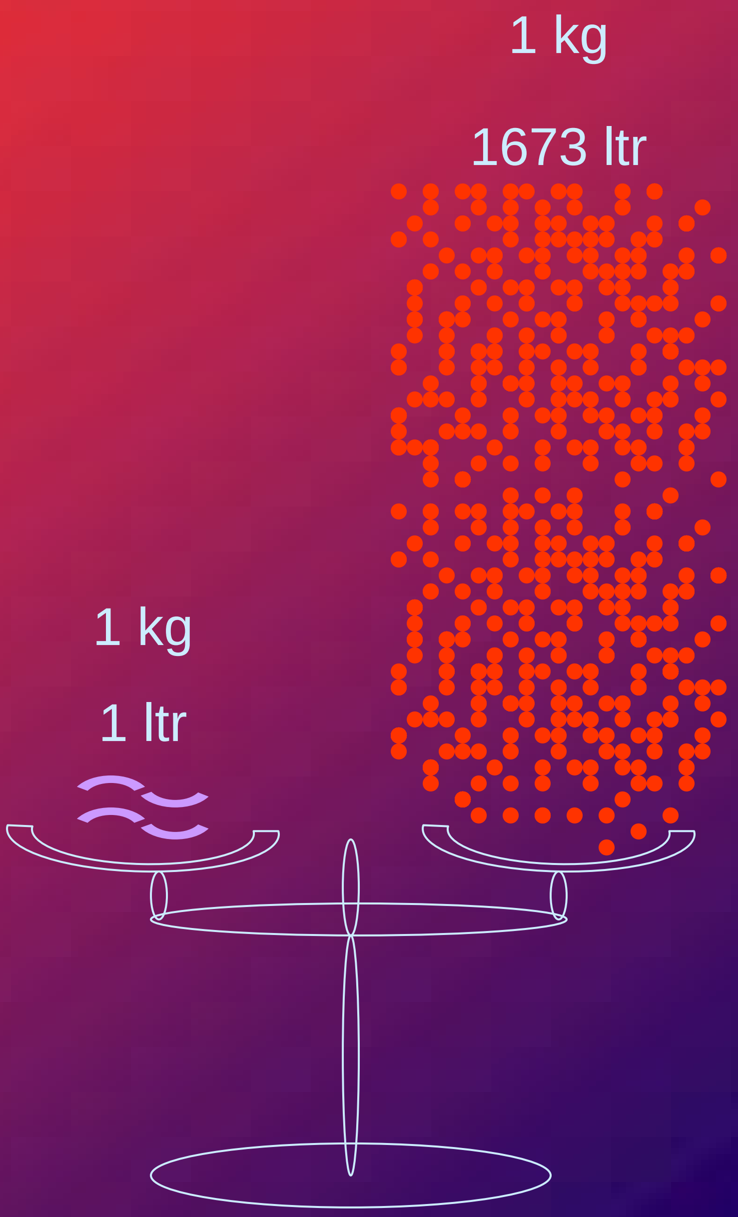
The additional ‘latent’ energy required to turn this boiling water into the dry gas called steam is 2257 kilo joules per kilogram.

The total energy in the steam is 2675 kilo Joules per kilogram.

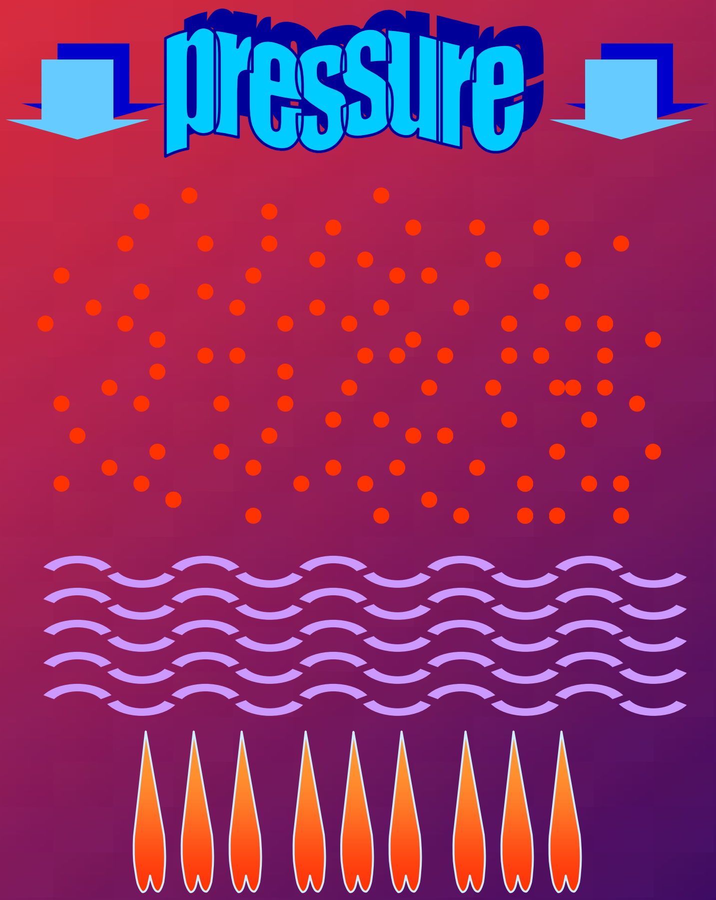
Sensible Heat & Latent Heat

The other major change in our kilo of water is that at 100 Celsius it had a volume of just over 1 litre.

When converted to steam it has a volume of 1673 litres !.



Sensible Heat & Latent Heat



If the pressure is increased, it will require an increase in the sensible heat, in order to liberate the molecules of water .

Sensible Heat & Latent Heat

At a 10 bar static pressure, water's boiling point is 184 Celsius, it would require a 782 kilo Joules of heat energy to bring it to boiling point and an additional 2008 kilo Joules of energy to change it all into a dry saturated vapour.

The total energy is 2790 kilo Joules per kilogram

Sensible Heat & Latent Heat

If only 90% of the extra energy is added, then only 90% of the water will be turned into steam

Sensible Heat & Latent Heat

Remember that during this process of chemical change from a liquid to a vapour, our kilo of water has remained at a constant temperature.

Similarly, having produced a kilo of steam, it will remain at a constant temperature until we have condensed all of the steam back to water and extracted all of the latent heat.

Sensible Heat & Latent Heat

Control the pressure

very accurately

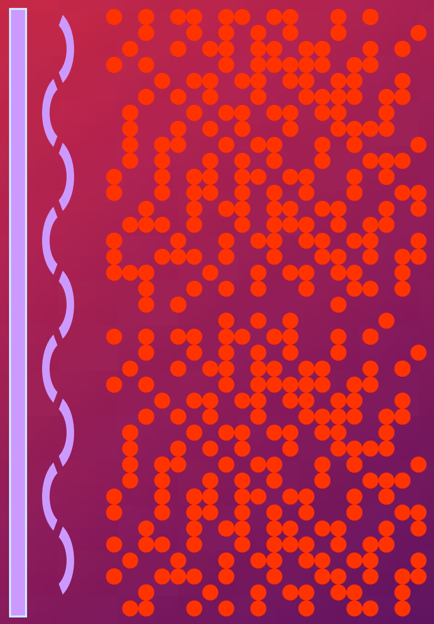
The temperature also will be controlled

very accurately.

Sensible Heat & Latent Heat

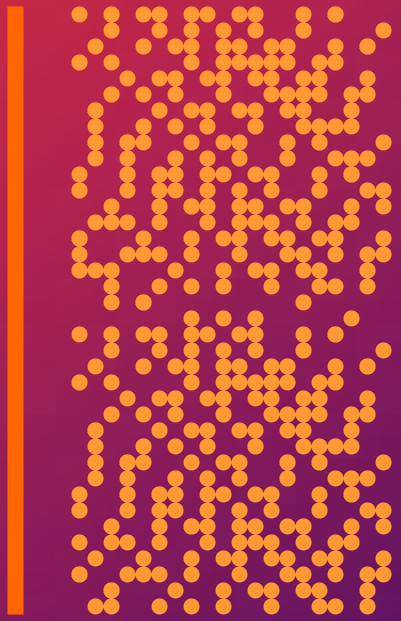
When the steam hits a cool surface, the latent heat is given up and the steam turns back to water

The resulting condensate being returned to the boiler for re-use.



Sensible Heat & Latent Heat

When steam as a dry vapour hits a hotter surface, then the steam can get hotter than it's saturation temperature.

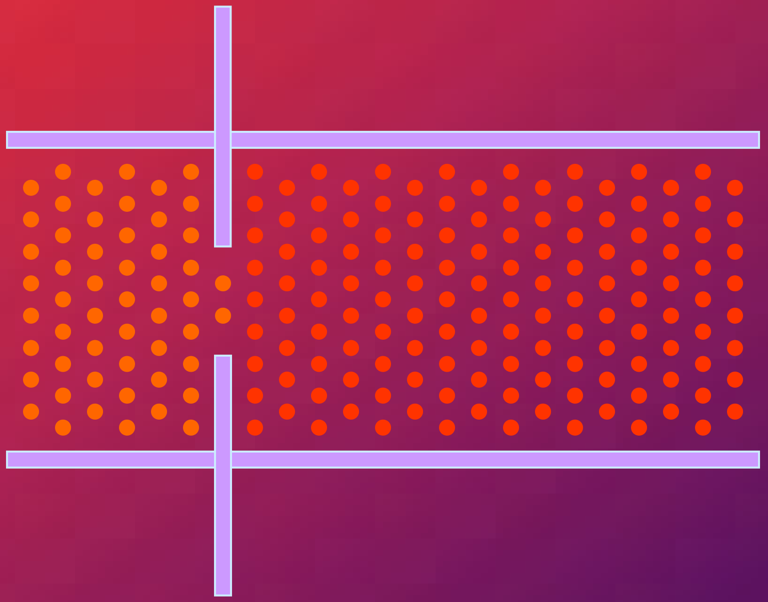


The result is superheated steam

Superheated steam is most often produced by passing the steam through a second heat exchanger in the boiler.

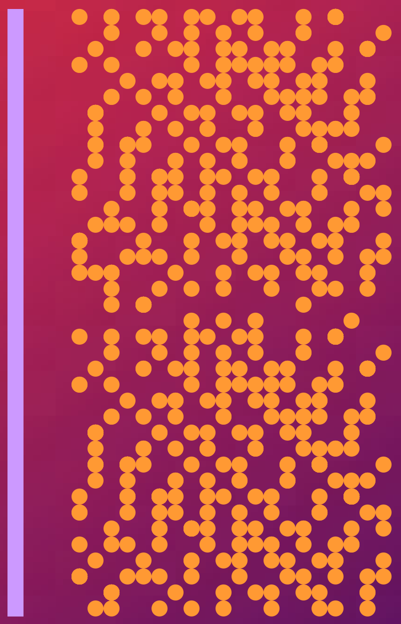
Sensible Heat & Latent Heat

Superheated steam will also be produced if the pressure of dry saturated steam is reduced by a restriction orifice or pressure reducing valve.



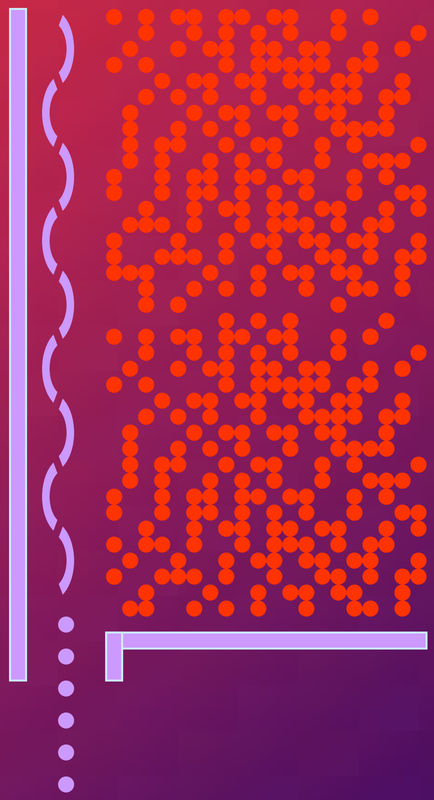
Sensible Heat & Latent Heat

Superheated steam is desirable in power plant such as steam turbines and may be useful in reducing condensate problems in distribution but is undesirable in heat exchange applications where it gives up it's temperature more reluctantly than saturated steam.



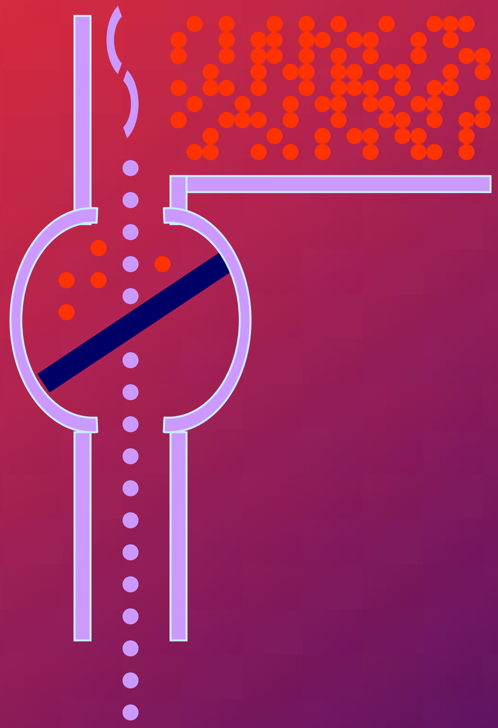
Sensible Heat & Latent Heat

Having used the latent heat of the steam, we are left with condensate and it’s sensible heat.



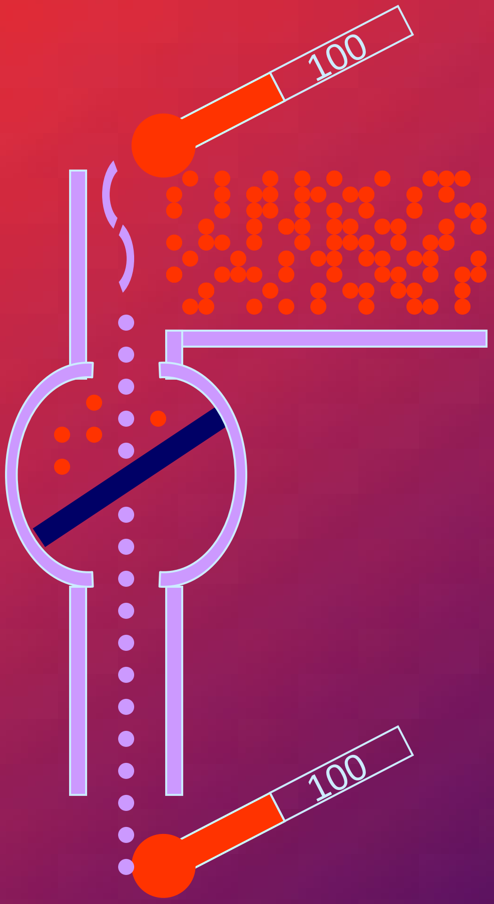
Sensible Heat & Latent Heat

The condensate drains into the steam trap where it is separated from the steam



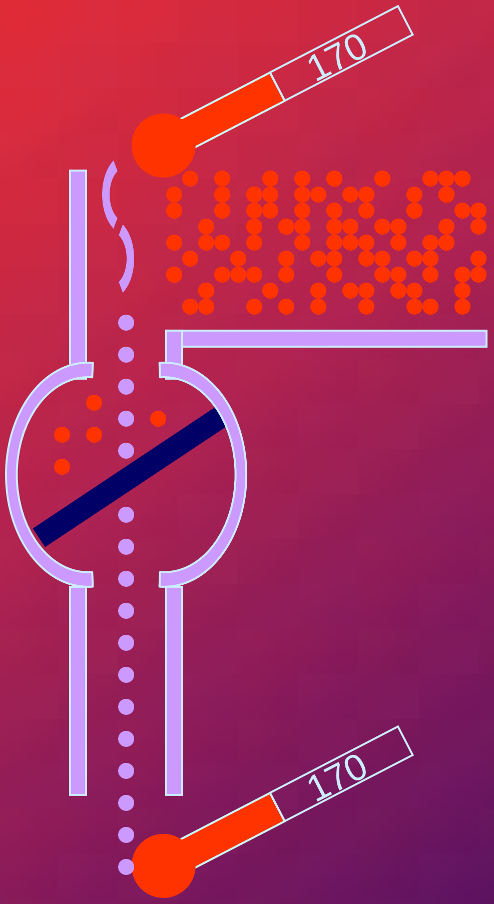
Sensible Heat & Latent Heat

Condensate being released through a steam trap is at atmospheric pressure, it's temperature will be 100 Celsius, and it will contain 419 kJ/kg of sensible heat.



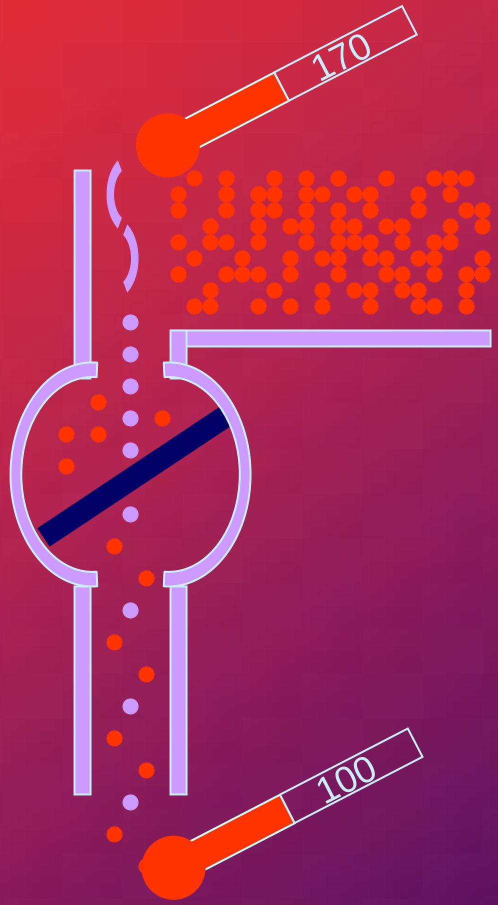
Sensible Heat & Latent Heat

If the condensate being released through a steam trap is at 7 bar gauge, it's temperature will be 170 Celsius, and it will contain 721 kJ/kg of sensible heat.



Sensible Heat & Latent Heat

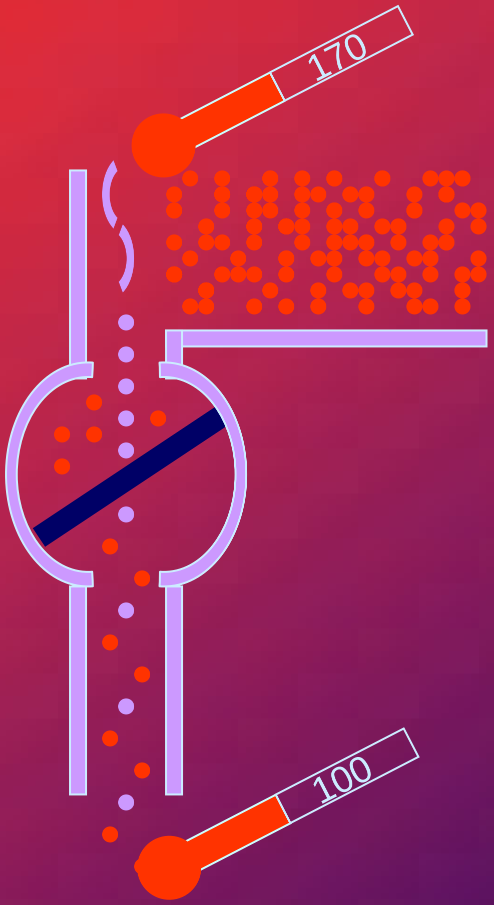
When the condensate line on the other side of the steam trap is at atmospheric pressure, a kg of condensate have a maximum temperature of 100 Celsius and can only contain 419 kJ/kg of sensible heat.



Sensible Heat & Latent Heat

As the temperature drops to 100 Celsius, the difference between the sensible heat at 7 bar g, (721 kJ/kg) and the sensible heat at 0 bar g (419 kJ/kg) i.e. 302 kJ will turn 12% of the boiling condensate back into steam.

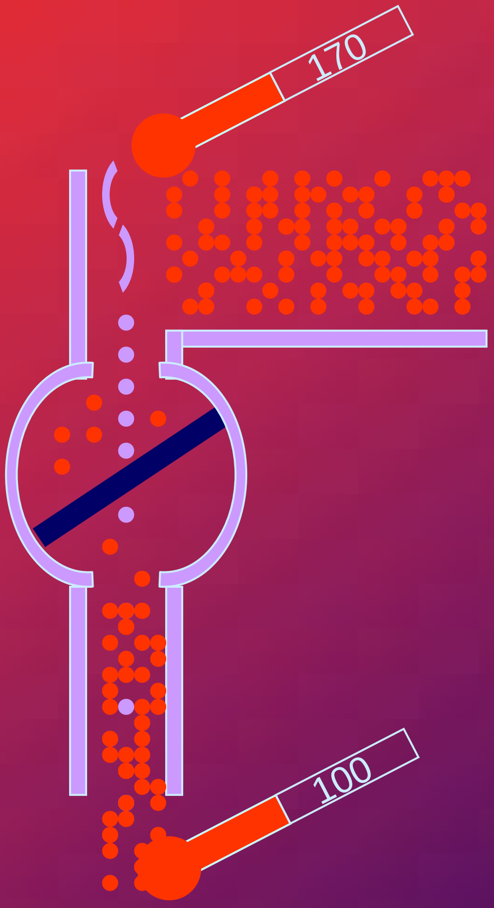
'Flash Steam'



Sensible Heat & Latent Heat

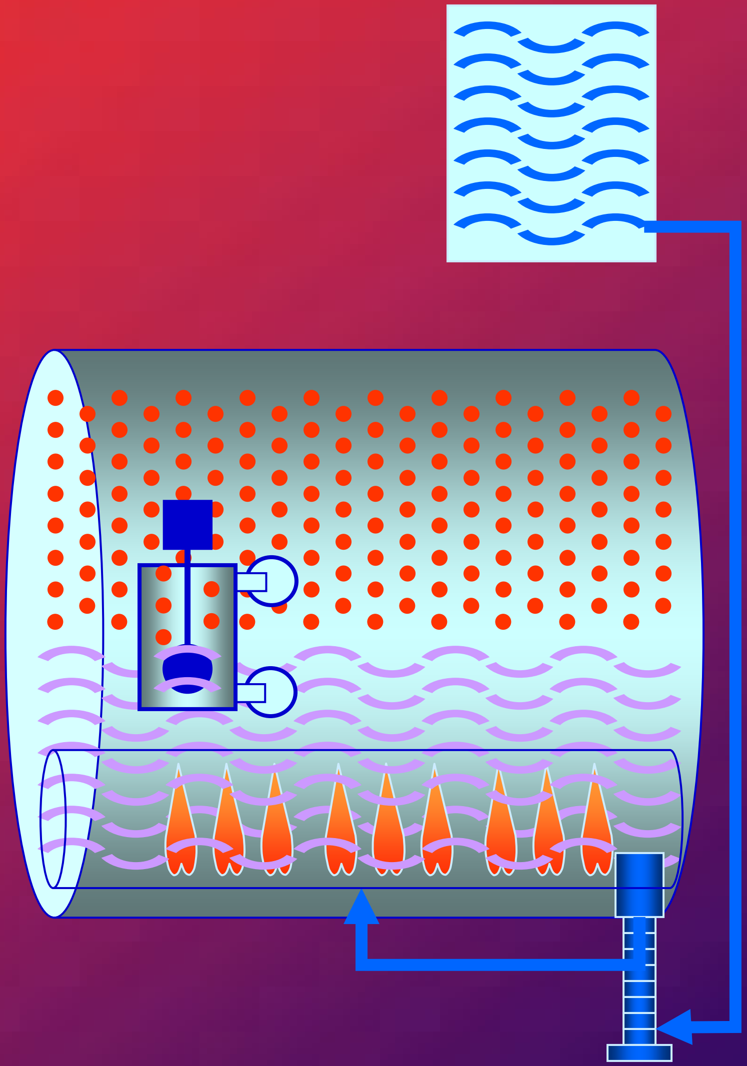
As the volume of a kg of steam is roughly 1600 times greater than a kg of condensate, the 12% by mass of flash steam will have a volume over 160 times that of the 88% condensate.

This frequently the cause of the noise heard from pipework adjacent to steam traps.



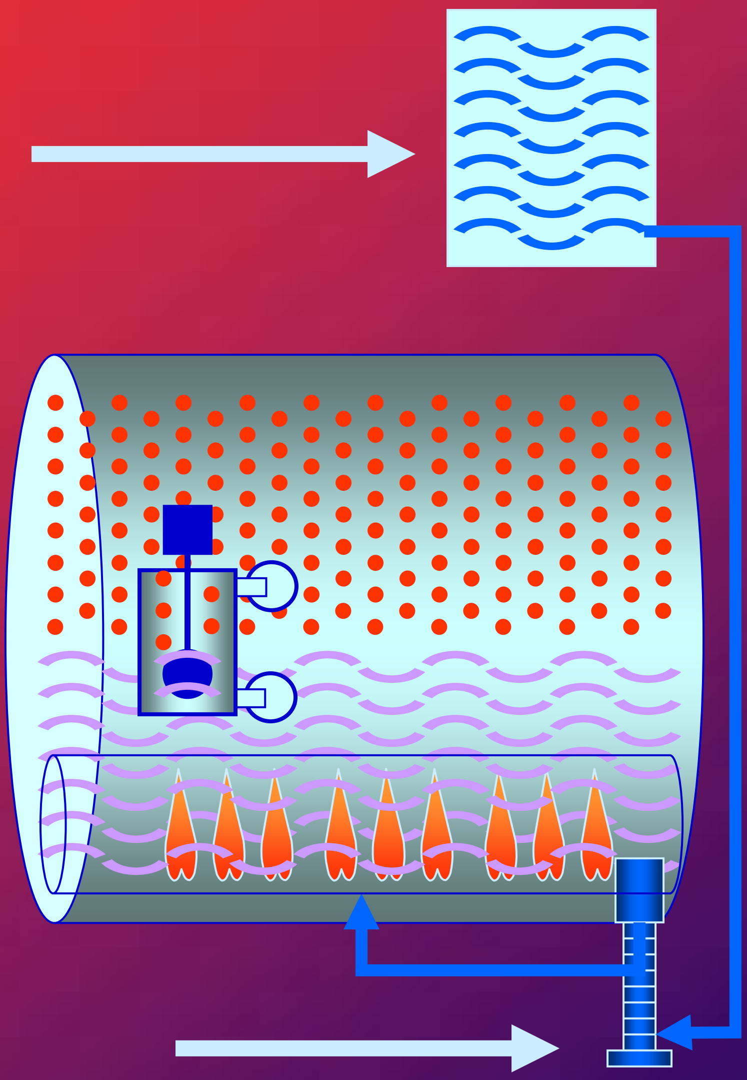
Making Steam

Producing the steam for process applications



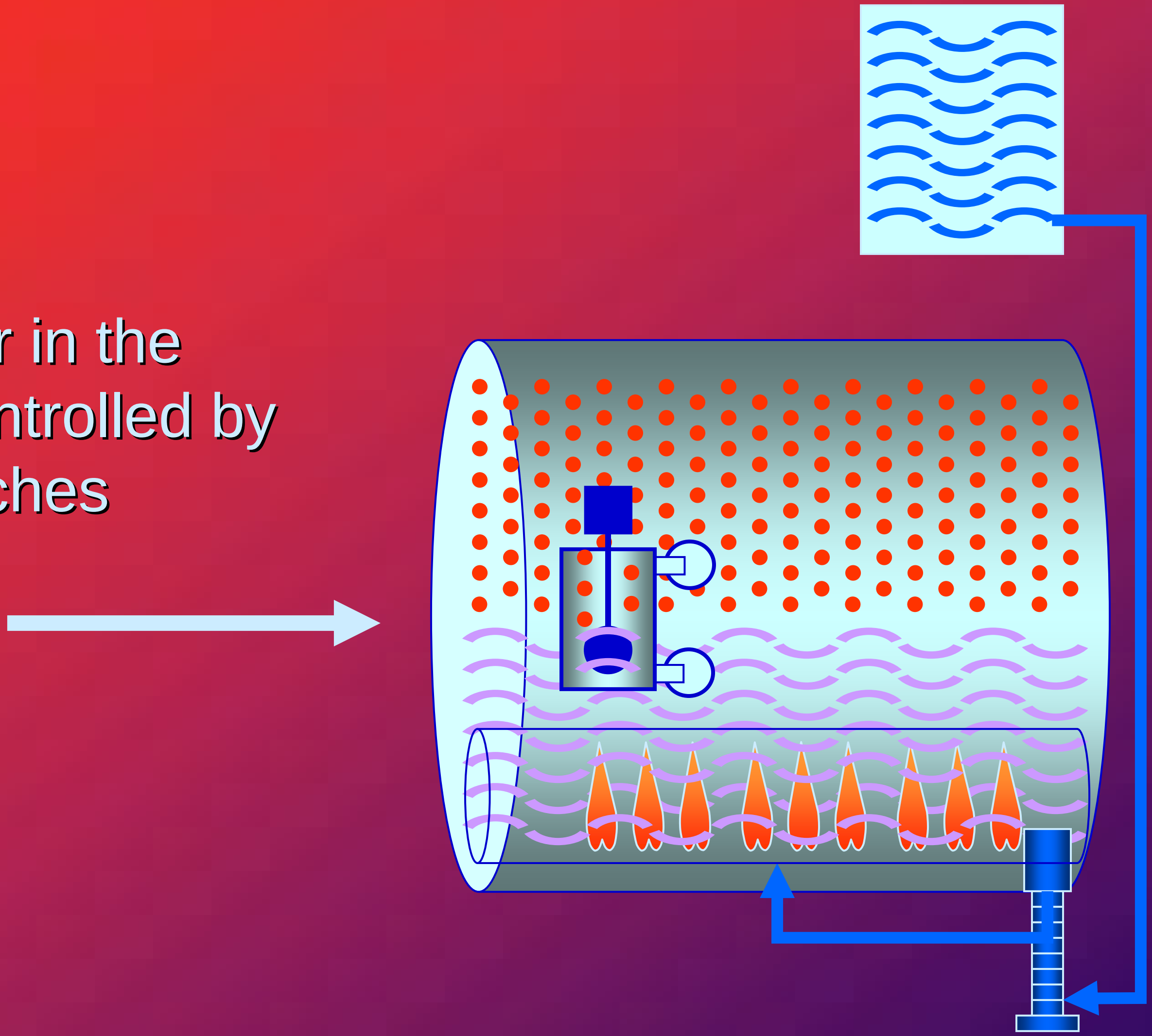
Making Steam

Water from a feed tank is pumped under pressure into the steam boiler



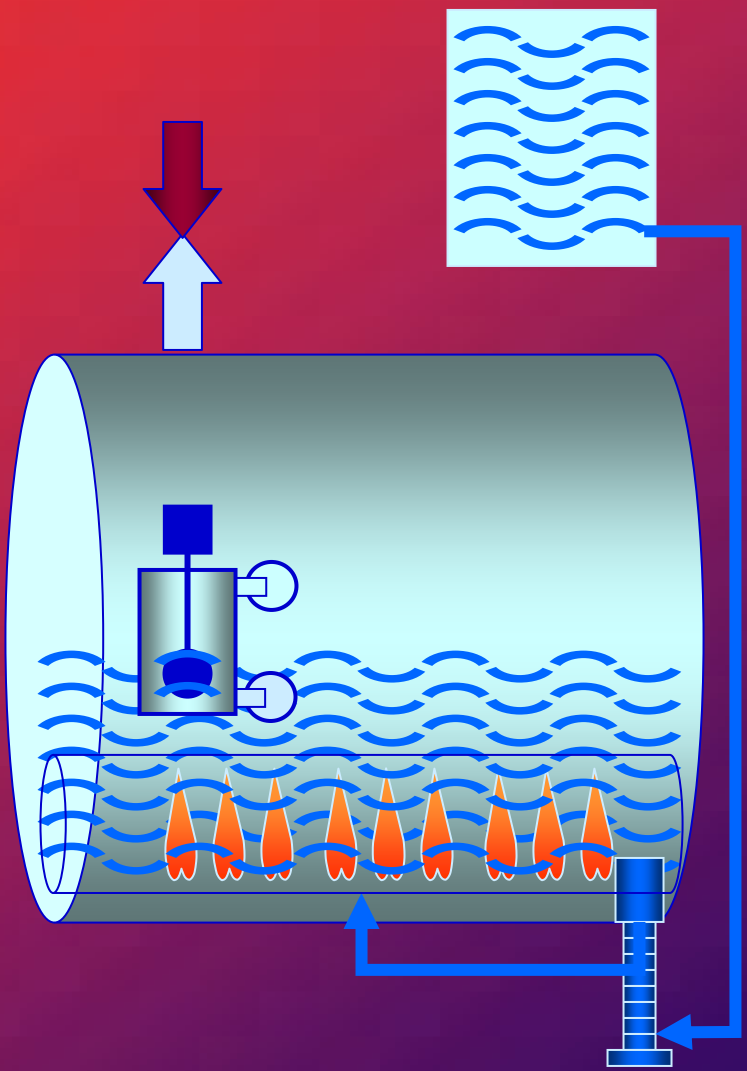
Making Steam

The level of the water in the boiler shell will be controlled by level controls or switches



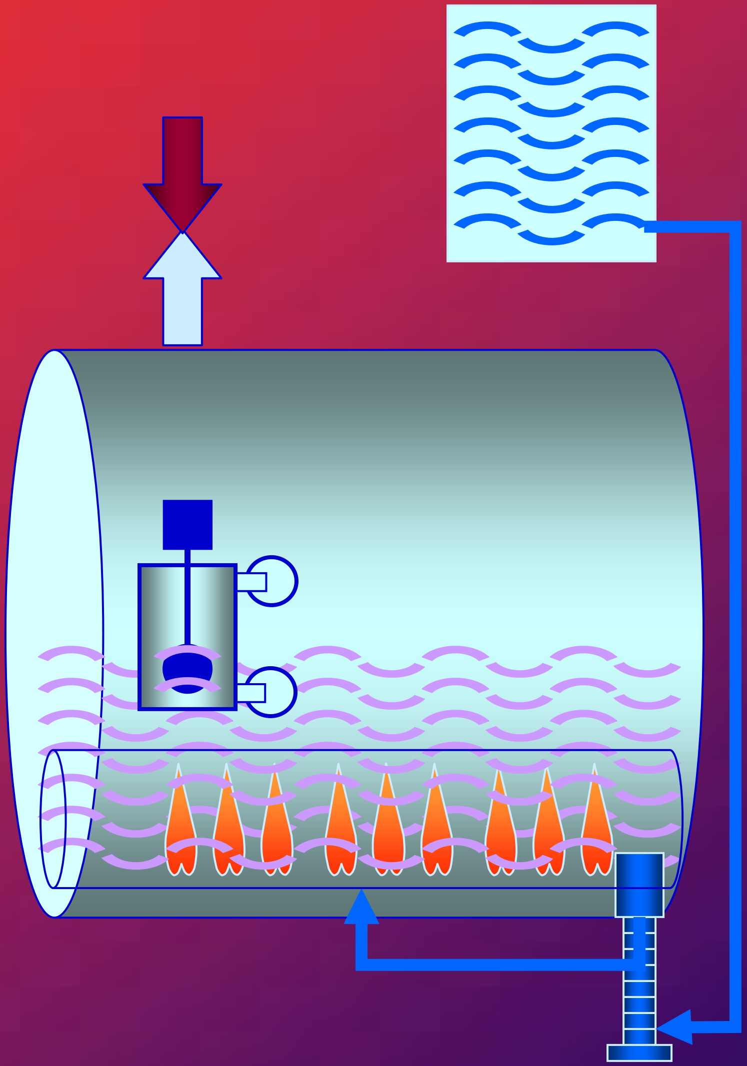
Making Steam

From a cold start, the boiler will be ‘fired’ with the steam outlet valves closed.



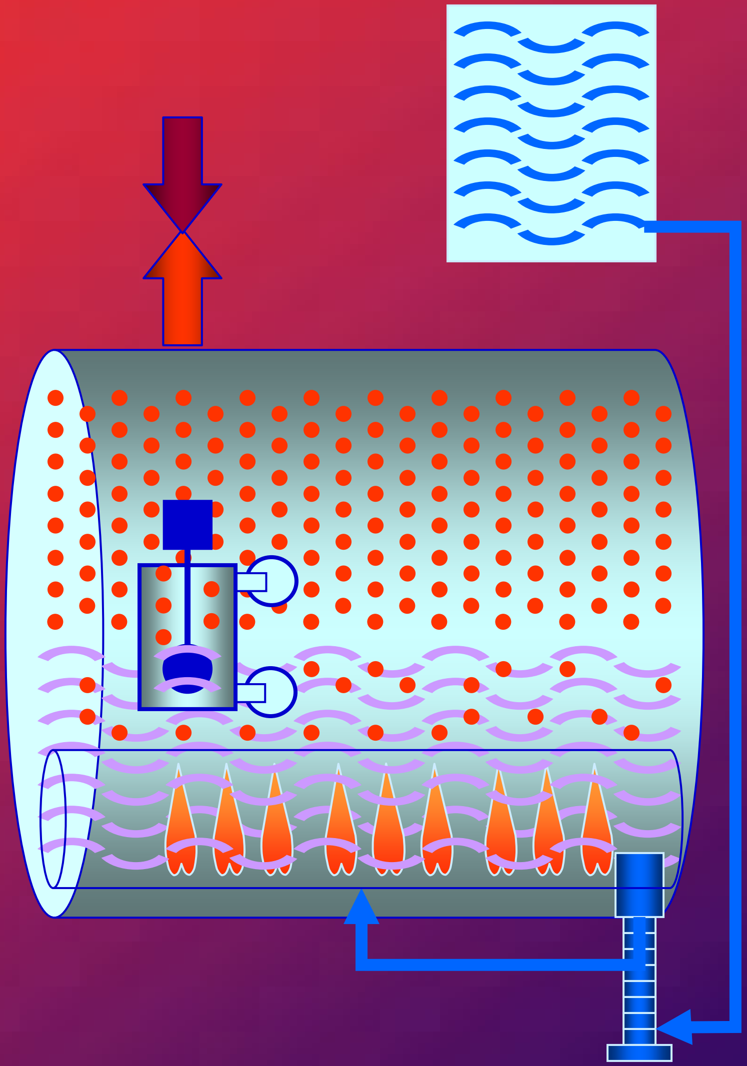
Making Steam

First, the water is raised to boiling point at atmospheric pressure.



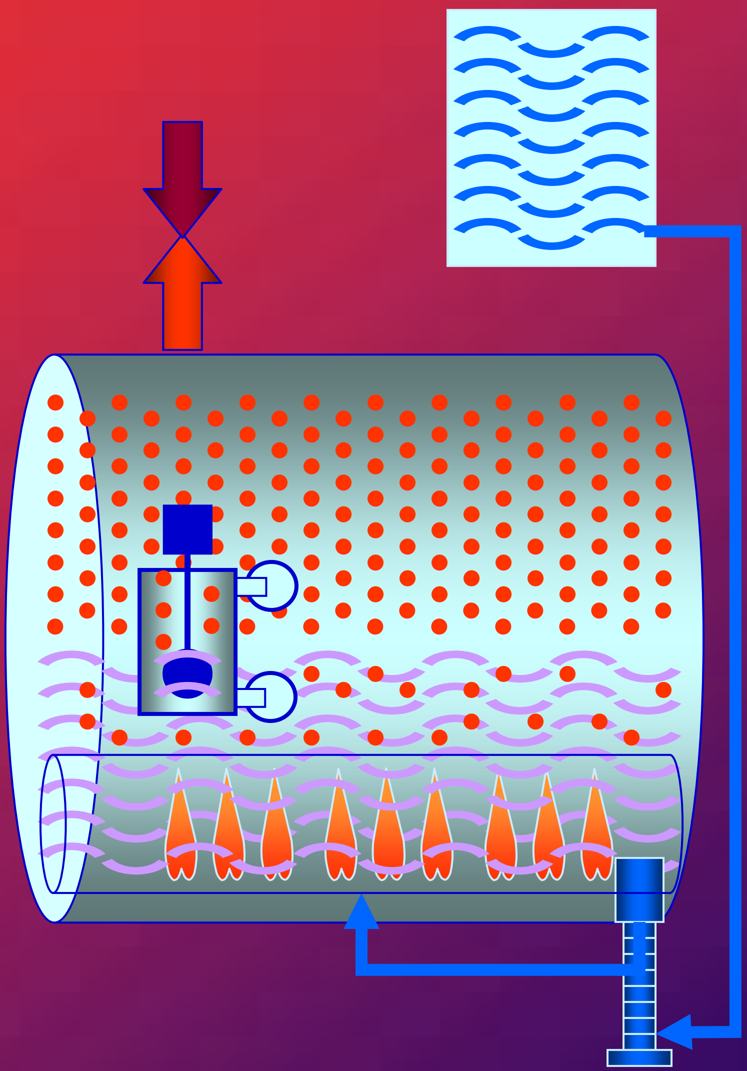
Making Steam

As the water boils the adding more heat causes bubbles of steam to form which float to the top and are released into the steam space.



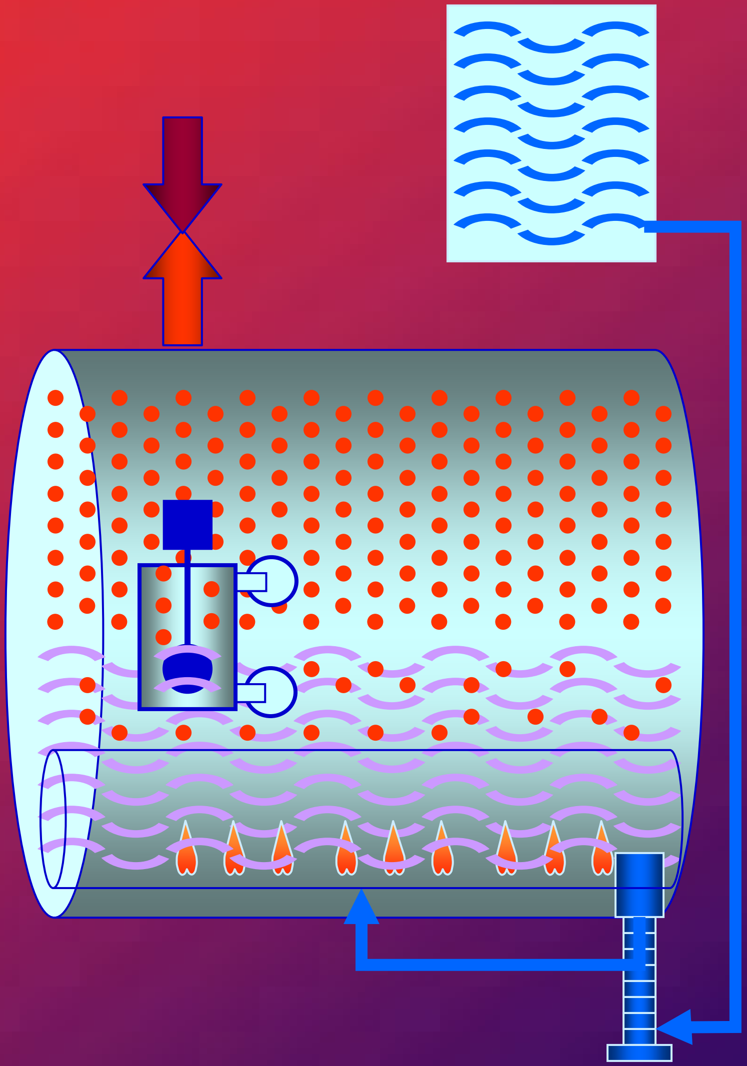
Making Steam

Because the outlet valve is closed and because the chemical change from a liquid to a vapour causes an expansion from 0.001 m3 per kilo to 1.673 m3 per kilo.



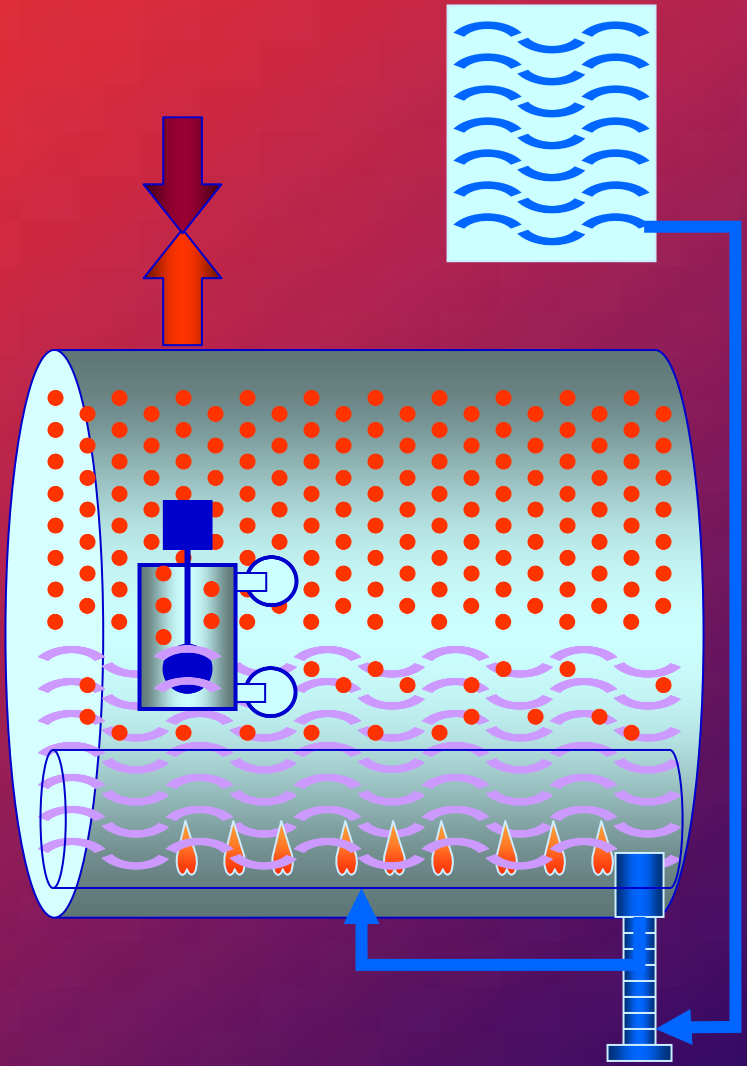
Making Steam

With this change of volume as water expands into steam, the pressure within the boiler will start to rise and will continue to increase until the pressure controls on the boiler turn down the heat source.



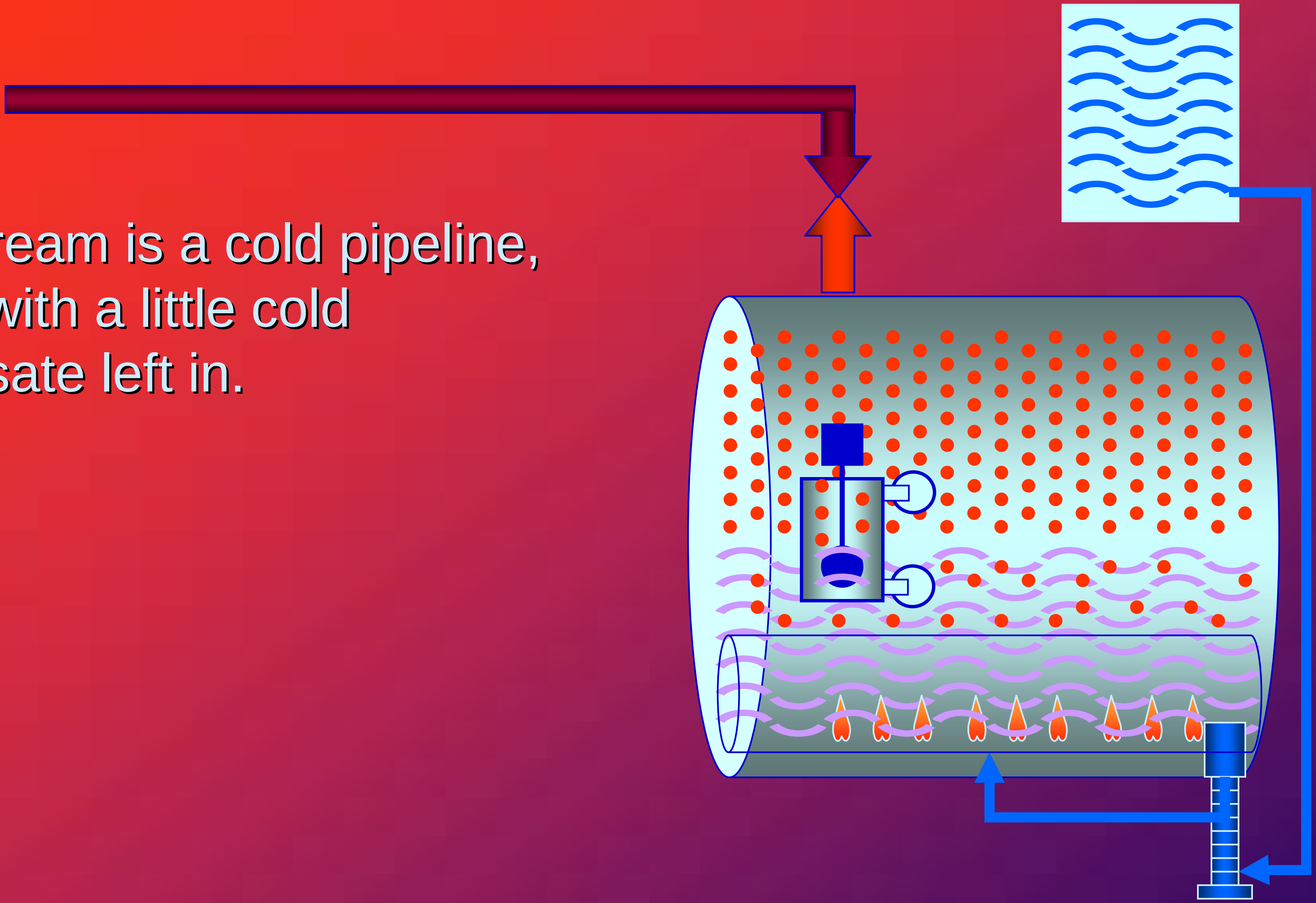
Making Steam

At this point, the boiler is fully charged with steam at a pressure of maybe around 10 bar and a temperature of around 200 Celsius.

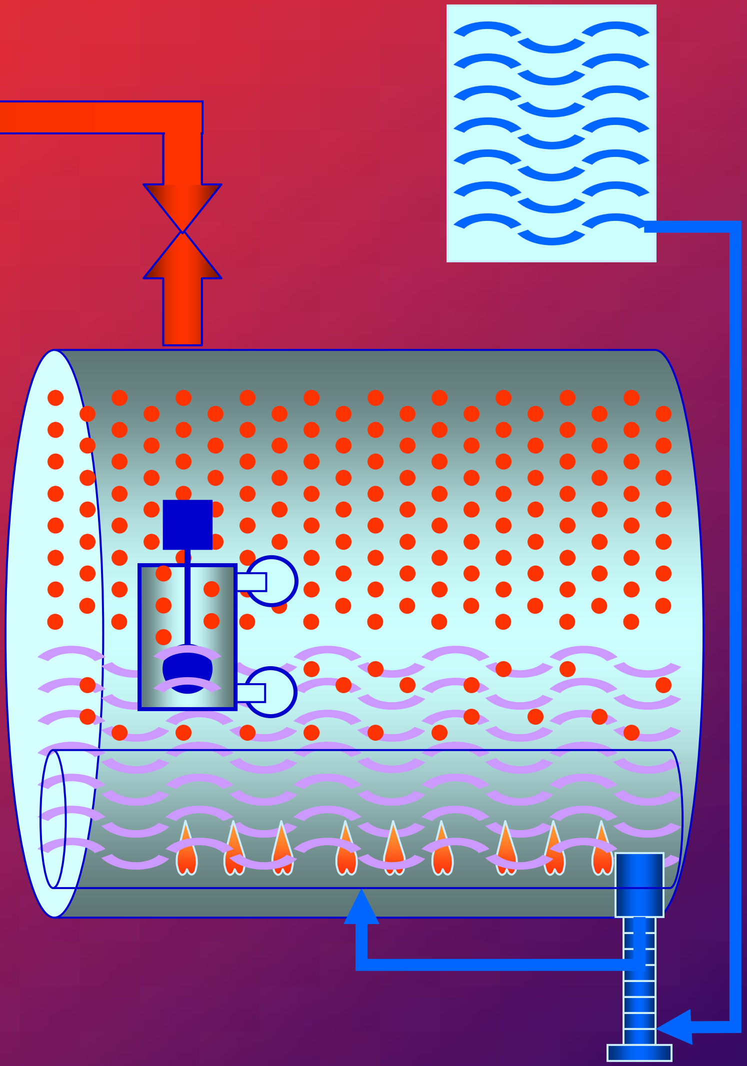


Making Steam

Downstream is a cold pipeline, maybe with a little cold condensate left in.



Making Steam

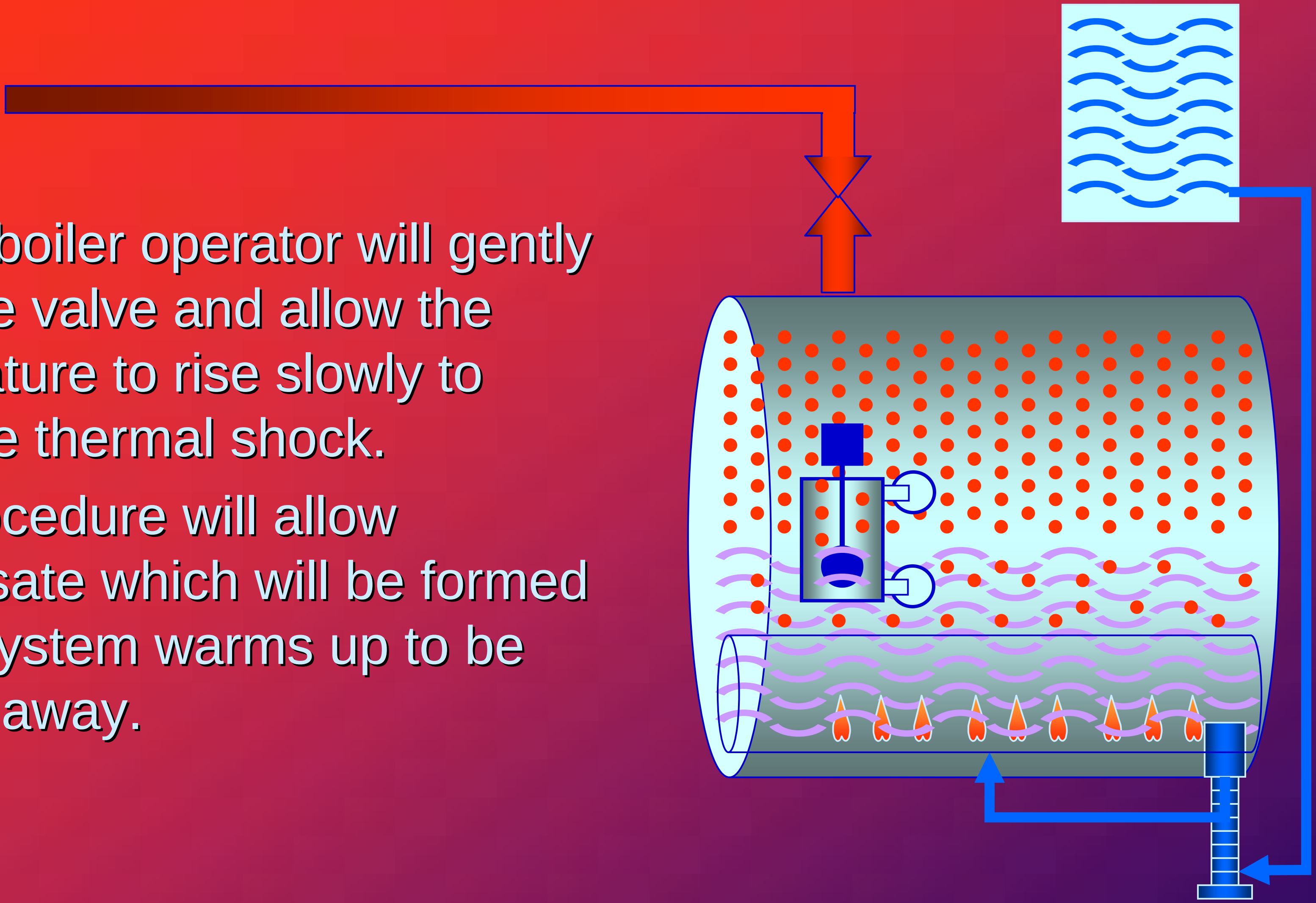


Imagine the consequences if the boiler steam valve is opened up too quickly and all the energy within the boiler is suddenly released into the distribution system.

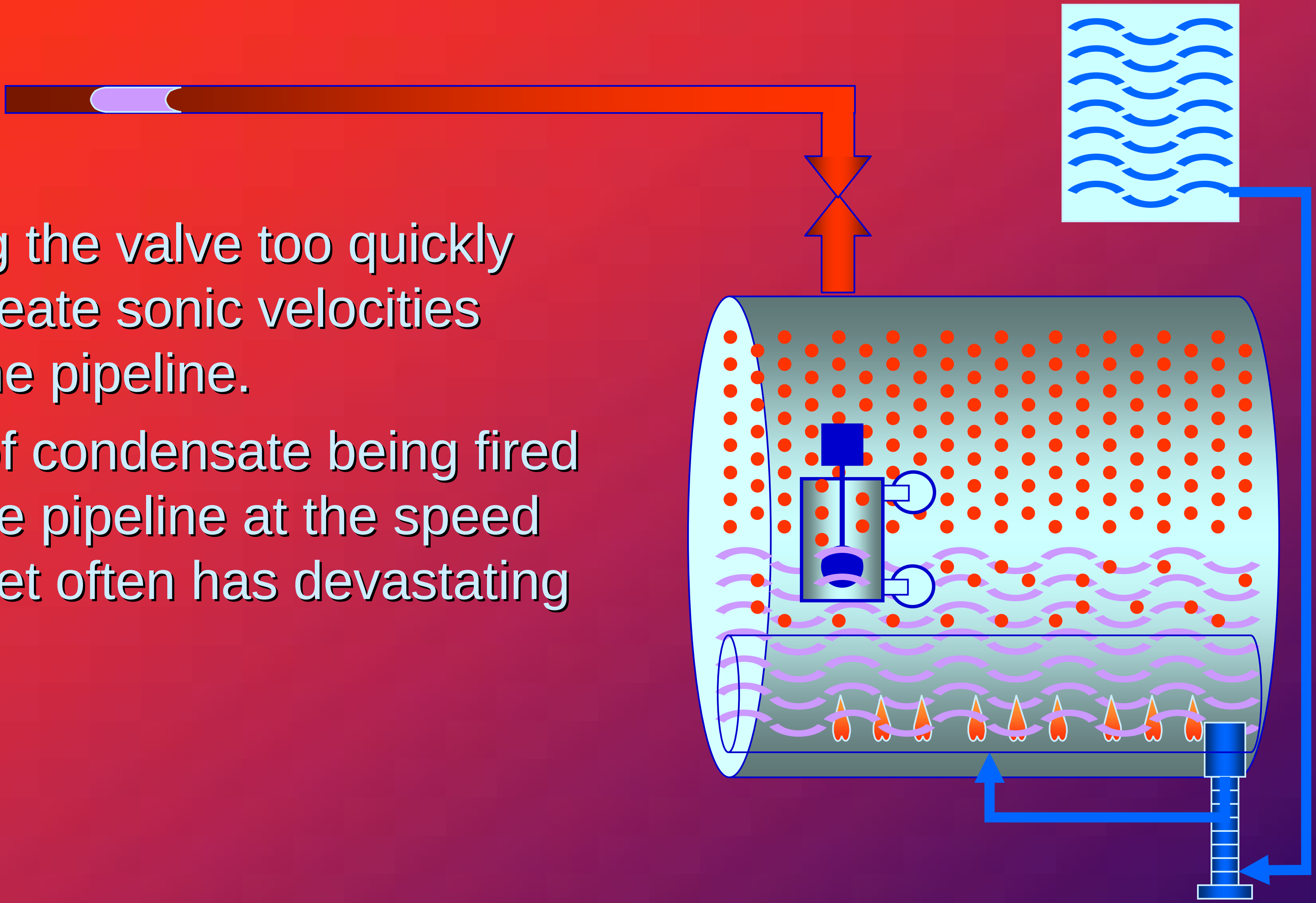
Making Steam

A good boiler operator will gently open the valve and allow the temperature to rise slowly to minimise thermal shock.

This procedure will allow condensate which will be formed as the system warms up to be drained away.



Making Steam

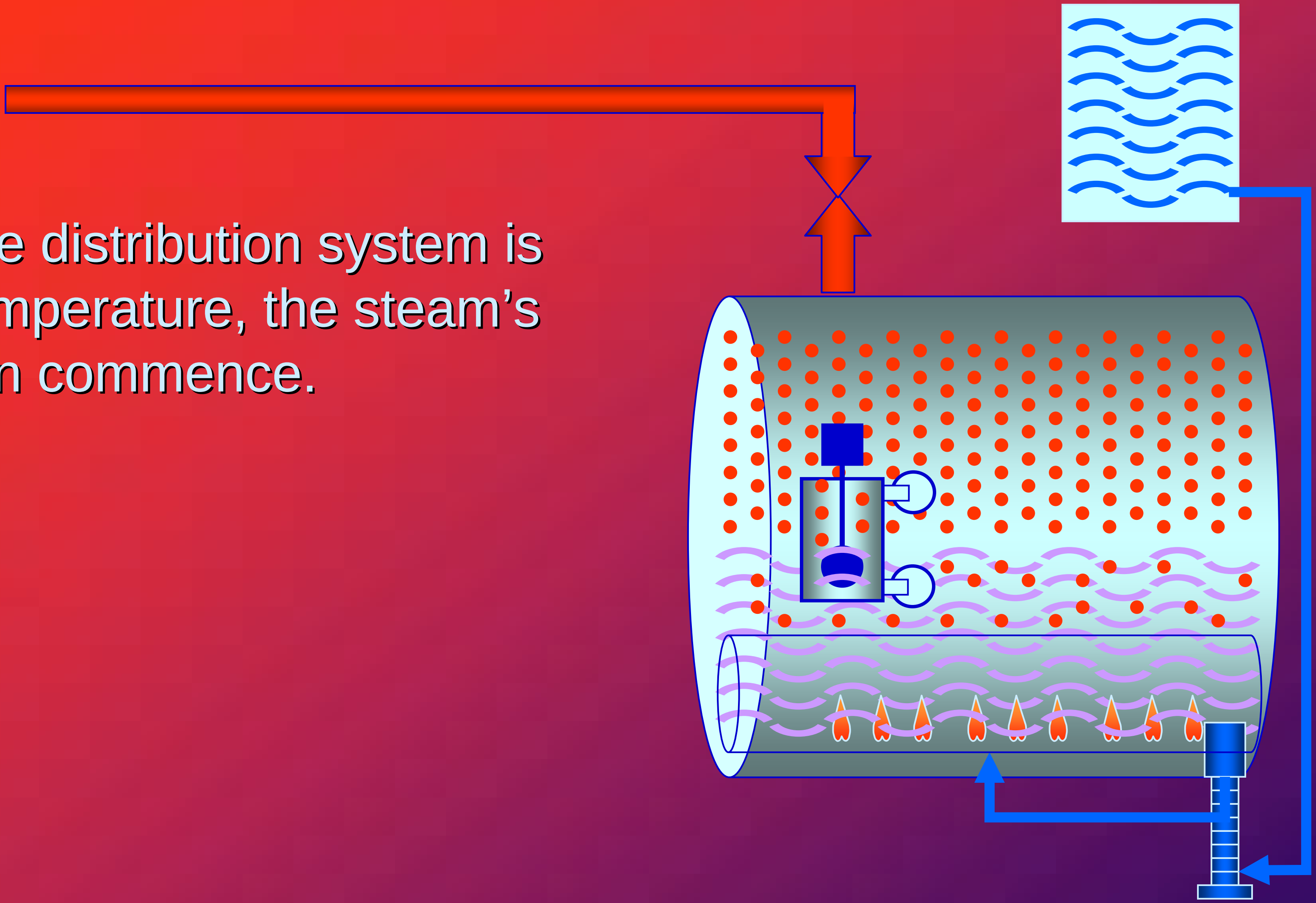


Opening the valve too quickly could create sonic velocities within the pipeline.

A slug of condensate being fired down the pipeline at the speed of a bullet often has devastating effects.

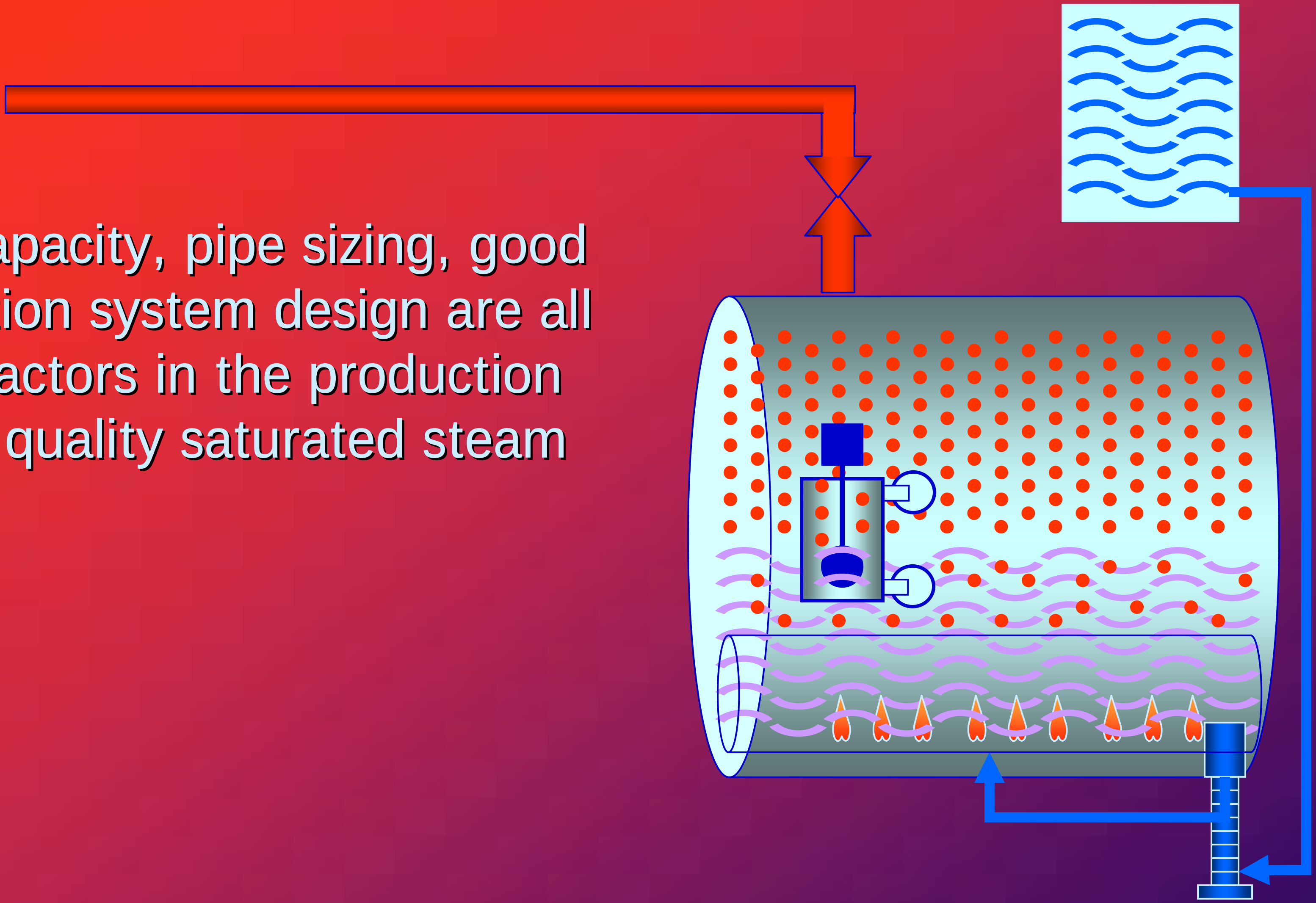
Making Steam

Once the distribution system is up to temperature, the steam's work can commence.



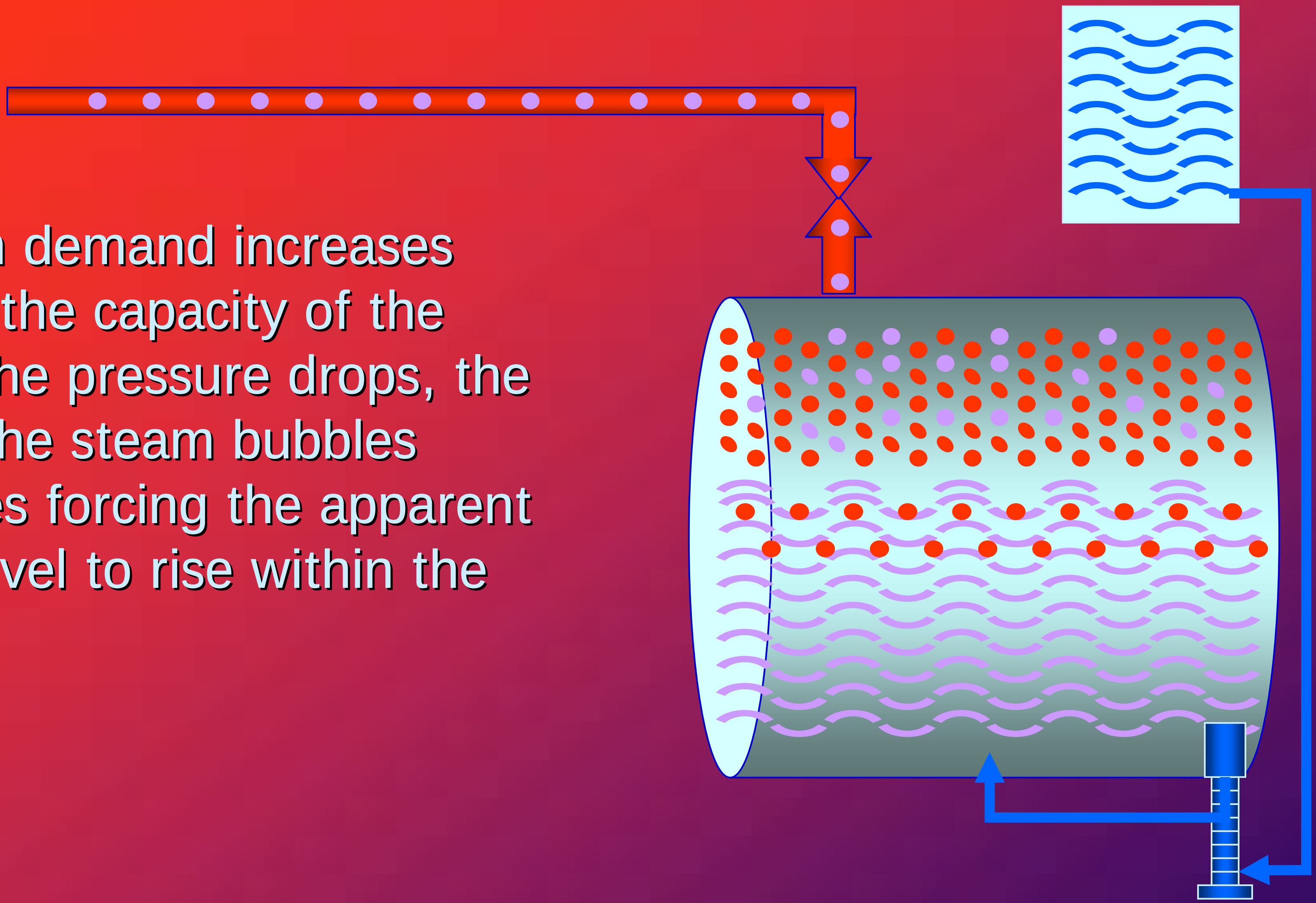
Quality of Steam

Boiler capacity, pipe sizing, good distribution system design are all critical factors in the production of good quality saturated steam



Quality of Steam

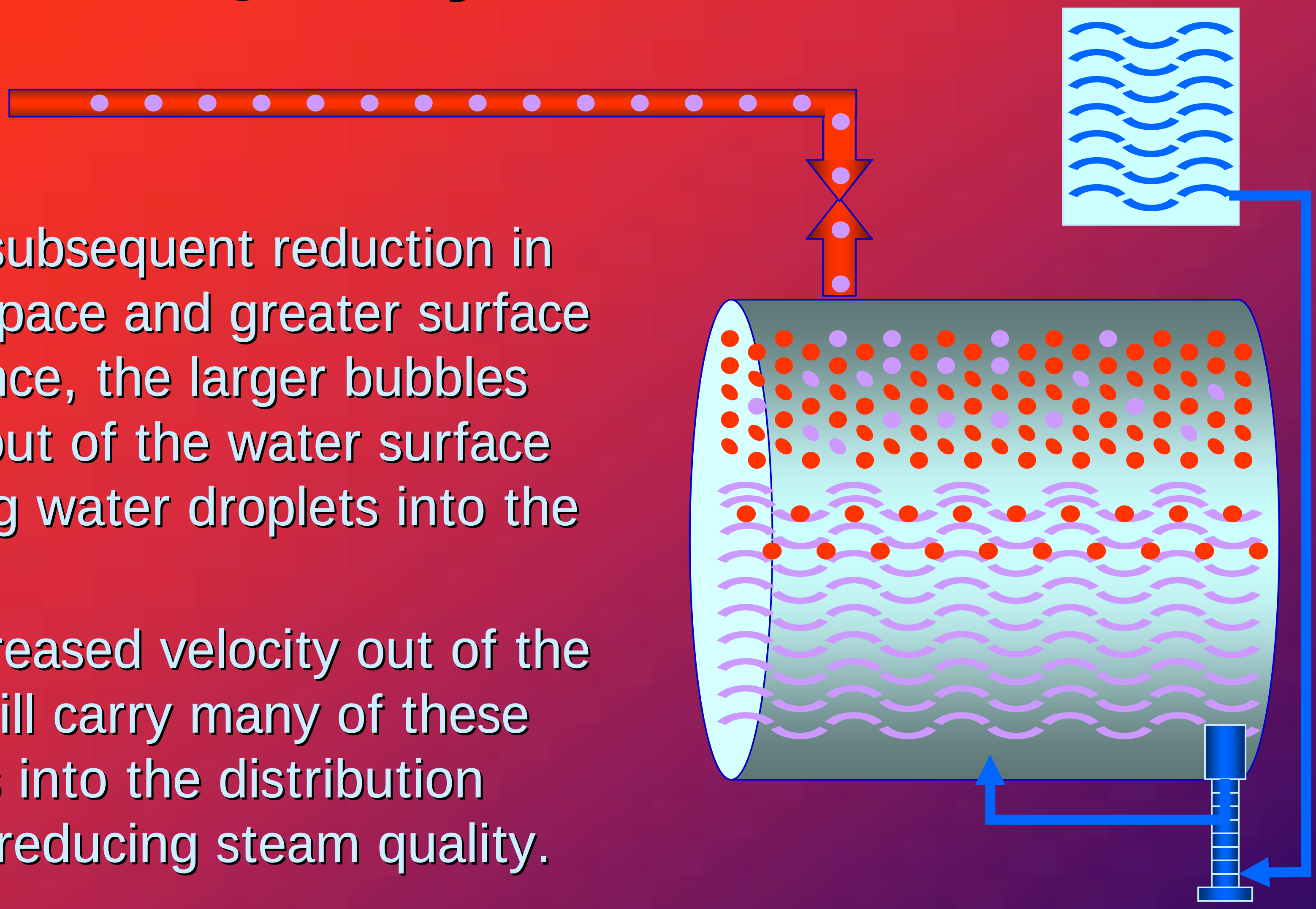
If steam demand increases beyond the capacity of the boiler, the pressure drops, the size of the steam bubbles increases forcing the apparent water level to rise within the boiler.



Quality of Steam

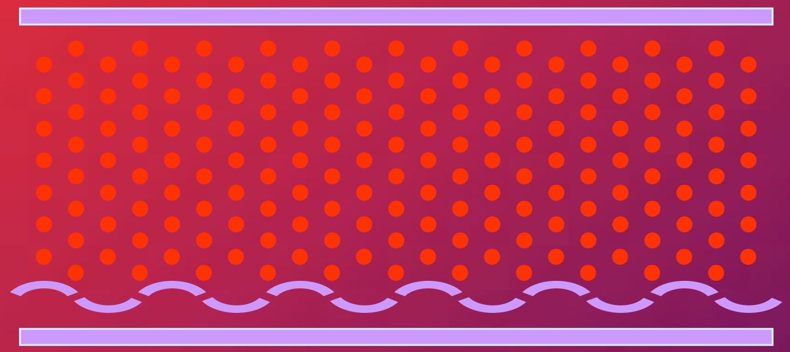
With a subsequent reduction in steam space and greater surface turbulence, the larger bubbles splash out of the water surface throwing water droplets into the steam.

The increased velocity out of the boiler will carry many of these droplets into the distribution system reducing steam quality.



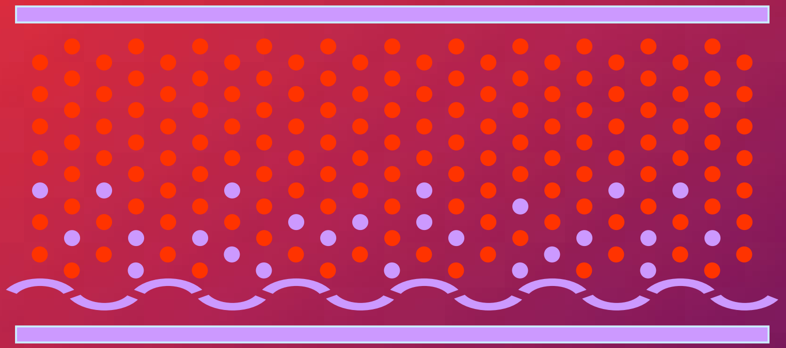
Quality of Steam

Within the distribution system some heat energy will be lost in the pipelines creating condensate.

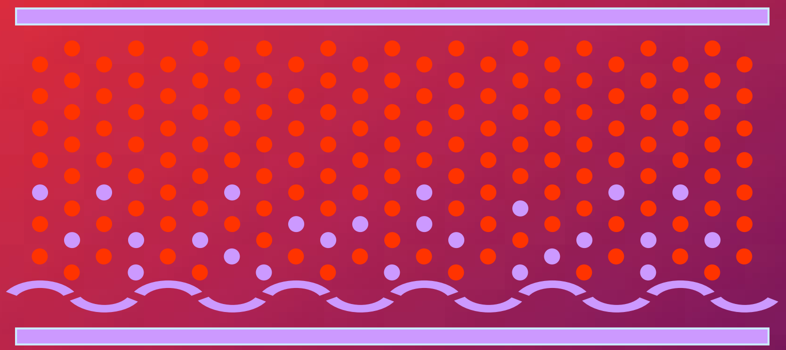


Quality of Steam

The distribution pipework must be of adequate size such that any water carried over and or condensate forming from the steam as a consequence of heat loss from the pipes is not picked up by excess pipeline velocity and carried in the steam.



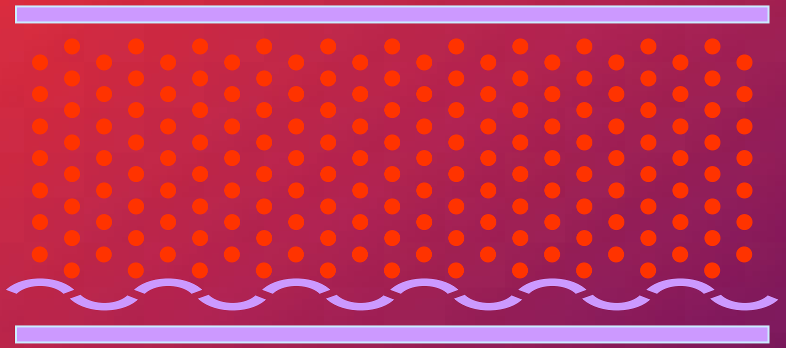
Quality of Steam



Velocities in excess of 40 metres per second are likely to cause reduced steam quality due to the increased water droplets in suspension.

Water droplets flying down a pipe line at say 50 metres per second (120 miles an hour) continuously are bound to cause wear and erosion.

Quality of Steam



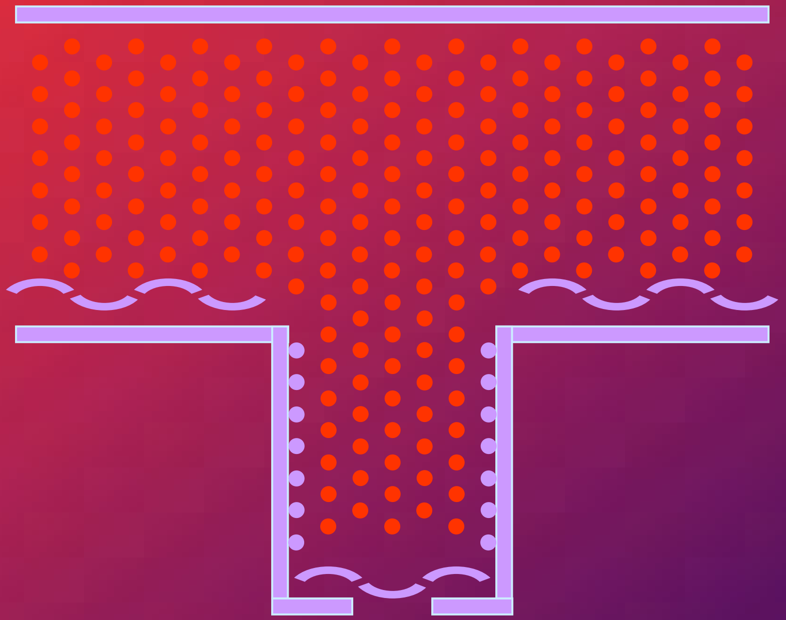
Most authorities consider that a steam velocity of 25 to 35 metres per second provides for acceptable pressure drop, acceptable heat loss, and minimum pick up of condensate.

This velocity may be reduced to minimise pressure loss where distribution lines are very long.

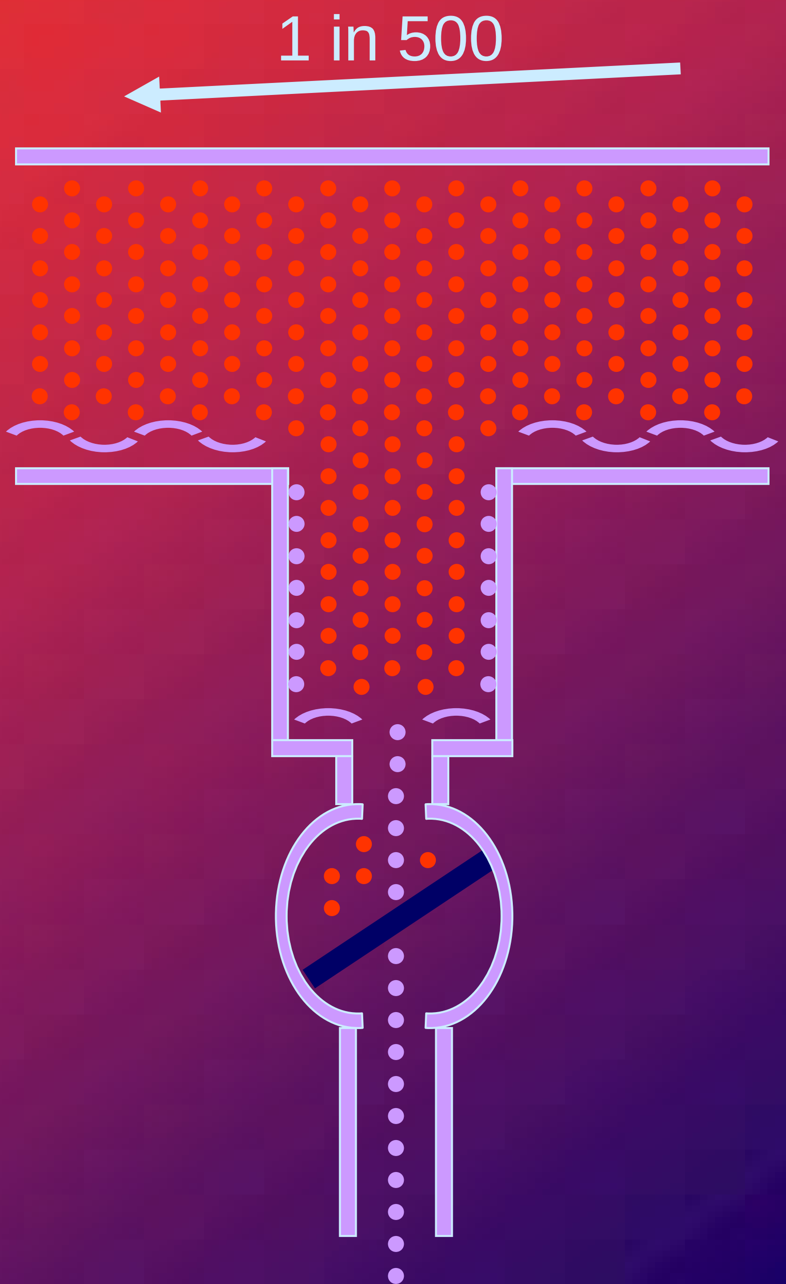
Quality of Steam

Good design of the distribution system with particular attention to drainage improves steam quality dramatically.

For efficiency and safety it is vital that all condensate is removed from the distribution mains as quickly as possible.



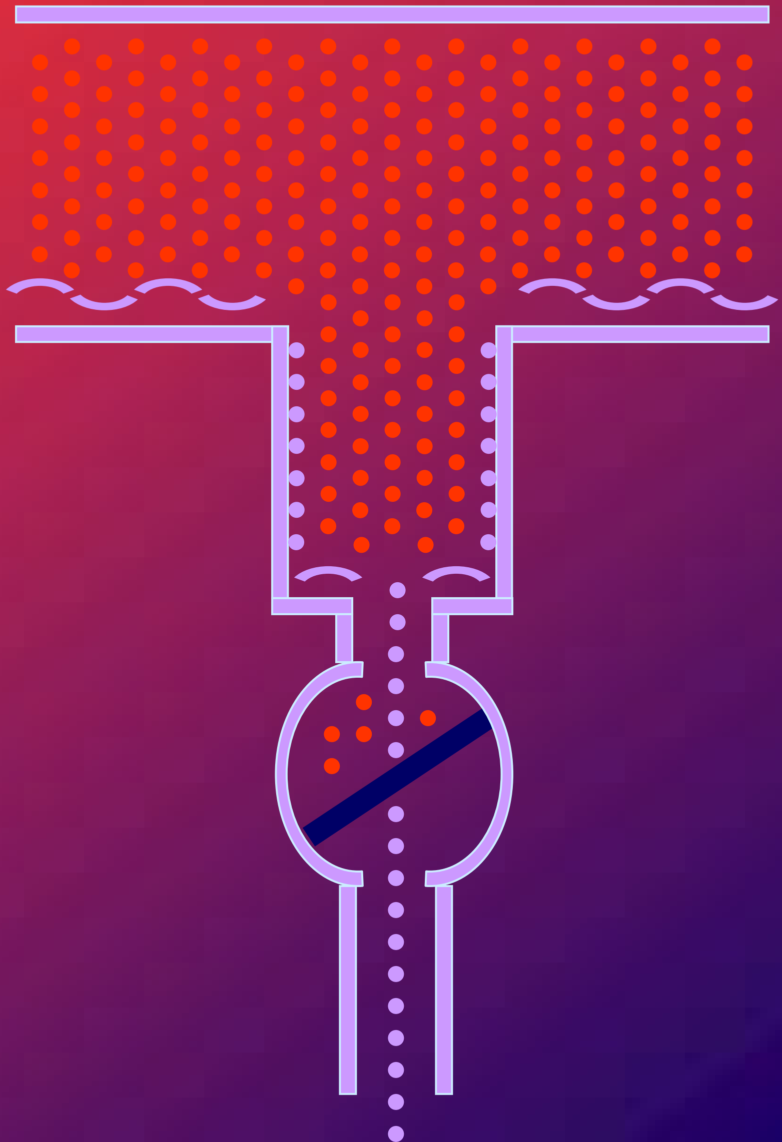
Quality of Steam



Lines should have a fall in the direction of flow, typically 20 mm per 10 meters of pipe, have collecting legs every 40 to 50 metres and no untrapped low points where water can collect.

Quality of Steam

Low points and collecting legs should be fitted with steam traps. In their most simple form, steam traps allow the passage of water to drain but won't allow steam to pass.

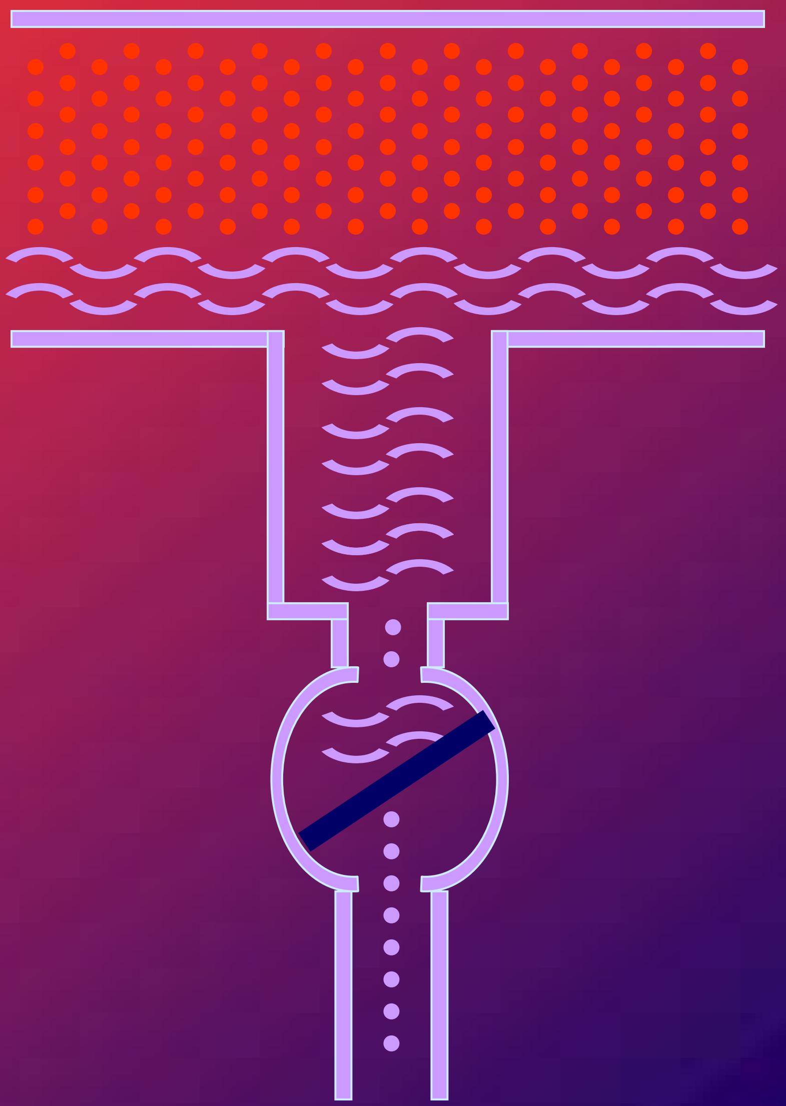


In most modern distribution systems the condensate and it's sensible heat will be returned to the plant room and used again for the production of steam.

Quality of Steam

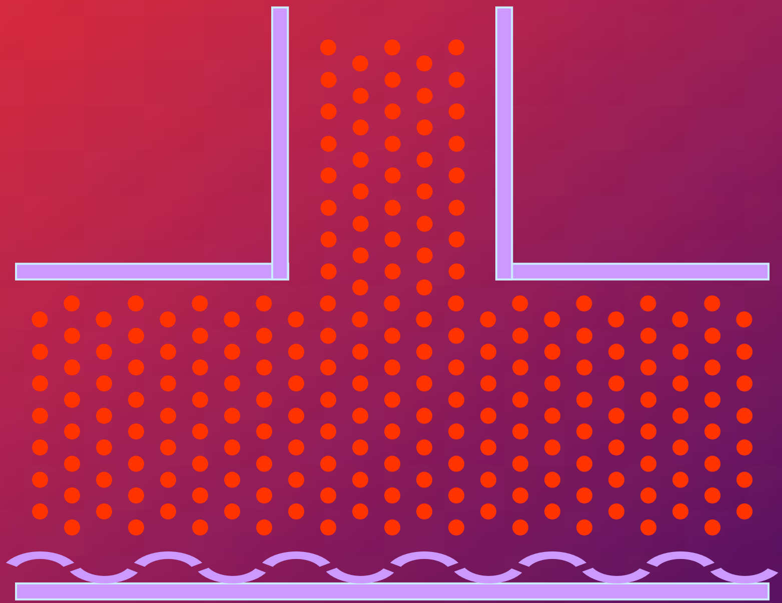
Before we leave the subject of distribution lines and trapping. On some systems there can be a further problem during that start up from cold.

The condensate pipe may not self drain back to boiler feed tank. It may require some pressure in the steam line to force the condensate through the steam trap. As the system is being primed slowly it may be same time before that pressure is available, at the same time we are producing large quantities of condensate which can't get away. Even with a gentle start up there could still be some water hammer as condensate gets pushed through the system.

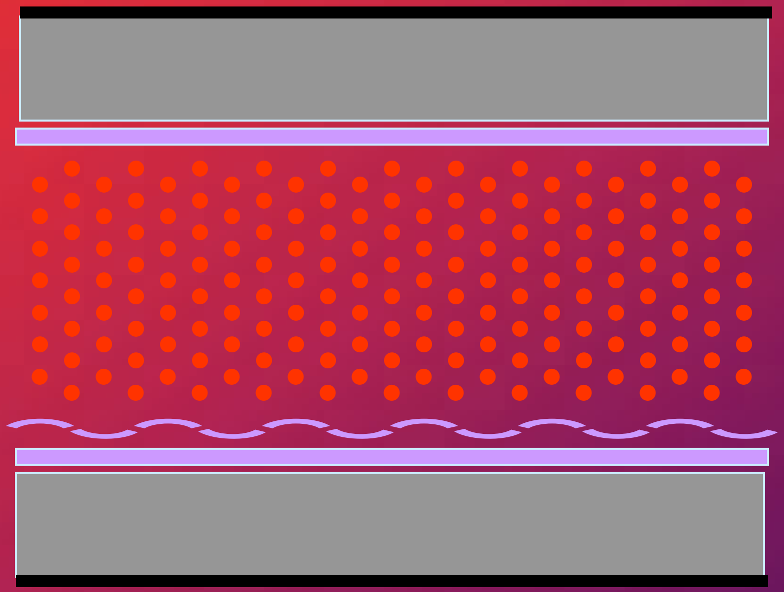


Quality of Steam

Branch lines should always be connected to the top of the steam main to provide the driest steam to the process.

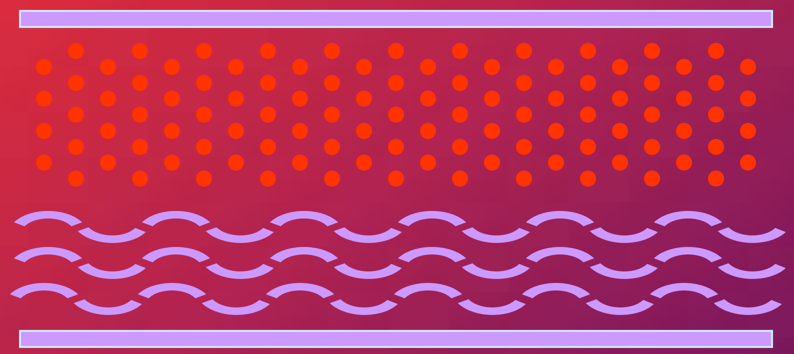


Quality of Steam



Distribution lines should be well insulated to minimise the amount of condensate being formed (and to save energy).

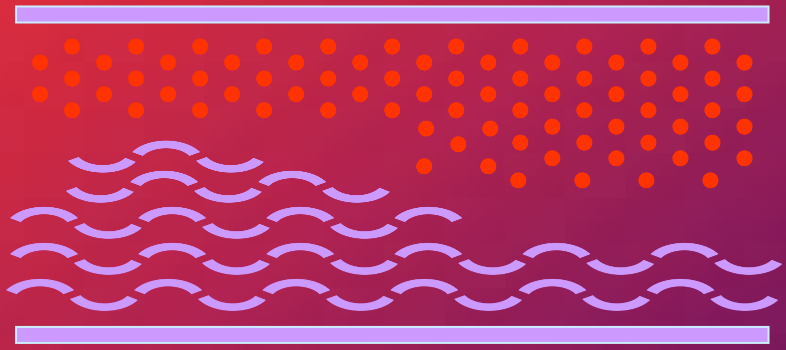
Quality of Steam



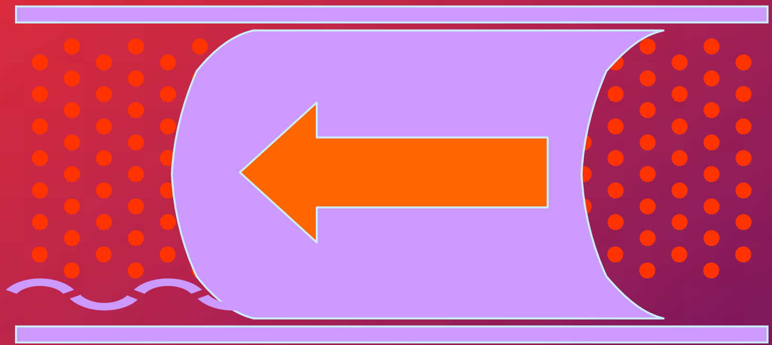
Imagine standing water in a low point in the pipe. The demand is low so the steam passes easily over the standing water.

Quality of Steam

Demand increases, the resulting increased velocity starts to push the water into a plug.



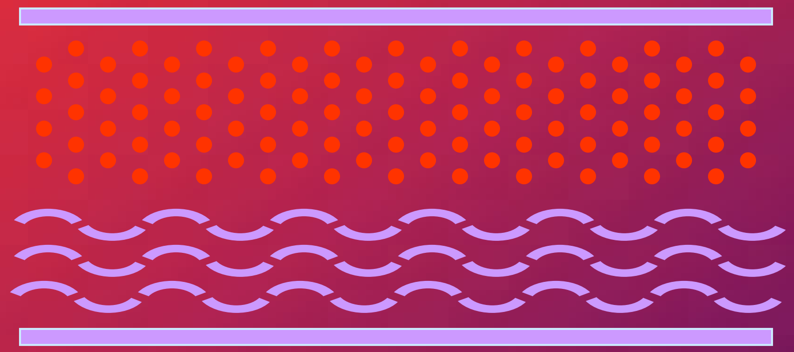
Quality of Steam



This plug which possibly weighs several kilos gets larger as it picks up more of the condensate in the line may be travelling down the pipeline at around 90 miles per hour.

The impact caused by the kinetic energy can be sufficient to bend the spindles of valves, break joints, and definitely cause mischief with flowmeters.

Quality of Steam



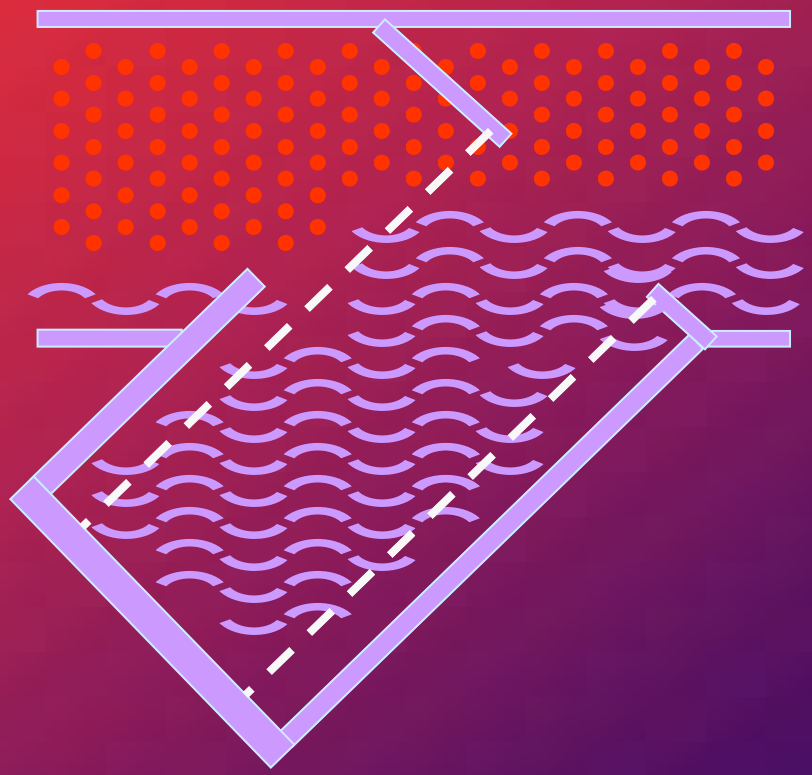
Standing water in distribution pipework may not only be as a result of a low section of pipe.

Badly installed pipe fittings, strainers, valves, and flowmeters may all contribute.

Quality of Steam

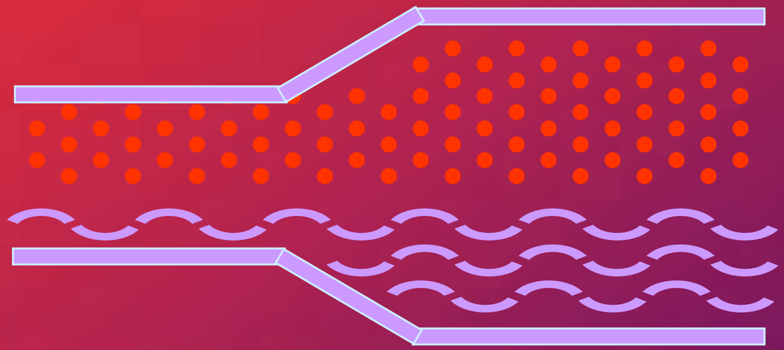
Strainers & Globe valves should be fitted on their side to prevent damming of the flow.

This example also shows that the strainers efficiency is reduced by being waterlogged

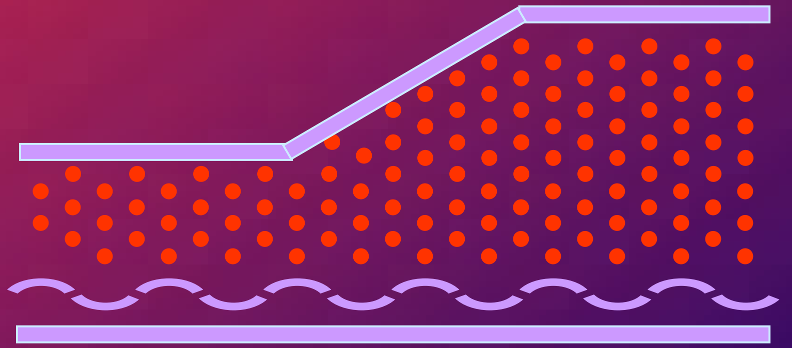


Quality of Steam

The damming effect of of a concentric reducing fitting.

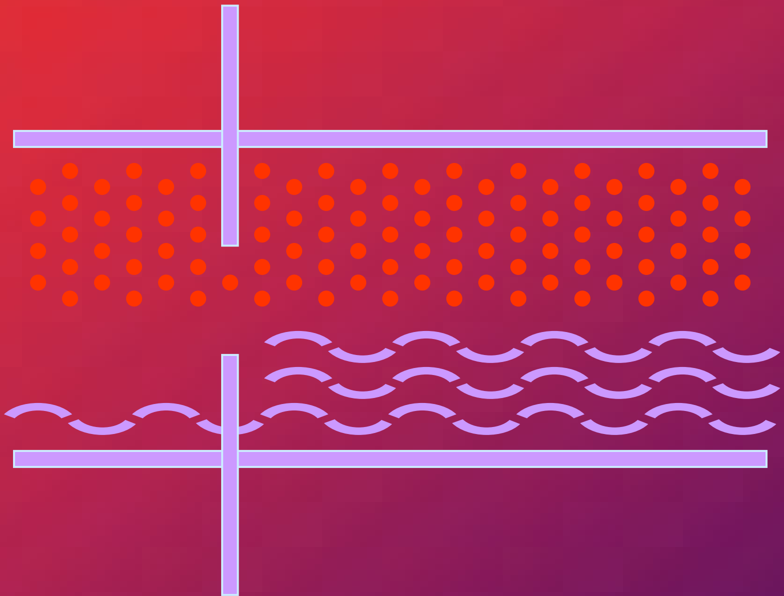


The benefit of an eccentric reducing fitting.

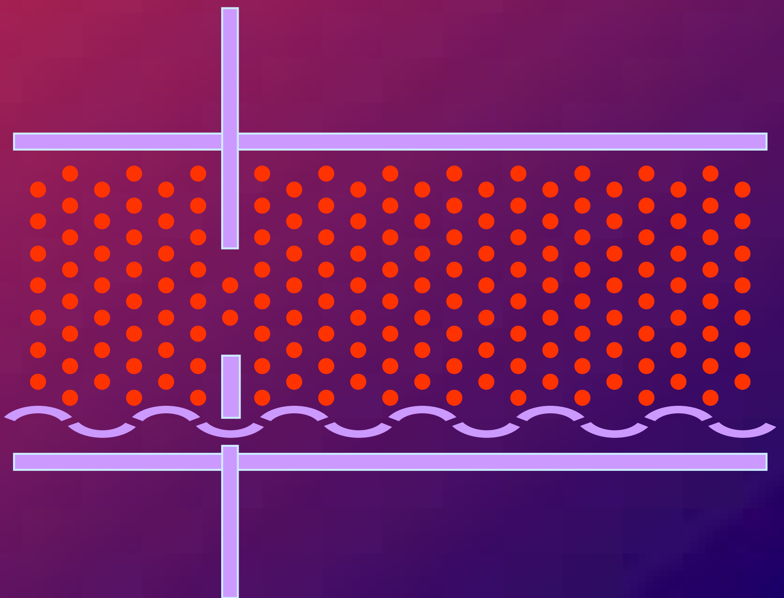


Quality of Steam

Orifice plates as well as causing a damming effect will be totally ineffective for measurement.



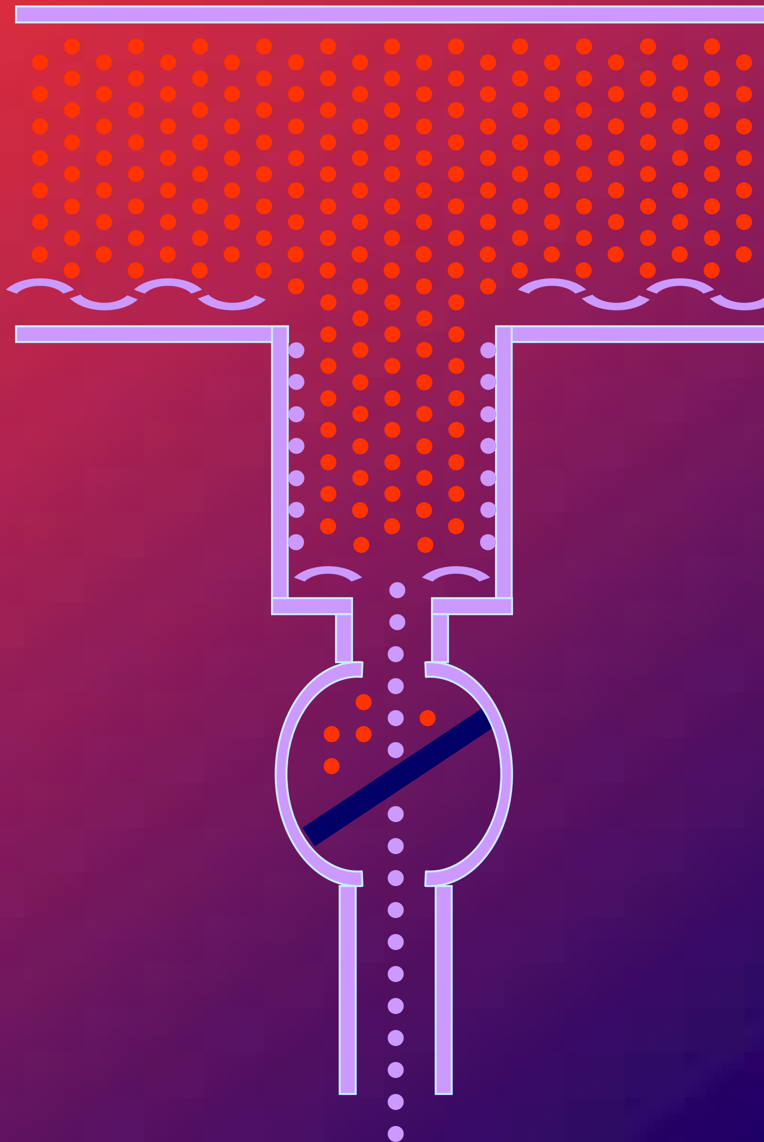
A drain hole in the bottom cures the problem and the change in coefficient of discharge can be allowed for.



Quality of Steam

Pressure reducing valves and steam control valves must always be preceded by a drain leg.

Better still is the installation of a proprietary steam separator which is designed to remove any water droplets suspended within the steam flow which would cause erosion of the valve seats.



Steam Terminology

Mass	'M' is the quantity of steam by weight in kgs
Density	'pb' is the mass per unit of volume kg/m3 at reference conditions
	'pf' is the mass per unit of volume kg/m3 at flow conditions
Specific Volume	'Vb' is the volume per unit of mass m3/kg or dm3/kg at reference conditions
	'Vf' is the volume per unit of mass m3/kg or dm3/kg at flow conditions
Pressure	'Pb' is the pressure kPa or bar at base conditions
	'Pf' is the pressure kPa or bar at flow conditions
Mass flowrate	'Qm' is the mass flowrate kg/hr
Enthalpy	'hb' is the specific enthalpy kJ/kg at reference conditions
	'hb' is the specific enthalpy kJ/kg at reference conditions
Flowmeter	'Kf' is the K-factor (vortex) pulses/m3
	'Sv' is the 20 mA span (vortex) m3/hr
	'Sm' is the 20 mA span (DP) kg/hr

Steam Tables

Steam tables are the most convenient way of showing the properties of steam. Unlike ideal gas, the properties of steam are not linear to changes in pressure or temperature.

A typical dry saturated steam table will look something like this.

Pressure		Temperature	Enthalpy			Density
Gauge	Absolute		Water	Evaporation	Steam	
bar	bar	Celsius	kJ/kg	kJ/kg	kJ/kg	m3/kg
3	4.013	143.75	605.3	2133.4	2738.7	0.461
5	6.013	158.92	670.9	2086.0	2756.9	0.315
10	11.013	184.13	781.6	2000.1	2781.7	0.177
15	16.013	201.45	859.0	1935.0	2794.0	0.124

Metering

Regardless of the chosen method of steam flow measurement, steam quality plays a major part in the meter's performance.

The steam should be dry and the pipeline free of condensate.

Wet steam will cause erosion particularly to orifice plates.

Wet steam's increased density will cause errors with DP type meters.

Wet steam has more sensible heat per unit of volume and less latent heat per kilo of mass.

Condensate could block the sensing holes on pitot tubes.

With the high velocities associated with Vortex meters, any condensate not drained upstream will almost definitely be come entrained into the steam flow.

Metering

Pipeline considerations.

Most principles of steam metering require a good velocity profile.

The velocity profile will be affected by bends, valves, tees, reducers and the often forgotten friction due to roughness of the pipe wall. It is also vital that the pipe internal diameter is correct for the meter being used.

Metering

Methods of steam measurement

Orifice plate	(only dry steam)
ISA of long radius nozzle	(dry and wet steam)
PTC-6 nozzle	(technically best option)
Venturi nozzle/classical venturi	(dry and wet steam)
Pitot tube	(only monitor function)
Target meter	(not a serious option)
Variable area	(not a serious option)
Spring loaded variable area	(is an option, mechanical...)
Turbine meter	(not recommended)
Vortex meter	(dry steam, good option)
Ultrasonic flowmeter	(option for larger pipes, HP)

Metering

An alternative to the measurement of the steam is to measure the boiler feed water or condensate return.

Boiler feed.

High accuracy at point of measurement but allowance must be made for ‘blow down’ of boiler and for any water droplet carry over.

Condensate return.

High accuracy but condensate must be free of any flash steam.

Ideal for measuring consumption of a single appliance

Metering

Secondary Instrumentation

Any primary flow meter is only as good as the instrumentation used to process or display the flow signal.

In virtually all applications a flow computer should be used to compensate for any variations in density.

With saturated steam it is only necessary to use either a pressure input or a temperature input.

With superheated steam, both pressure and temperature inputs should be used.

Some principles of meter will benefit from linearisation by the flow computer.

Voor meer informatie,

ga naar

Energiemetingen

op

www.flowmeters.nl