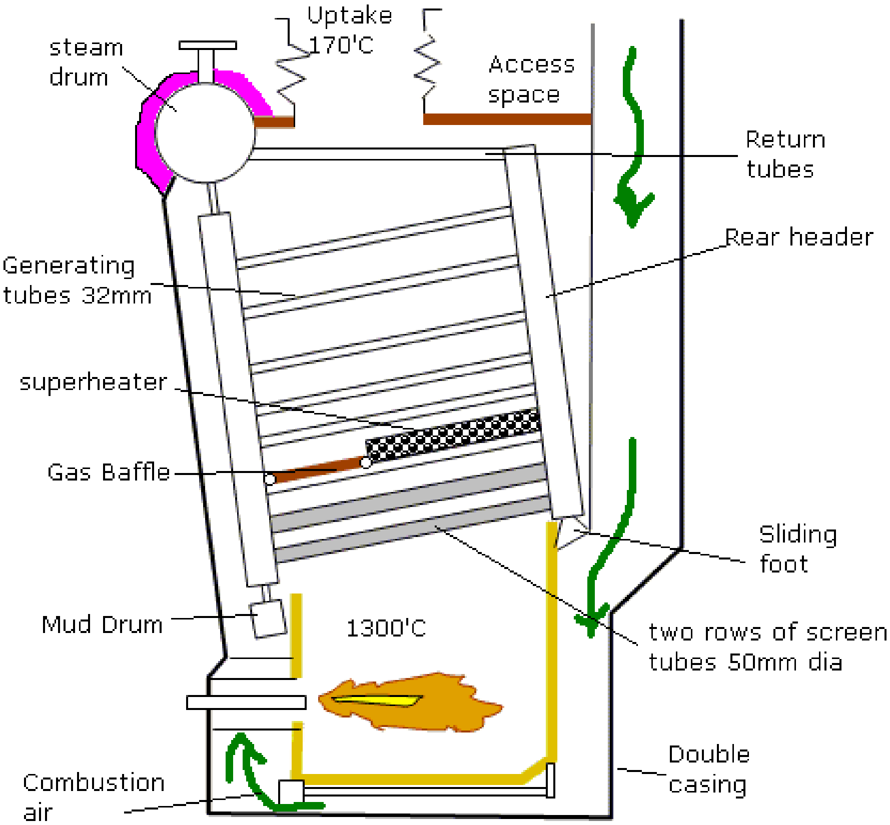
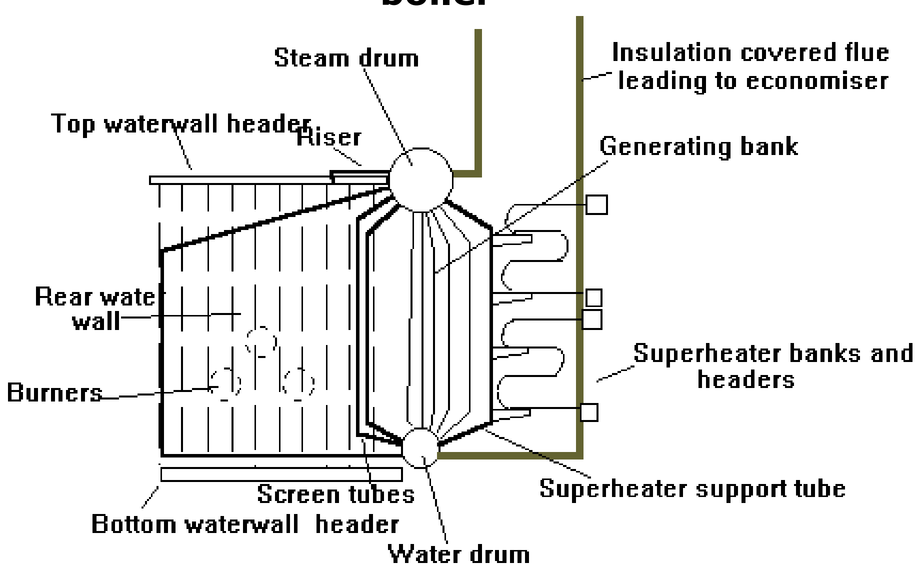
Basic Boiler Construction

Header

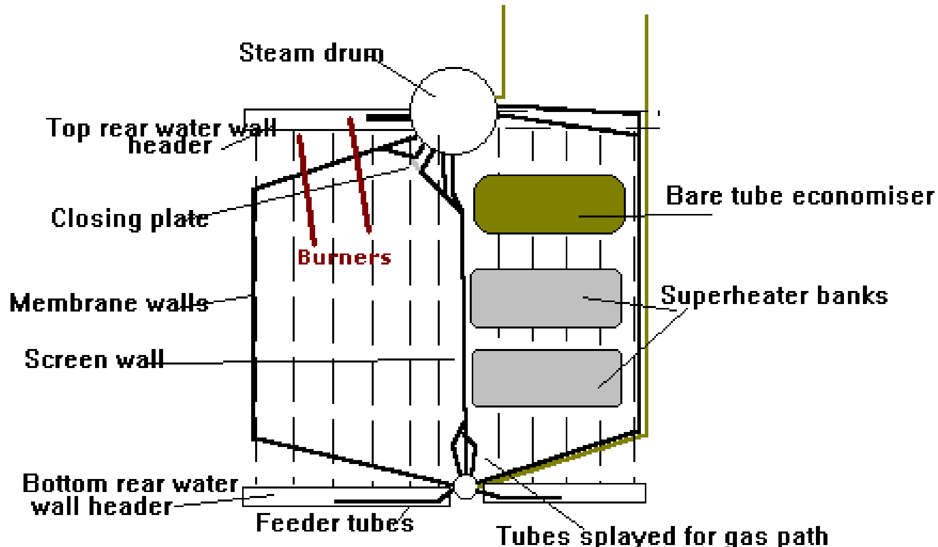


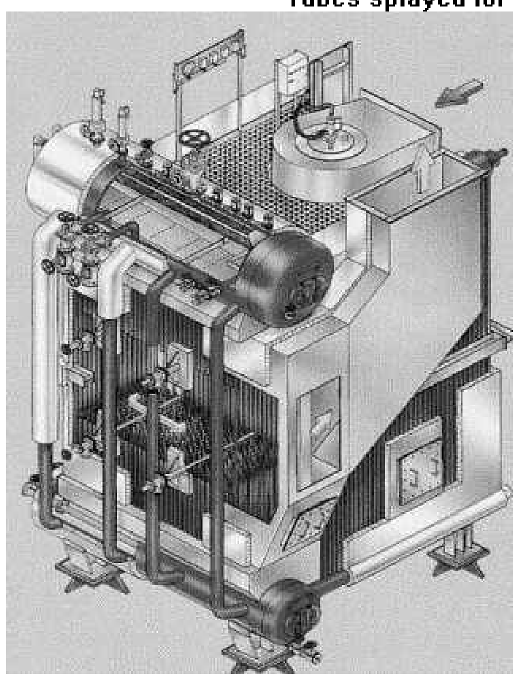
This design allows the use of lower quality feed. It is easy to clean and easy to maintain and replace tubes. Disadvantages are the large number of handhole doors and the extensive brickwork. The drum is all welded and the casing bolted.

Front fired studded wall refractory covered boiler



Roof fired membrane wall modern Radiant heat boiler





Components

Steam drum

In the early designs the drums were riveted or solid forged from a single ingot, but for modern boilers the drum is generally fabricated from steel plate of differing thicknesses and welded. The materials used are governed by classification society rules. Test pieces must be provided.

The cylindrical drum is normally constructed from four plates. Two dished End plates, a thick wall tube plate (thicker to accommodate the holes drilled in it without increased stress) and completed with a thinner wrapper plate.

Construction takes the form of rigidly clamping the de-scaled, bent wrapper and tube plates together. In addition test pieces cut from the original material are attached to the construction in such away that the longitudinal weld extends either sided of the join. These pieces are later removed and shaped test shapes cut out from specified areas including across the weld.

The longitudinal weld is critical (taking twice the circumferential stress) and is normally carried out by specialised automatic machinery using submerged arc techniques.

The dished end pieces are accurately aligned and welded.

On completion the construction is cleaned and non-destructive testing-such as x-ray photography, carried out. Final machining is carried out and any stub pieces and doublers attached. The now complete drum is heat treated at 600 to 650'C.

The final process is hydraulic testing to classification requirements. Natural circulation within a boiler is due to the differing specific gravities of the water at the differing temperatures, the steam drum provides a reservoir of cool water to give the gravitational head necessary for natural circulation. Cool water entering the steam drum via the feed lines provides the motive effect for the circulation distributing it to the downcomers.

Also the space within the drum provides for the separation of the steam and water emulsions formed in the water walls and the generating tubes. Water droplets entrained with the separated steam are removed by separating components fitted in the drum as well as the perforated baffle plates fitted at the water line.

The space above the water line provides for a reserve steam space needed to maintain plant stability during manoeuvring conditions.

Also fitted is the chemical injection distributing pipe and the scuming plate.

The smaller the drum is made, the less thickness of material that is required. However, the limitation to how small is that sufficient space must be allowed for the separation of water from the steam before passing out to the superheater space otherwise dryers must be used. Also, due to the smaller reserve of water, larger fluctuations in water level occur during manoeuvring.

Water drum

Distributes feed water from the downcomers to the headers and generating tubes. Provides a space for accumulating precipitates and allows them to be blown down.

Water drum size is limited to that required to receive the generating tubes, for modern radiant heat boilers with only a single bank of screen tubes and no generating tubes between the drums, the water drum has been replaced by a header and the downcomers fed straight to the waterwall headers. With system blow down is done at the steam drum. Too small a water drum can cause problems of maintaining ideal water level and little steam reserve

Headers

These have a similar purpose to the water drum but are smaller in size. Due to their reduced size they may have a square cross section without resorting to exceptional thickness.

Generating tubes

Consists of a large number of small diameter tubes in the gas flow, more commonly found in boilers of an older design.

For roof fired boilers the generating bank may consist of one or two rows of close pitched tubes. For a modern radiant heat boiler the generating bank has been omitted to allow the replacement of the water drum by a distribution header, a bare tube economiser is fitted generating 5% of the steam capacity. The generation bank is normally heated by convection rather than radiant heat.

For a set water circulation the tube diameter is limited to a minimum as the ratio of steam to water can increase to a point where the possibility of overheating could occur due to the lower heat capacity of the steam.

The number of tubes is limited to prevent undercooling of the gas flow leading to dew point corrosion.

Screen tubes

These are larger bore tubes receiving the radiant heat of the flame and the convective heat of the hot gasses. The large diameter keeps the steam/water ratio down hence preventing overheating. There main duty is to protect the superheater from the direct radiant heat. On a modern marine radiant heat boiler the screen wall is formed out of a membrane wall.

Waterwall tubes

Contains the heat of the heat of the furnace so reducing the refractory and insulation requirements.

- **Comes in three designs**
- **water cooled with refractory covered studded tubes**
- **Close pitched exposed tubes**
- **Membrane Wall**

Downcomers

These are large diameter unheated i.e. external to the furnace, their purpose is to feed water from the steam drum to the water drum and bottom headers.

Riser/Return tubes

These return steam from the top water wall headers to the steam drum.

Superheater tubes

These are small diameter tubes in the gas flow after the screen tubes. Due to the low specific heat capacity of the saturated steam they require protection from overheating in low steam flow conditions, say when flashing.

Superheater support tubes

These are large diameter tubes designed to support part of the weight of the superheater bank of tubes.

Material requirements

Tube temperatures for the water cooled sections are considered to be saturation temperature plus 15°C. Solid drawn mild steel is generally used.

Tube temperatures for convection superheater sections is considered to be final superheat temperatures plus 30°C. For Radiant heat a higher temperature is considered.

For Superheater tubes operating above 455°C a Chrome Molybdenum alloyed steel is required.

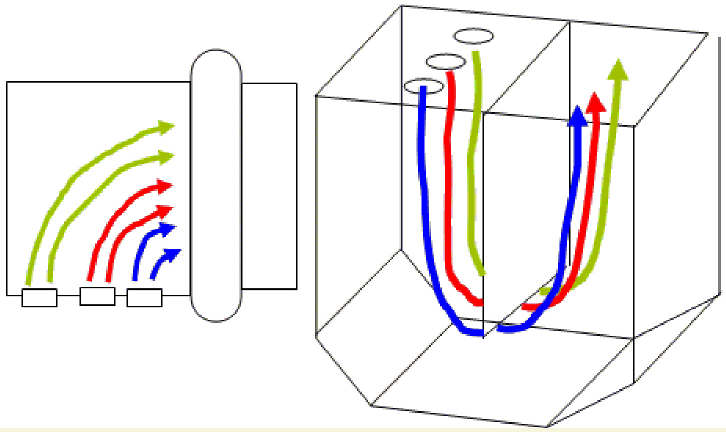
Advantages of membrane/monowalls

These were originally introduced in land power stations after experience had been gained in making the lower parts of the furnace sufficiently tight to hold liquid ash. This was achieved by welding steel strips between the floor tubes. Further development resulted in completely gas tight furnace wall panels being constructed by welding together either finned tubes or normal plane tubes with steel strips in between and welded. In both methods he longitudinal welds are done by automatic processes and panels of the required size are built up in the factory ready for installation into the boiler in one piece.

- Entire walls may be prefabricated
- Maintenance costs, particularly of insulation are lower
- Lower quality fuels may be used due to the much reduced amount of insulation reducing problems of slagging
- Simplified water washing procedures
- Due to gas tight seal there is no corrosion of outer casing.

A disadvantage would be that tube replacement following failure is more difficult. Also, the possibility of entire walls parting from the drum can occur during a furnace explosion.

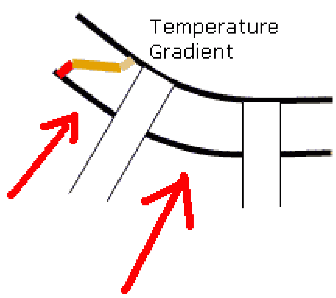
Advantages of roof firing over side firing



- **Increased efficiency due to the longer length allowed for the flame giving more time for complete combustion. This also allows more heat to be released as radiant rather than convective cutting down the required number of screen wall generating tubes**
- **The longer period allowed for complete combustion means that less excess air is required; this has the knock on effect of lowering the Dew Point of the flue gasses.**
- **Equal length flames**
- **Better gas flow**
- **For roof fired the effect of each flame is the same, for side firing it differs. To keep within the design limitations the boiler must be operated to the highest effect flame with the other two operating at reduced effect**

Ligament Cracking Mechanics

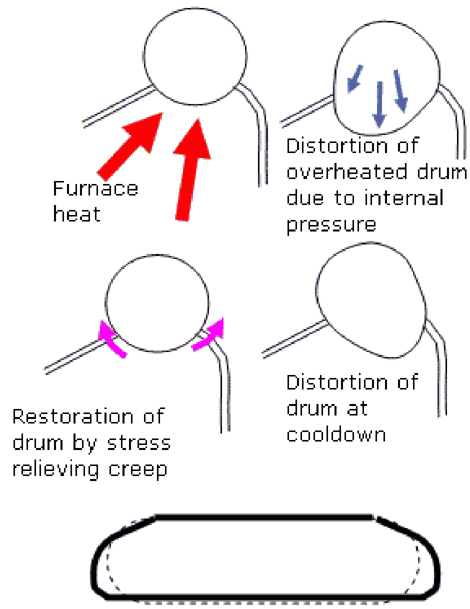
Generally associated with failure of refractory plug located beneath steam drum.



Hot gasses acting on the thick section tube plate set up a temperature gradient leading to creep, plastic flow to relief thermal stress and high tensile stress on the surface at cool down. In addition grain growth leads to the metal becoming brittle

A more severe form may lead to distortion of the entire drum in two possible directions. The thick section tube plate is exposed to the heat of the furnace and is subject to overheating. Thermal distortion takes place leading to stressing. This stressing is relieved by creep. When the drum cools a set distortion is in place

The distortion may occur in three ways, in a radial or axial direction as shown below.

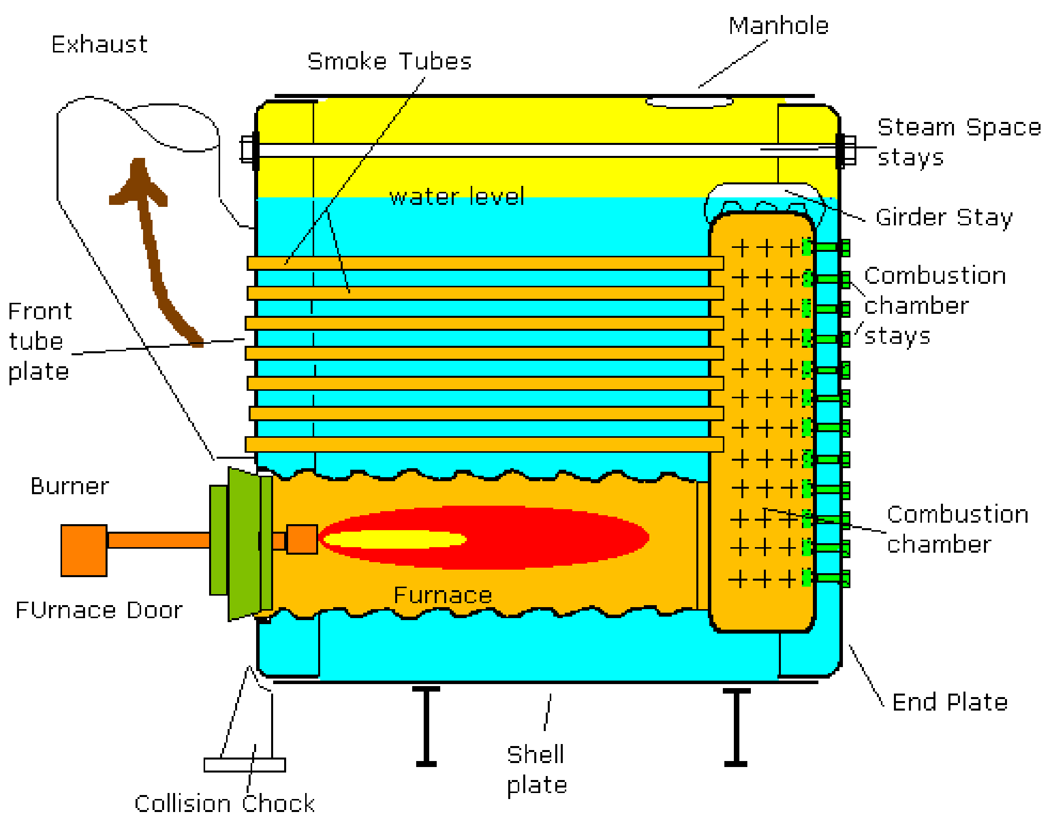


Thermal distortion of steam drum

The Direction of the cracking indicates how it occurred.

Smoke tube Boilers

Tank (Scotch) Boiler



These were the most common form of boiler design before the introduction of water tube designs. See Comparisons of water tube and Smoke tube boilers.

This style of boiler still see active service was low quantities of low quality steam is required, such as for cargo and fuel tank heating when in port.

This style of boiler is relatively cheap, supplied as a packaged unit and requires less stringent feed water conditioning and level control.

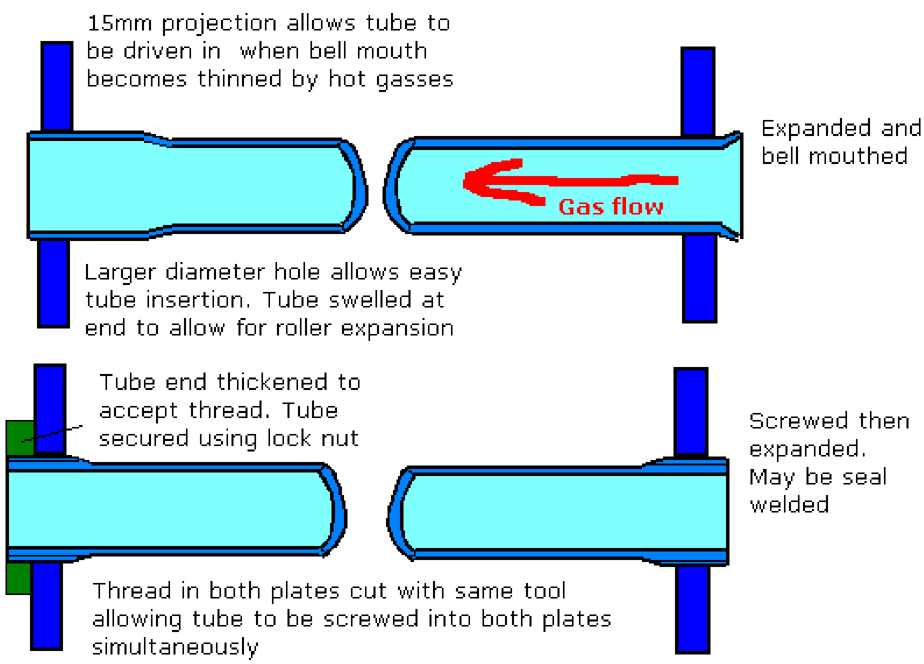
Design

Consists of a shell wrapper plate to which is welded (or for later designs riveted, end plates.. Pressure is naturally container in the shell plate due to is cylindrical design. The flat end plates, however, must be 'stayed' to prevent buckling and distortion.

The combustion chamber is of similar section and is also 'stayed'.

The boiler shown above is a single furnace, two pass design. Larger boilers may have multiple furnaces and have multiple passes by replacing the exhaust stack with a return chamber and fitting another bank of tubes.

The smoke tubes may be plain or threaded to act as stays. There are one stay tube for every three plain tubes approx.



To aid circulation the tubes are arranged in vertical rows to offer minimum resistance.

Fuel is combusted in the corrugated watercooled furnace. The corrugations increase the surface area and allow a degree of flexibility to allow for expansion and contraction.

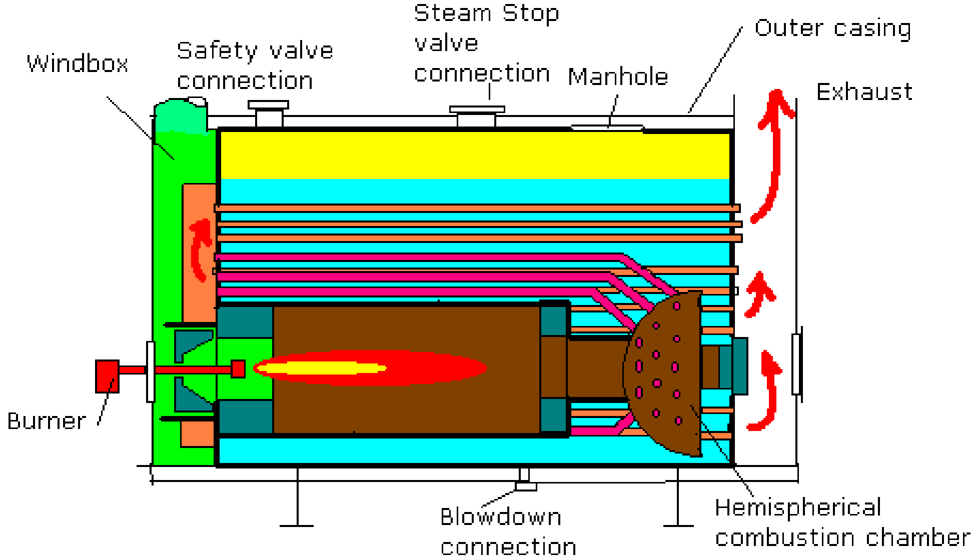
The hot gas passes to the water cooled combustion space though to the smoketubes. The upper portion of the combustion chamber lies close to the water level and is therefore liable to distortion due to in correct water level maintenance.

Access to the boiler is via a manhole door on the upper shell plate. In addition a smaller door may be fitted below the furnace to allow inspection and scale/sludge removal.

Modern (packaged) boiler

This style of boiler may be fitted to the vessel as a complete unit with its own fuel and water delivery systems, control and safety equipment mounted directly on the unit. Alarms and shut downs may be are given at the local control panel which may be interfaced with ships alarms system to allow UMS operation.

The design is similar to the Scotch boiler other than the combustion chamber which requires no stays. This design is a three pass design.



Operation

Although the maintenance of the water level is not so critical as with water tube designs, it should not be allowed to fall too much as overheating of furnace and combustion spaces leads to catastrophic failure due to component collapse. The content of the boiler is then expelled via the furnace door.

Similarly, although water treatment is not so critical scale must not be allowed to build up which can lead to overheating of material

Although package boilers of this design are fairly robust it should not be forgotten the potential for danger a poorly maintained unit can be.

The author carried out a supposed routine inspection on one such unit. Opening the upper manhole revealed that the unit has been 'wet layed' with water left at normal working level rather than being pressed up. Severe pitting was present at and just below the water level.

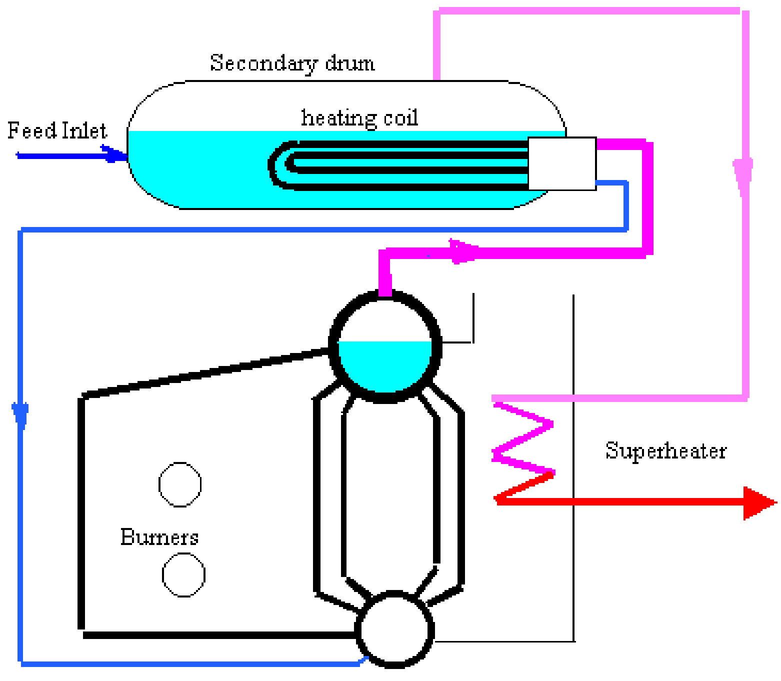
The lower man hole door beneath the furnace was opened after draining the water. Heavy wastage could be seen later measured at 60 % of the shell plating with pitting on top of this. Evidently no oxygen scavenger, such as Sodium Sulphite, had been added before laying up.

In this condition, operation at full load would almost certainly have led to catastrophic failure.

Dual Pressure (double evaporation) Boilers

The main reason for the adoption of this design of boilers is to allow use of modern high efficiency watertube boilers without fear of damage through contamination by cargo or fuel oils.

The basic design consists of a D-Type boiler design upon which is mounted a Steam/Steam generator drum. The steam generated by the main boiler heats water in the Steam/Steam generator which produces steam requirements.



The primary drum is initially filled with high quality feed water and suitably dosed. Make up is limited to small amounts due to leakage therefore the feed pump may be of simple design. An example could be a steam or air driven reciprocating pump. The chemical treatment is simple with little requirement for addition or blow-down.

The above design shows the fitting of a superheater. These are normally only fitted where the generated steam will be required to power turbine operated machinery most typically an alternator.

Secondary drum.

The U-tube heating elements are passed through the manhole dorr and expanded into headers welded into the dished end of the drum. The tubes are well supported. A manhole may be fitted at the lower part of the shell allows access to the heating elements.

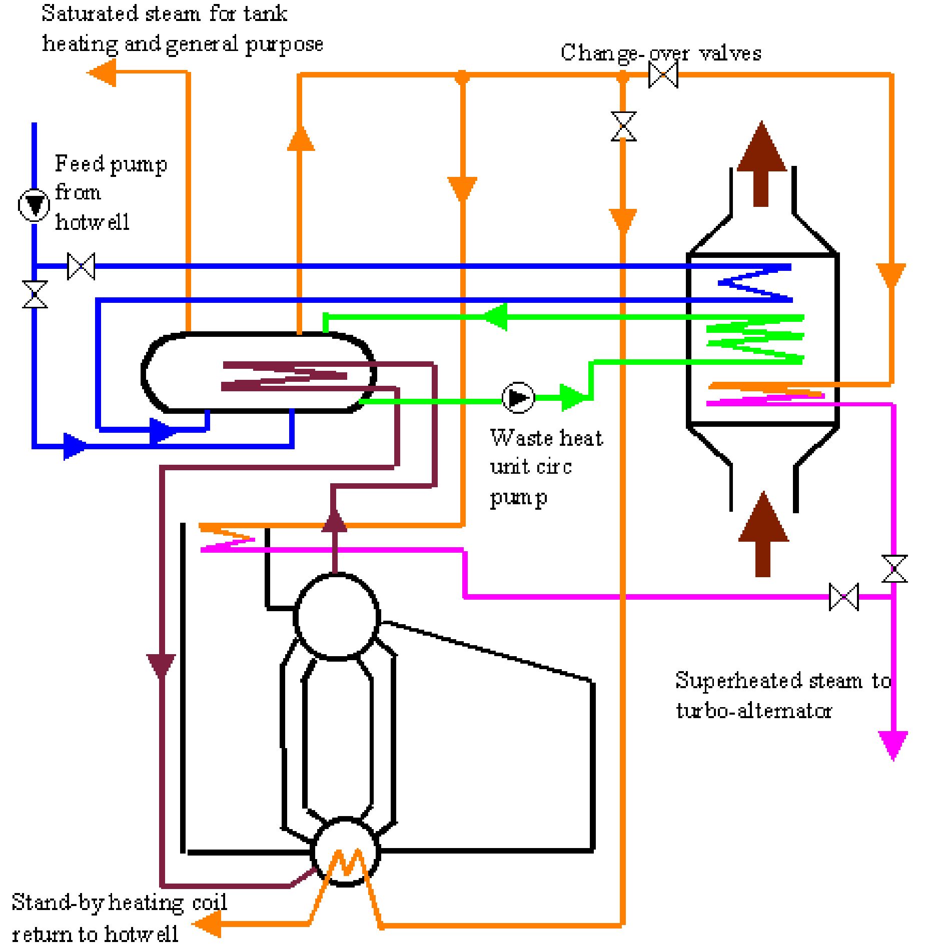
The drum is generally mounted integral, supports are attached to the structure of the primary boiler. The secondary drum also acts as a steam receiver for the exhaust gas boiler. Typical pressures are 63 bar for the primary circuit and 23.5 for the secondary.

The author has not sailed with pressures anywhere near this with this design. Primary pressures of 35bar and secondary pressures nearer 15 bar have proven sufficient even to drive an alternator. Of note is that these designs are obviously more expensive than a normal single steam drum plant even taking into account the improved efficiency. They are therefore generally associated with larger motor powered plant with large waste heat units capable of supplying all requirements including an alternator. However the author has sailed on this plant on a 20,000 tonne product tanker.

Where these boilers are installed in Motorships a "simmering coil" may be fitted. This is located in the primary drum and is supplied from the exhaust economiser to keep both circuits warm thereby preventing any possible damage due to lay-up.

Mountings are those typically found on any boiler with low level water alarms and low/low level shut off on both boilers. The accumulation of pressure test for the safety valves fitted to the secondary drum are calculated with the primary boiler firing at maximum rate generating maximum heating steam supply.

Typical circuit incorporating Dual Pressure Boiler



Under port conditions the main boiler is fired to providing heating steam for the secondary drum. From this steam is supplied for tank heating or to a turbo-alternator via a superheater.

When the vessel is underway the main boiler may stop firing. A waste heat circulating pump passes water from the secondary drum via the waste heat unit back to the drum. The steam produced is again available for tank heating and powering a turbo-alternator.

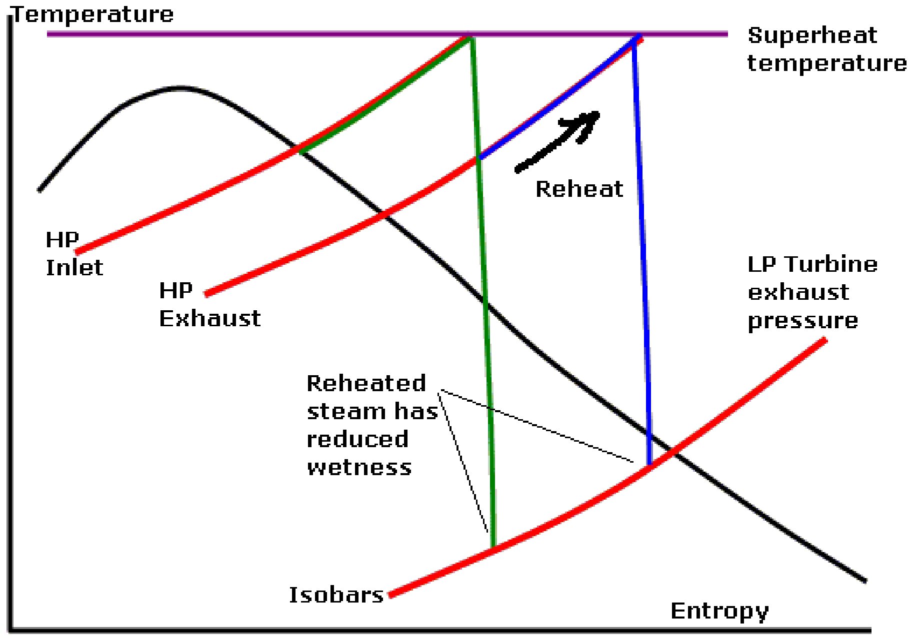
Cross over valves is fitted for Harbour and sea-duty conditions.

Advantages and disadvantages of watertube boilers

- **Advantages over tank**
- **Savings in weight of about 3:1 for a comparable heating surface area**
- **Possibility of using higher temperatures and pressures without unduly increasing wall thicknesses increases plant efficiency.**
- **More efficient combustion space allowed**
- **Greater flexibility of the structure and rapid circulation prevents the problems of thermal stressing in the tank boilers which leads to grooving. In water tube boilers roof and floor tubes are sloped at 15' to ensure circulation**
- **thinner tube materials allow rapid steam raising and faster heat transfer rates**
- **Saving in space for same steaming rate**

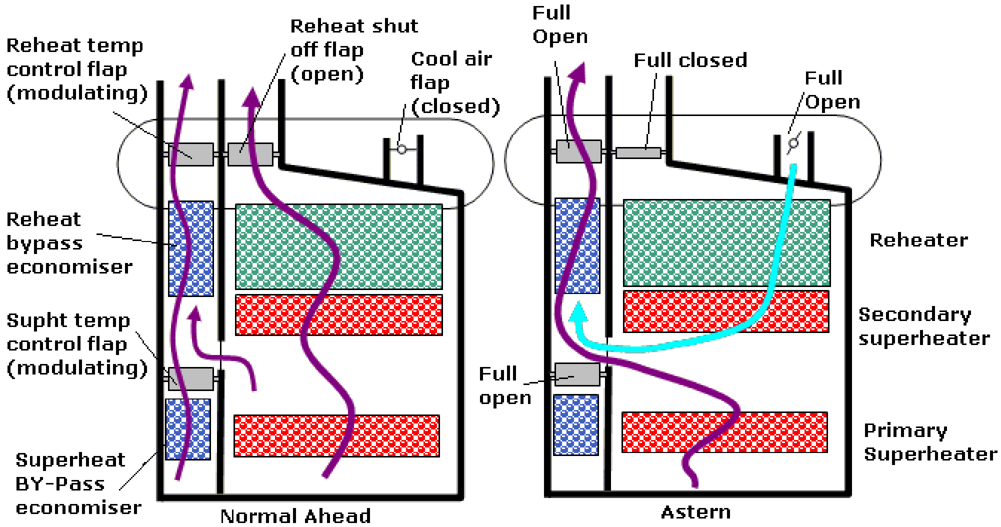
- **Wider safety margins- limited tube diameters and protected drum surfaces mean failure in tubes releases a flow of steam dependent on tube diameter**
- **Thin tubes are easier to bend, expand and bell mouth**
- **Disadvantages**
- **Lower reserve of water means a more efficient water level control is required**
- **High quality feed required**
- **little allowance to corrosion </UL< ul>**

Marine Radiant Reheat Boilers

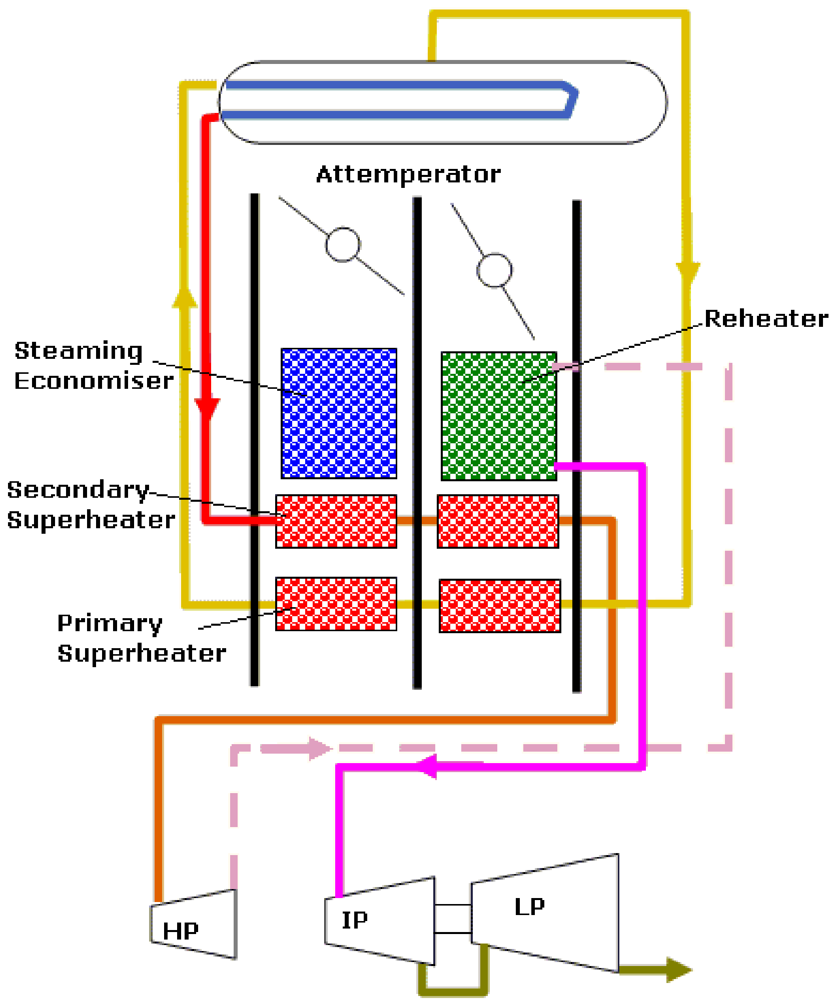


To increase plant efficiency reheat systems are used. In this the exhaust from the HP Turbine is led back to the furnace and reheated to superheat temperatures. This allows the steam to be expanded to lower pressures in the LP turbine with reduced need for blade taper twist and other efficiency degrading designs to cope with the steam wetness.

The boiler design is of a standard roof fired radiant furnace with a gas tight membrane water wall and single row of screen tubes. The convection space is divided into a superheater and re-heater section and a section containing superheat and reheats temperature control by-pass economisers. Gas dampers allow cooling air from the windbox to pass over the re-heater section during astern manoeuvres to prevent overheating and thermal shocking when the plant is moved ahead.



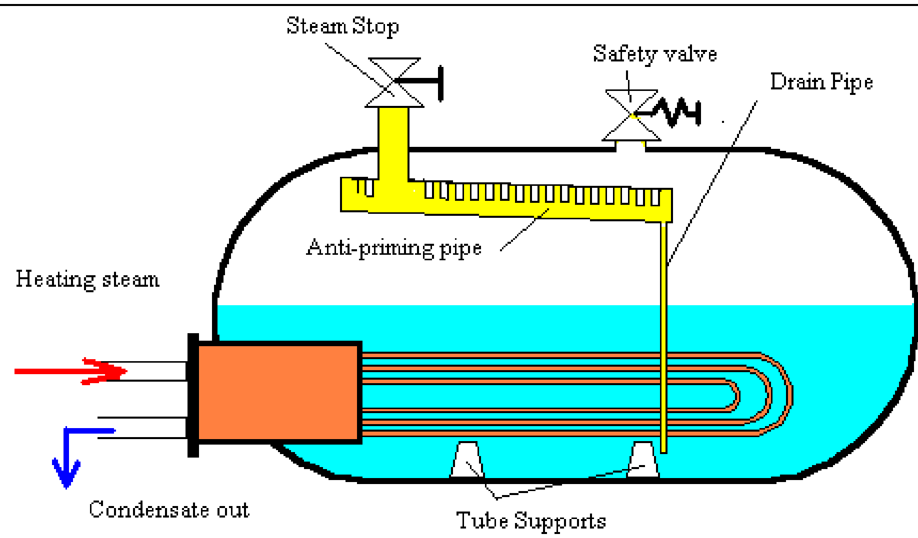
An alternate design using water drum attemperation for superheat control rather than by-pass economisers splits the convective zone into two parts.



The superheaters in the reheat section ensure that gas is cooled sufficiently to prevent overheating in the reheat in the event of gas damper leakage. Provision is made to allow windbox air into the reheat space in the event of damper failure.

- **Advantages of MRR boiler. These are common with any radiant boiler over the convective type design**
- **Increased plant efficiency**
- **Improved combustion**
- **Less excess air requirement. This has the additional advantage of reducing dew point corrosion in the uptake**
- **Refractory limited to burner quarls and exposed section of water drum and bottom header. This allows for poor quality fuels due to reduced slagging**
- **Furnace Gas tight**

Steam-Steam Generators-



Found on steam propulsion plant and used for the production of low pressure steam for tank heating purposes. The heating steam circuit may be separated from the main system to reduce the risk of oil contamination in the main boilers.

Generally the heating steam is supplied from the Intermediate Pressure system. Under sea conditions there is sufficient exhaust steam capacity to supply the IP system requirements. In separated duty, live HP steam may be separated and pressure reduced as make up.

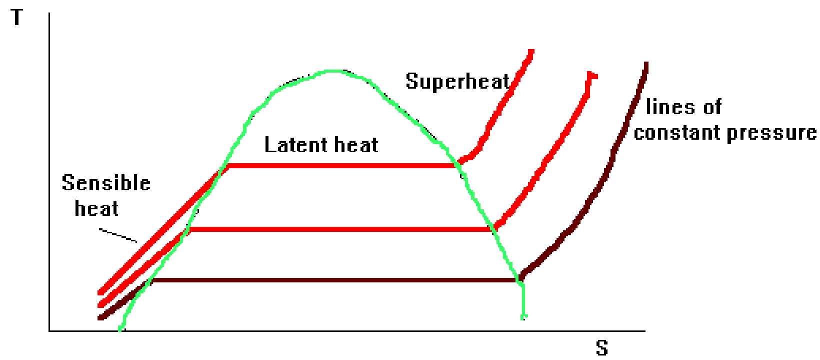
Superheaters

Reason for superheating steam

The maximum efficiency possible for a plant is given by the Carnot cycle and can be calculated using the formula:

$$Efficiency = T1- T2/ T1$$

Where T1 is the maximum temperature in a cycle (Kelvin) and T2 is the minimum temperature in a cycle. For the steam plant these equate to boiler outlet temperature and the exhaust temperature of the turbine.



Hence, to increase final temperatures at boiler outlet conditions either; the boiler pressure can be increased, or the degree of superheat can be increased. Boiler pressure increase is ultimately limited by the scantling requirements, more importantly however; the energy stored within the steam is little increased due to the reduction in the latent heat.

Increasing the degree of Superheat not only increases the temperature but also greatly increases the heat energy stored within contained another advantage would be that the onset of condensation through the turbine would be delayed. However this increases the specific volume which would require excessively large plant. Also there would be insufficient pressure drop for efficient expansion through the turbine. There would also be little allowance for feed heating.

There is therefore a combination of increased Pressure and Superheat to give the increased efficiency potential allied with practical design parameters.

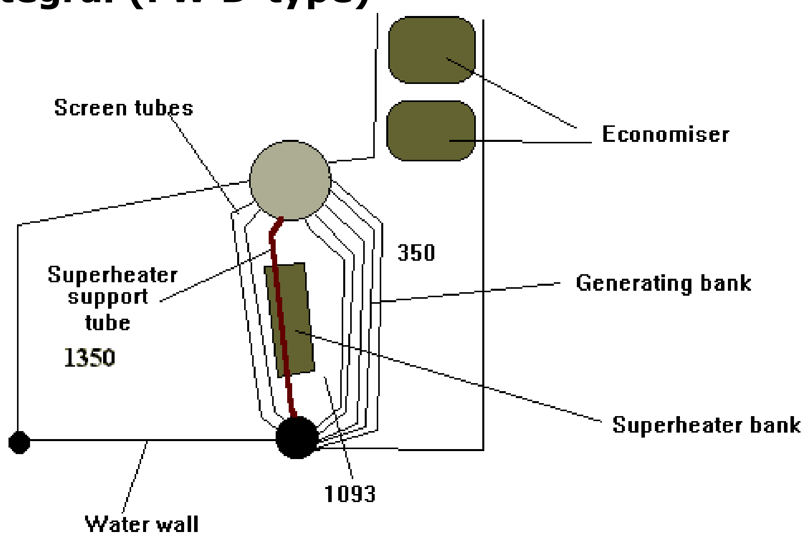
Limit of Superheat

Superheated steam, having a lower specific heat capacity then water does not conduct heat away as efficiently as in water cooled tubes, and hence the tube metal surface temperature is higher.

This has led to the external superheat design and parallel steam flows in an effort to keep metal temperatures within limits. For mild steel, up to 455°C superheat is possible; for higher temperatures, up to 560°C the use of chrome molybdenum steels is required. The use of special alloy steels introduces manufacturing and welding difficulties. It can be seen that there is a requirement for some form of superheat temperature control

Positioning of the superheater

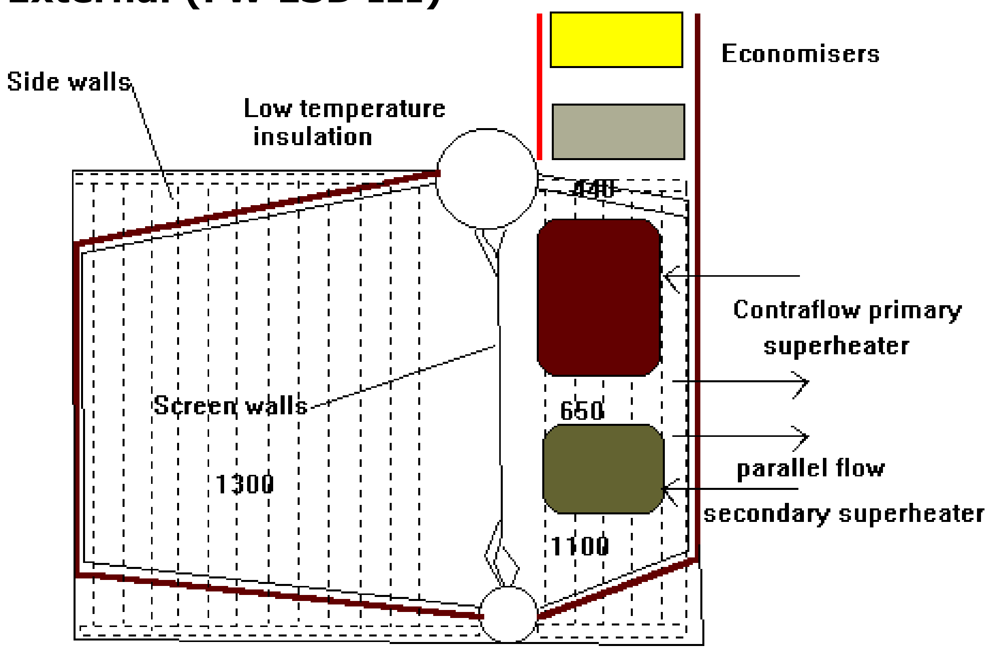
Integral (FW D-type)



This design suffered from heavy slagging of the tubes, particularly the superheater bank, caused by the vanadium bearing ash of the increasingly poorer quality fuel blends.

This ash caused a heavy bonding slag deposit which often bridged the gap between the tubes. This slagging attached to the hot surfaces of the superheater support tube led to wastage and failure. Increasing slagging would eventually lead to blockage and hence reduced gas path with increased gas velocities over the smaller number of tubes, this led to overheating and failure. Access for cleaning was limited, this and the problems outlined above led to the external superheater design.

External (FW ESD III)



In this position the superheater was protected from the radiant heat of the flame and with roof firing complete combustion was ensured within the furnace space with no flame impingement, this allied to reduced gas temperatures meant that conditions for the superheater bank was less arduous. The positioning of the superheater banks allowed for easier inspection and cleaning. More effective sootblowing could also be employed. With the positioning of the bank external meant that the surface area of the nest had to increased to give the same heating effect. Mounting of the tubes in the athwart ships direction allowed for a simpler mounting arrangement. The secondary superheater, mounted below that of the primary superheater was of the parallel flow type, this ensured that the lower temperature attemperated steam was in the tubes in the highest temperature zone. In modern Radiant Heat boilers it is common to mount the primary superheater below that of the secondary and use parallel flow throughout; this ensures adequate cooling throughout.

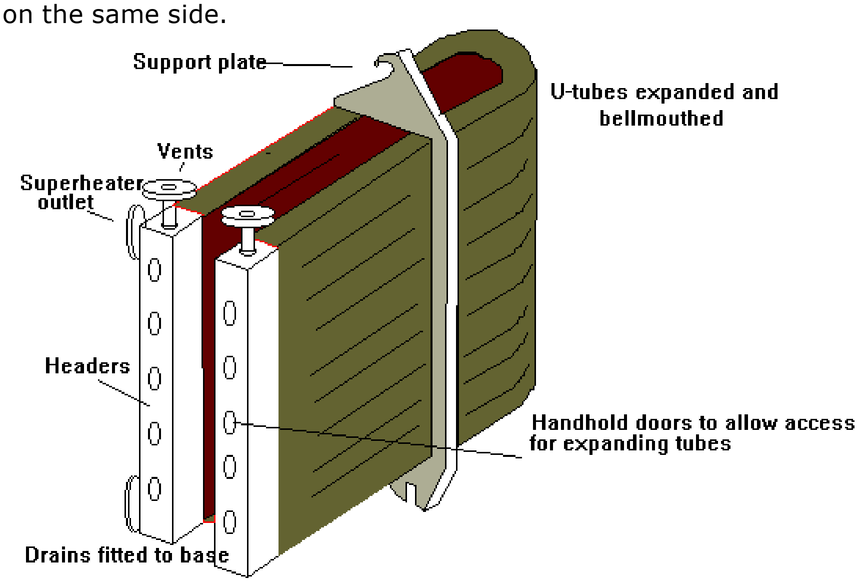
Designs of Superheater banks and mounting arrangements

U-Tubes

Use limited to the integral positioning fort he superheat bank, the modern method is to hang the tubes vertically; this prevents the sagging that can occur with the tubes in the horizontal.

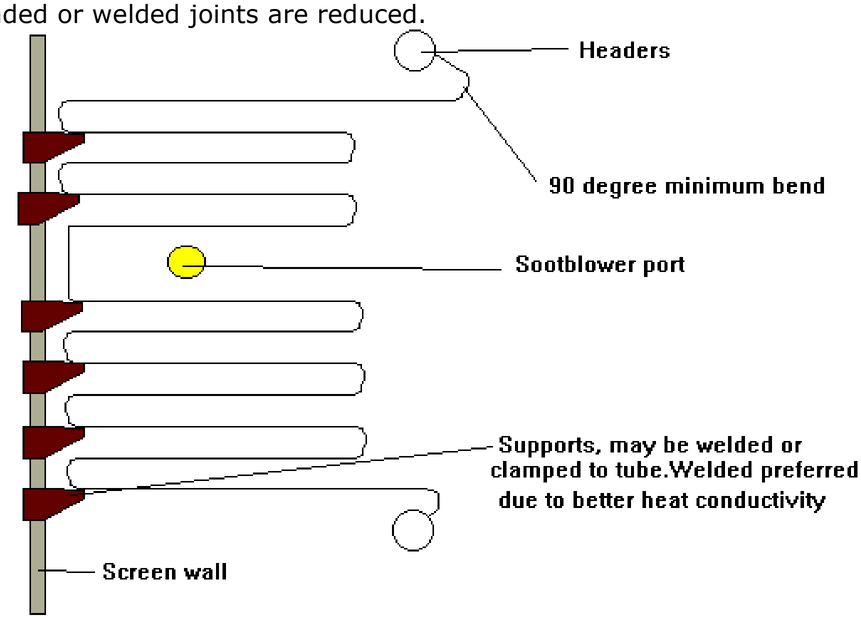
The tubes were supported by a support plate which hung off a special increased diameter water cooler tube called the support tube. As the supports were situate in a high temperature zone they were susceptible to failure.

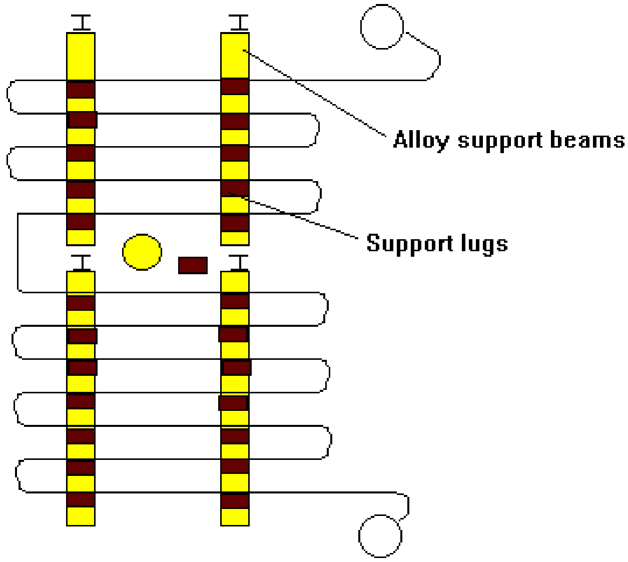
Division plates were welded into the headers, these allowed the steam to make many passes increasing the efficiency of the bank. Small hole were formed in these plates to allow for proper drainage, failure of these plates caused short circuiting, overheating and subsequent failures. Failure of a single tube, although possible leading to a restriction in the flow meant that the heating surface was reduced by only a small amount. The superheater inlet and outlet flange were mounted on the same side.



External (melesco type)

In this design there are no baffles fitted inside the header, instead the steam makes a multipass over the gas by way of the many limbs or bends of each tube. The disadvantage of this system is that if a tube should fail then a significant reduction in heating surface would occur. Simpler, more reliable support methods are possible allied to the easier access and sootblowing arrangement. This type of superheater has the advantage that the number of expanded or welded joints are reduced.



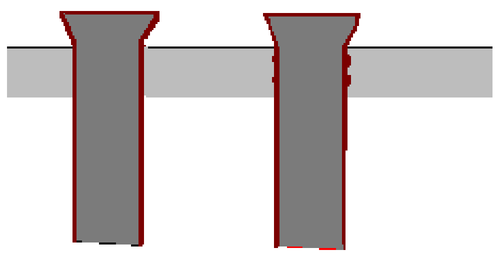


With this design the initial passes are made of Chrome Molybdenum steel. a transition piece attaches this to the mild steel passes. The inlet header is made out of mild steel and the outlet an alloy steel.

Methods of attachment

Expanded

Only used in superheaters fort temperatures up to 450°C Tube ends must be cleaned and degreased and then drifted and roller expanded into the hole, the end of the tube must be projecting by at least 6mm. The bell mouth must have an increase of diameter of 1mm per 25mm plus an additional 1.5mm. It is important that the tube enter perpendicular into the head, a seal will be assured if the contact length is greater than 10mm, if it is not possible to enter perpendicularly then the contact length should be increased to 13mm. For larger diameter pipes then grooved seats are used.



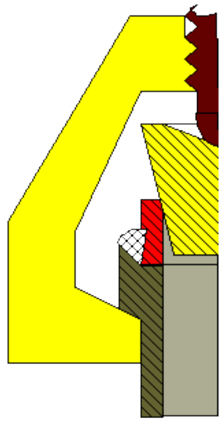
Welded

Welding gives advantages over expanding in that access to the internal side of the header is not so important and so the number of handhole doors can be much reduced eliminating a source of possible leakage. welding also generally provides a more reliable seal.

The disadvantage is that heat treatment following welding is required.

The purpose of the backing ring fitted to the conventional attachment method is to prevent the weld metal breaking through into the tube

- **The Melric joint offers the following advantages over the conventional method;**
- **Dispenses with butt joints and internal backing rings**
- **Allows for maximum access for welding**
- **The joints can be annealed locally by electric heat muff or torch according to manufacturers recommendations**
- **The stub bosses can be readily blanked off externally in the event of tube failure and so do not require the access to the header internal side**



Air Heaters

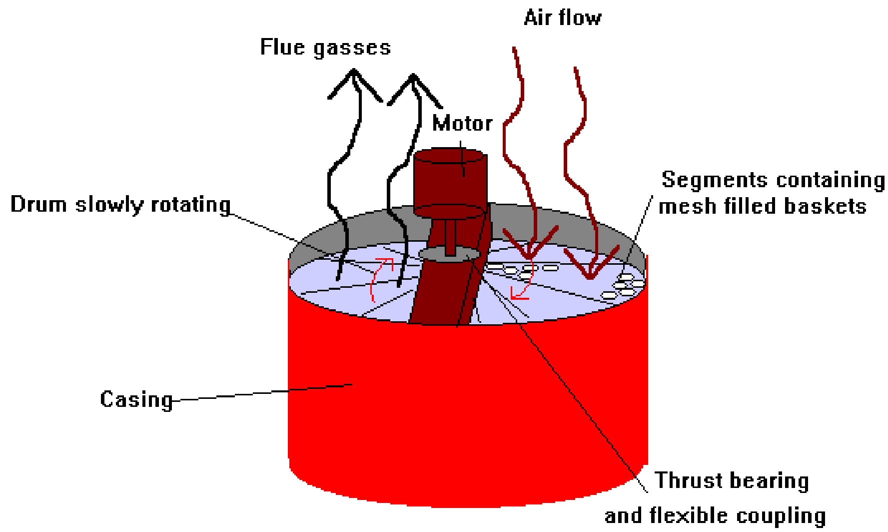
Reasons for their use

- **These are fitted for three main reasons**
- **To increase efficiency by recovery of heat from flue gases (except where bled steam heaters are in use, these increase overall plant efficiency but by a different method)**
- **Accelerate rate of combustion**
- **Avoid effect of cold air impinging on boiler surface**
- **As a by product air heaters also form a convenient way to warm up a standby boiler before initial firing.**
- **However, the effects of dew point corrosion and fouling in smoke tube air heaters should be taken into account when designing the heat absorption limit. I.E. the amount of heat to be removed from the flue gas should have a limit.**
- **For water tube boilers gas air heaters are only considered where the temperature at inlet to economiser is greater than 200°C. Due to greater heat transfer efficiency between gas/water economisers are preferred to gas/air exchangers.**

At low loads all gas/air heaters should be bypassed to keep uptake temperatures as high as possible.

Types of air heaters

Lungstrom gas/air heater (regenerative)



The drum contained within the cylindrical casing is formed into segments into which are placed removable (for cleaning) baskets, consisting of vertical plates (to give minimum resistance to flow) The drum slowly rotates, about 4rev/min, driven via a flexible coupling, gear train, clutch and thrust bearing by one of two electric motors; one mounted on top the other below.

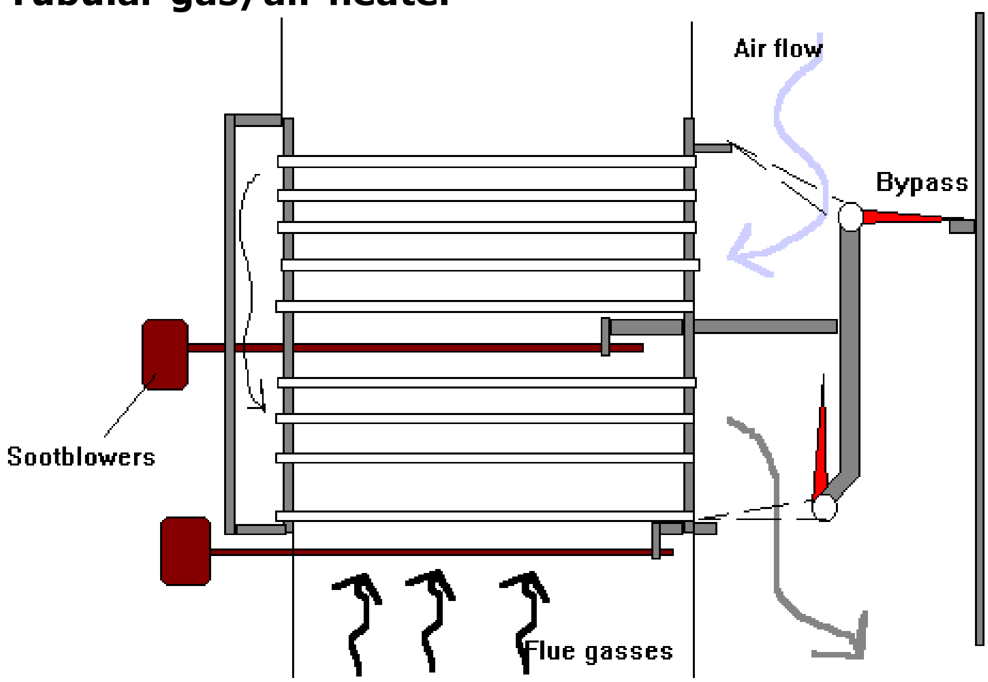
As the drum rotates a segment will enter the gas side, here it removes heat from the gas, it continues to rotate until entering the air side where it will give up its heat to the air. The heat transfer is very efficient, however, soot and corrosive deposits quickly build up in the mesh and hence an effective soot blowing method is essential. This normally takes the form of an arm, pivoted at the circumference of the drum with a single nozzle at the other end. This sweeps across the drum rather like a record arm. One of these arms is fitted top and bottom.

Gas leakage to the air side is prevented by the air being at a higher pressure and by fine radial clearance vanes fitted in the drum segments.

By passes for both air and gas sides are fitted to prevent fouling with the reduced gas flow and temperature, also during manoeuvring when the possibility of different gas/air flow rates occurring leading to high metal temperatures and possible fires.

Failure by uptake fires is not uncommon with this as in most gas/air heater designs.

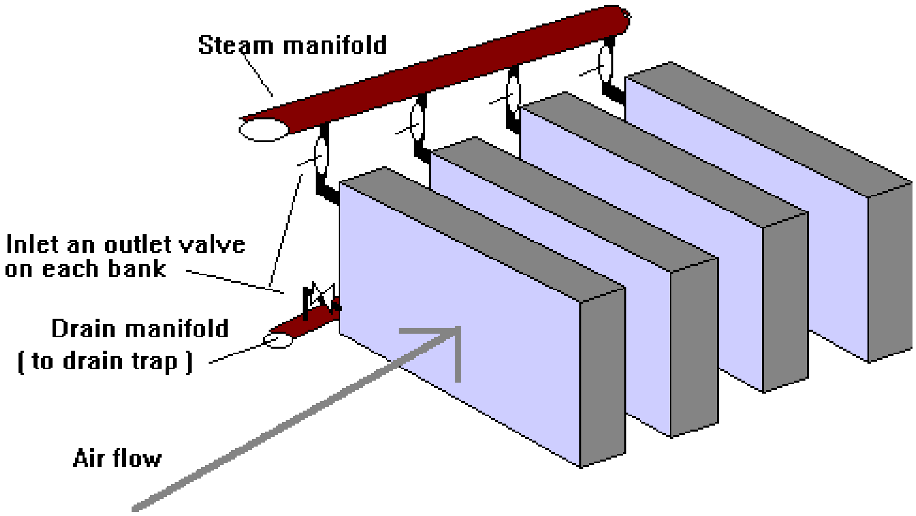
Tubular gas/air heater

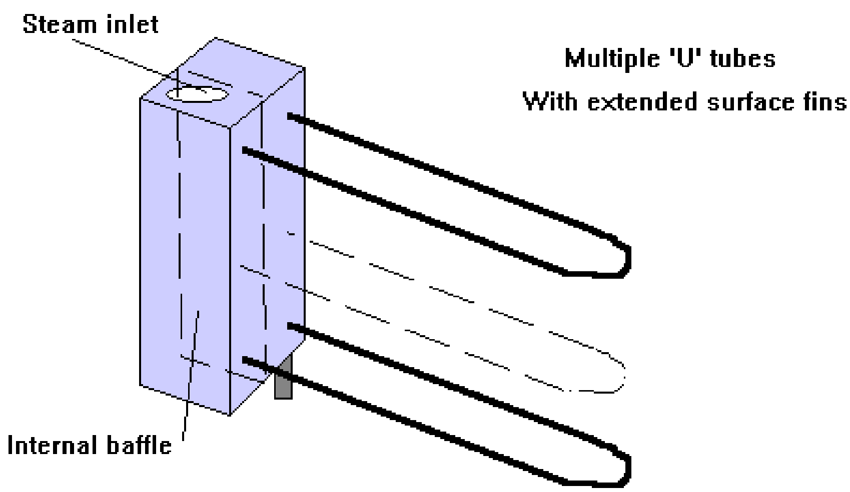


Shown above is the horizontal tube type air heater which was less susceptible to choking with soot than the vertical types sometimes found with older scotch boilers.

To aid cleaning water washing was sometimes carried out to aid the sootblowers.

Bled steam air heater





The use of individual banks and 'U' tubes allow for ease of isolation when these become perforated without large loss of heating surface. The tubes were expanded into the headers and made of cupronickel with copper fins.

Burners

Combustion of fuel in furnace and burner design

Process

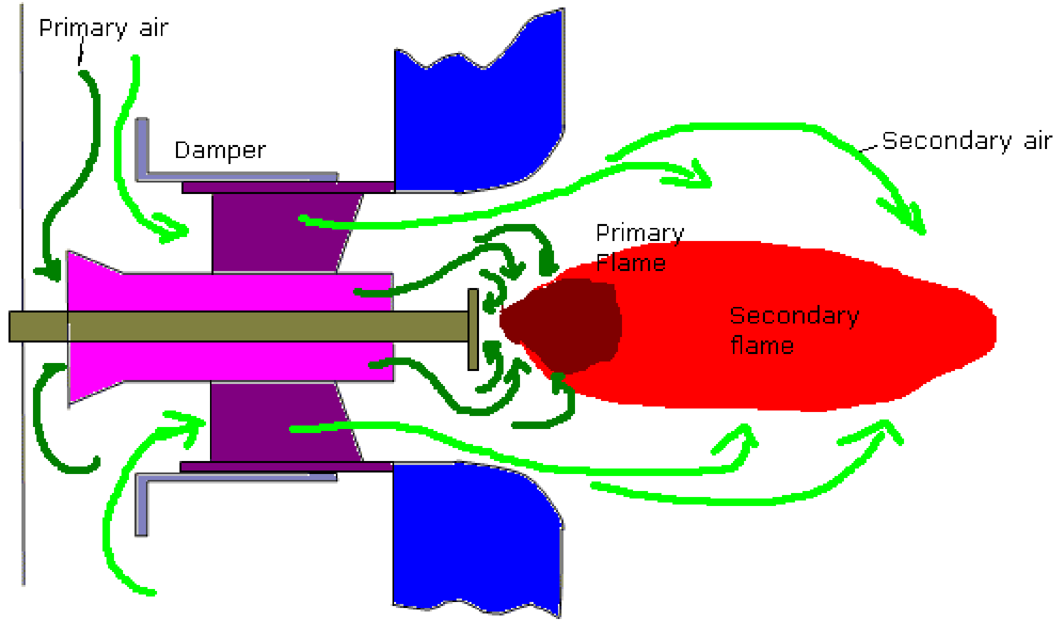
The heat producing constituents of the fuel are hydrogen, carbon and sulphur.

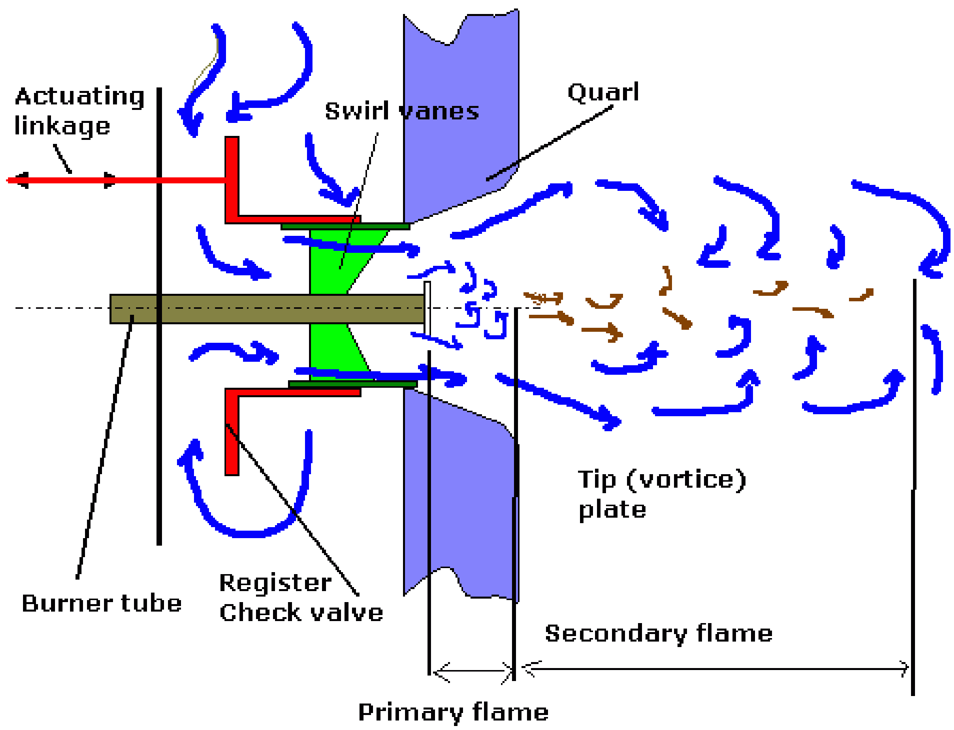
The calorific value of the combustion processes measured in mega joules for each Kg of fuel burnt

- **Carbon to carbon dioxide - 34**
- **Hydrogen to water - 120.5 (assuming the water vapor is not allowed to condense)**
- **Sulphur to sulphur dioxide - 9.3**

The main cause of heat loss with the process is that taken away by nitrogen. Therefore, to achieve maximum efficiency the excess air should be kept to a minimum. However there is a limit to the reduction in the excess air in that the combustion process must be fully completed within the furnace and within a finite time.

The main type of combustion process is called the suspended flame. The flame front remains in the same position relative to the burner and quarl. The fuel particles pass through the flame completing their combustion process and exiting at the same rate as the fuel entering.





Primary Flame-To burn oil the temperature must be raised to vaporisation temperature; this can not be done in heaters due to gassing but is done by radiant heat in the flame. The lighter hydrocarbons in the atomised spray are rapidly heated and burnt in the primary flame. The heavier fractions pass through this achieving their vaporisation temperature. The primary flame is essential to good combustion. By design the primary flame exists where it receives maximum reflected heat from the shape of the quarl. The size of the primary flame (shown smaller than actual in drawing) just fills the quarl space. Too large and impingement leads to carbon deposits building up. Too small unheated secondary air reduces combustion efficiency. The tip plate creates vortices reducing the mixing time for the air/fuel and reduces the forward speed of the flame.

Secondary Flame - Here the heavier fractions are burnt. The velocity of the air and fuel must be matched to the required flame propagations rate.

Combustion in furnace space

For proper combustion of fuel in the furnace and adequate supply of air must be supplied and intimately mixed with a supply of combustible material which has been presented in the correct condition.

Air - it is the purpose of the register, swirler vanes and (vortices) plates, and quarl to supply the correct quantity of air for efficient combustion suitably agitated to allow proper mixing.

The air is generally heated on larger plant to;

- **prevent thermal shocking**
- **improve the combustion process**
- **improve plant efficiency (bled steam and regenerative)**

Fuel It is the purpose of the burner to present the fuel in suitable condition for proper combustion. Generally this means atomising the fuel and giving it some axial (for penetration) and angular (for mixing) velocity. For effective atomisation the viscosity of the fuel is critical, for fuels heavier than gas or diesel oils some degree of heating is required. It should be noted that the temperature of the fuel should not be allowed to raise too high as this can not only cause problem with fuel booster pumps but also can cause flame instability due to premature excessive gasification (is that a real word-answers to the normal address).

The smaller the droplet size the greater the surface areas/volume ratio is, this increases evaporation, heating and combustion rate.

Combustion zones

Register - supplies the correct quantity of excess air. Too little allows incomplete combustion, smoking, soot deposits and flame instability. Too much excess air reduces combustion efficiency by removing heat from the furnace space, may cause 'white' smoking and promote sulphurous deposits. In addition too much excess air increases the proportion of sulphur trioxide to dioxide promoting increase acid corrosion attack in the upper regions. The register and to some extent the quarl determine the shape of the flame, short and fat for side fired boilers, long and thin for roof fired.

Flame burning off the tip - may occur after initial ignition or after a period of high excess air. The effect of this is to move the primary flame away from the quarl thereby affecting the combustion process leading to black smoke and flame instability. Two methods of bringing the flame back are to reduce excess air and introduce a hand igniters to ignite the fuel correctly, or to rapidly close then open the register damper.

Types

There are six main types of burner in common use;

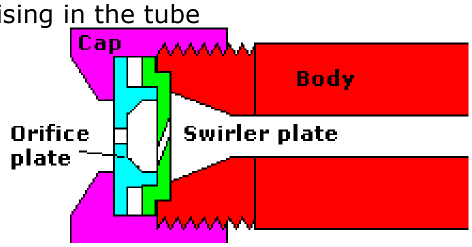
- **Pressure jet**
- **Spill type pressure jet**
- **Variable orifice pressure jet**
- **Spinning cup**
- **Steam assisted**
- **Ultrasonic**

Turndown ratio of minimum to maximum flow (roughly the square root of the ratio of maximum to minimum pressure).

Pressure jet

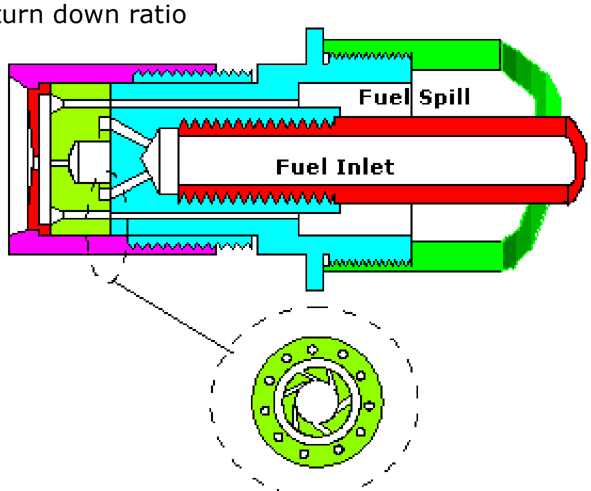
This is the simplest and oldest design of burner. Atomisation of the fuel is achieved by forcing the fuel under pressure through an orifice at the end of the burner; the pressure energy in the fuel is converted to velocity. Spin is given to the fuel prior to the orifice imparting centrifugal force on the spray of fuel causing it to atomise.

The disadvantage of this burner is its low 'Turn-Down' ratio (in the region of 3.5). The advantage is that it does not require any assistance other than supplying the fuel at the correct pressure. Due to this it is still seen even on larger plant were it is used as a first start or emergency burner. Another disadvantage over assisted atomisation burners is the lack of cooling from steam or air means the burner must be removed when not in use from lit boilers to prevent carbonising in the tube



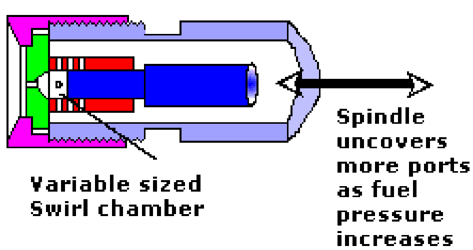
Spill type pressure jet

The method of atomisation is the same as for simple pressure jet type. The burner differs in that a proportion of the supplied fuel may be spilled off. This allows for increased turn down ratio



Variable orifice pressure jet

Fuel Pressure entering the burner acts against a spring loaded piston arrangement. Increasing pressure causes the piston to pull a spindle away from the tip, this has the effect of enlarging a closed swirl chamber and uncovering ports. In this way atomisation efficiency is maintained over a greater fuel supply pressure range.

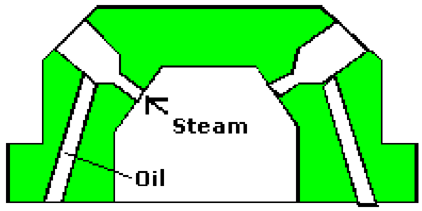


Steam assisted

Steam assisted atomisers. This can refer to both external and internal steam/fuel mixing. For first start arrangements compressed air may be used.

The two main types of internal mixing (the most common) are the 'Y' jet and the Skew jet.

Y- Jet



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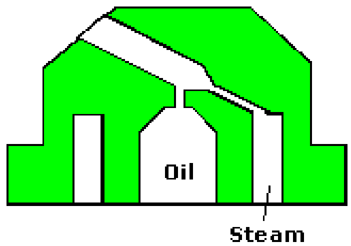
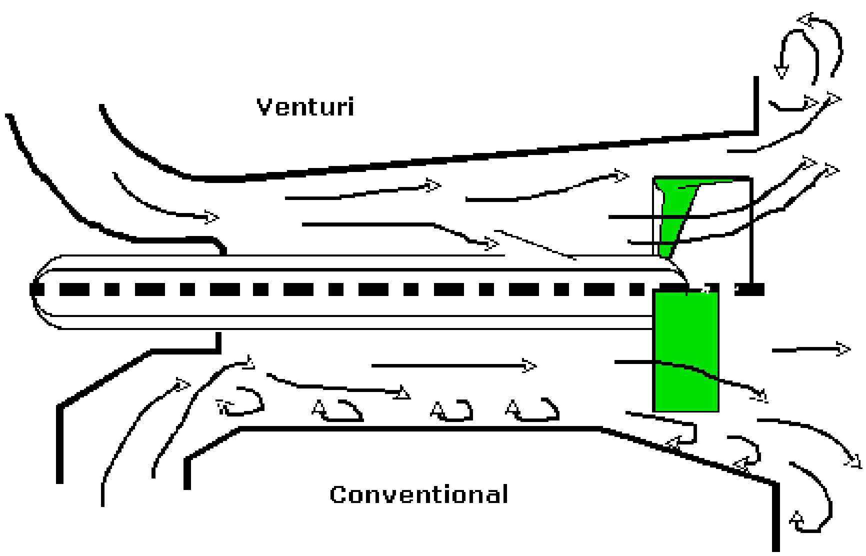
Skew Jet



The main advantage of this design over the 'Y' jet is the reduced 'bluff' zone due the reduced pitch diameter of the exit holes.

Matched to a Venturi register, a very stable efficient flame is formed. The Fuel/Steam mix exits the nozzle in a series of conic tangents, fuel reversals inside the fuel cone allow efficient mixing with air over a wide 'Turn-Down ratio (20:1). In addition this type of nozzle is associated with reduced atomising steam consumption (0.02Kg per Kg fuel burnt) **Venturi and conventional register throat design**



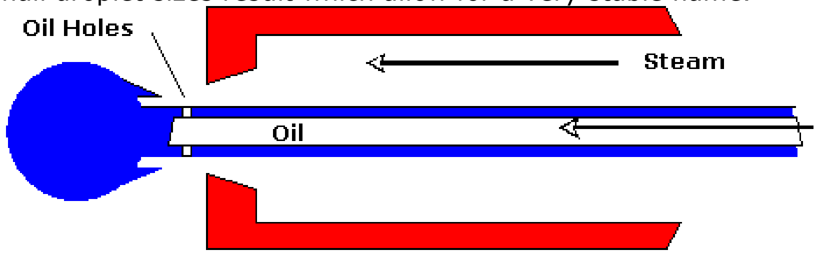
Ultrasonic

Manufactured by Kawasaki is said to offer the following advantages;

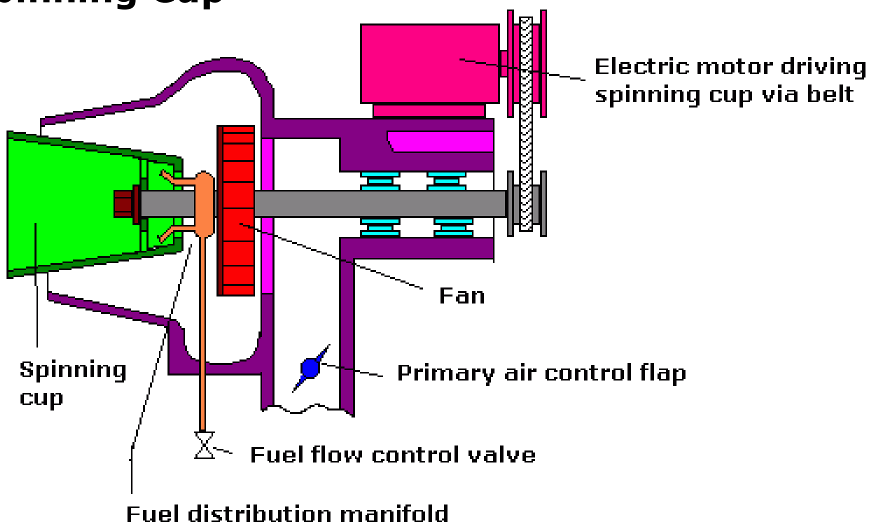
- **Wider turn down ratio with lower excess air (15 :1)**
- **Low O_2 levels**
- **Simplified operation**
- **Reduced acid corrosion problems**

Atomisation is achieved primarily by the energy of ultrasonic waves imparted onto the fuel by the resonator tip which vibrates at a frequency of 5

MHz to 20 MHz under the influence of high speed steam or air impinging on it. Extremely small droplet sizes result which allow for a very stable flame.



Spinning Cup



Fuel is introduced onto the inner running surface of a highly polished fast spinning cup (3 to 7000 rpm). Under centrifugal force this fuel forms a thin film. Due to the conical shape of the cup the fuel flows to the outer edge spilling into the primary atomising air stream. The fuel is broken into small droplets and mixed with the primary air supplied by the shaft mounted fan. Secondary air is supplied by an external fan for larger units. Packaged units of this design have the air flow valve controlled by the fuel supply pressure to the distribution manifold.

The spinning cup offers the following advantages;

- **Wider turn down ratio with lower excess air**
- **Low O_2 levels**
- **No requirement for atomising air or steam**
- **Low fuel pressure requirements to an extent that gravity flow is sufficient**
- **Stable flames achievable with very low fuel flows although maximum flow limited by size of cup. This allied to being limited to side firing making the design more suitable for smaller installations.**

Refractories

A material in solid form which is capable of maintaining its shape at high tempo (furnace tempo as high as 1650°C) have been recorded.

Purpose

i. To protect blr casing from overheating and distortion and the possible resulting leakage of gasses into the machinery space.

ii. To reduce heat loss and ensure acceptable cold faced temperature for operating personnel

iii. To protect exposed parts of drum and headers which would otherwise become overheated. Some tubes are similarly protected.

iv. Act as a heat reservoir.

v. To be used to form baffles for protective purposes or for directing gas flow.

Properties

i. Must have good insulating properties.

ii. Must be able to withstand high tempo's

iii. Must have the mechanical strength to resist the forces set up by the adjacent refractory.

iv. Must be able to withstand vibration.

v. Must be able to withstand the cutting and abrasive action of the flame and dust

vi. Must be able to expand and contract without cracking Note: no one refractory can be used economically throughout the boiler

Types

i. Acid materials- clay, silica, quartz , sandstone etc

ii. Neutral materials-chromites, graphite, plumbago, alumina

iii. Alkaline or base materials- lime, magnesia, zirconia

Note that acid and alkaline refractories must be separated

Forms

i. Firebricks - these are made from natural clay containing alumina , silica and quartz. They are shaped into bricks and fired in a kiln

ii. Monolithic refractories - These are supplied in the unfired state, installed in the boiler and fired in situ when the boiler is commissioned.

iii. Mouldable refractory - This is used where direct exposure to radiant heat takes place. It must be pounded into place during installation. It is made from natural clay with added calcided fire clay which has been crushed and graded.

iv. Plastic chrome ore - This is bonded with clay and used for studded walls. It has little strength and hence stud provides the support and it is pounded inot place. It is able to resist high temperatures

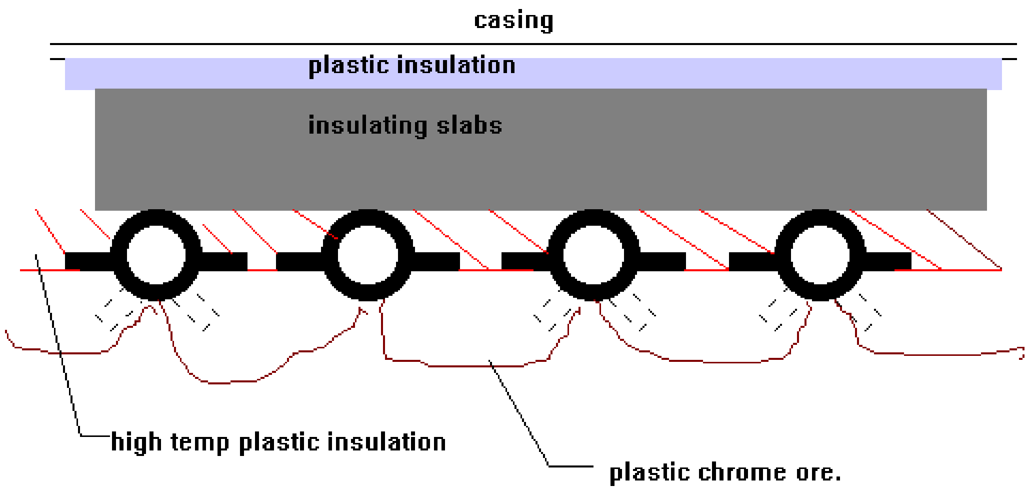
v. Castable refractory - This is placed over water walls and other parts of the boiler were it is protected from radiant heat. It is installed in a manner similar to concreting in building

vi. Insulating materials - Blocks, bricks, sheets and powder are usually second line refractories. I.E. Behind the furnace refractory which is exposed to the flame. Material; asbestos millboard, magnesia, calcined magnesia block, diatomite blocks, vermiculite etc. all having very low heat conductivity.

Furnace linings

Studded tubes

- These are lined with plastic chrome ore

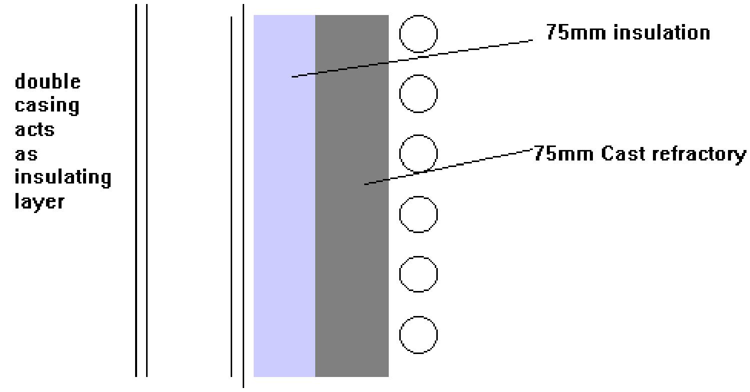


The amount of studding and the extent of tube surface covered with chrome ore is varied to suit the heat absorption rate required in the various zones of the boiler furnace.

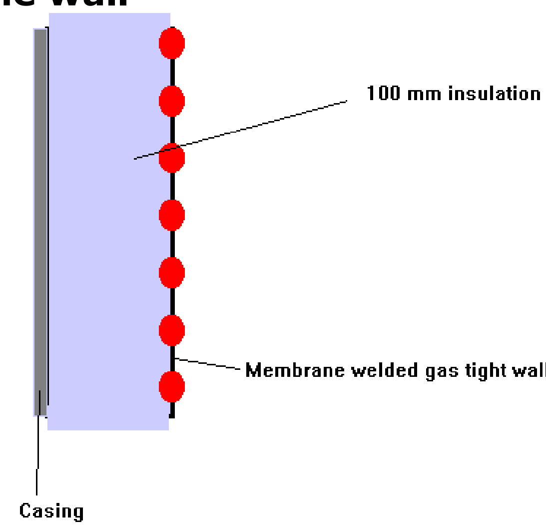
Floor tubes may be situated beneath a 3" layer of brickwork, the tubes are embedded in crushed insulating material below which is a layer of solid insulation and then layers of asbestos millboard and magnesia.

PRESENT DAY TYPES

TANGENT WALL.



Membrane wall



Furnace floors

Two layers of 50 mm firebrick above the tubes and 100 mm slab insulation below. Tubes in castable insulation are covered with crushed firebrick. **Note**: before castable insulation applied, tubes coated with bitumen to allow expansion clearance when tubes are at working tempo.

Front walls

In front fired boilers these need additional insulation (200 mm) made up of 125 mm mouldable refractory backed by 50 mm castable or slab and 25 mm of asbestos millboard.

Burner openings

These have specially shaped bricks called quarls or have plastic refractory.

Brick bolts

There are two basic types;

i. ***using a hole right through the brick***
ii. ***Using a recess in the back of the brick.***

A source of weakness is where bricks crack; bolts will be exposed to the direct heat which leads to failure. Adequate expansion arrangements must be provided. For floor tubes a coating of bitumen mastic is first applied before the castable refractory is applied. When the boiler is fired the bitumen mastic is burnt away then a space is left for expansion

Refractory failure

This is one of the major items of maintenance costs in older types of boiler

SPALLING

This is the breaking away of layers of the brick surface. It can be caused by fluctuating temperature under flame impingement or firing a boiler too soon after waterwashing or brick work repair.

May also be caused by failure to close off air from register outlet causing cool air to impinge on hot refractory.

SLAGGING

This is the softening of the bricks to a liquid state due to the prescience of vanadium or sodium (ex sea water) in the fuel. This acts as fluxes and lowers the melting point of the bricks which run to form a liquid pool in the furnace Eyebrows may form above quarls and attachment arrangements may become exposed Material falling to floor may critically reduce burner clearance and reduce efficiency

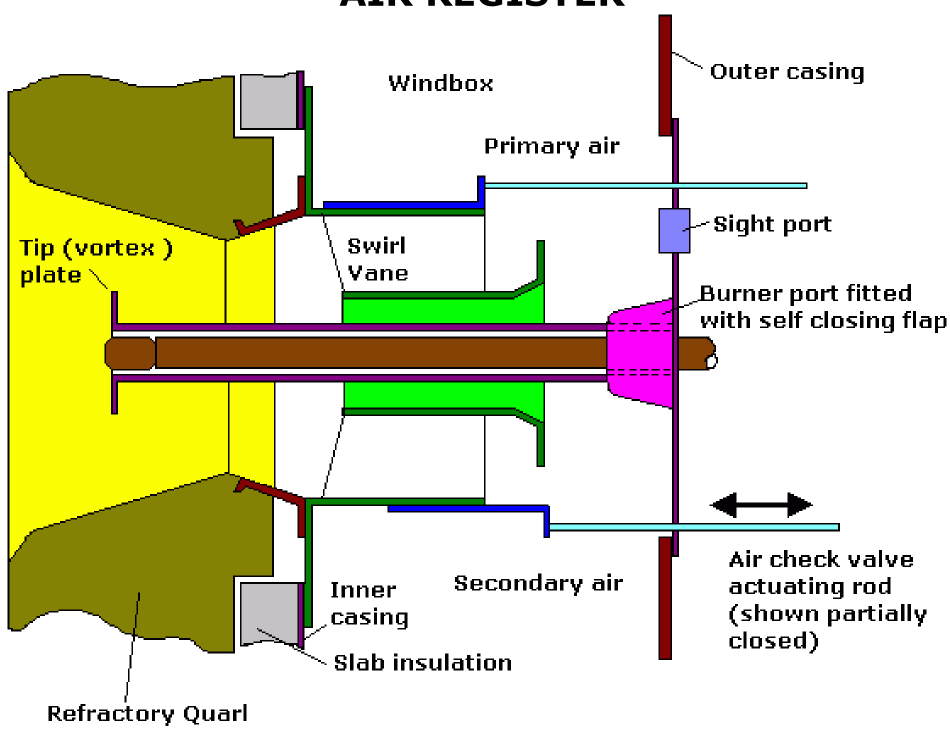
Flame impingement may lead to carbon penetrating refractory.

SHRINKAGE CRACKING

Refractories are weaker in tension than in compression or shear thus, if compression takes place due to the expansion of the brick at high temperature, if suddenly cooled cracking may occur.

Registers

AIR REGISTER



This is the name given to an assembly of vane air swirler plates etc fitted within the boiler casing in association with each burner, its functions is to divide air into primary and secondary streams and to direct them such as to give the correct air flow pattern.

The air must pass through the air check to enter the register. In some cases the check can be formed by the swirl vanes themselves by rotating them about their axis, in other cases a sliding sleeve is used.

The inner primary air flows until it reaches the tip plate (stabiliser) then spills over to form a series of vortices which reduces the forward velocity of the air. This retains the primary flame within the quarl. The outer, secondary air passes over the swirler vanes which cause the air to rotate thus assisting the mixing of air and fuel. The secondary air shapes the flame, short and fat for side fired, longer and thinner for roof fired. A small amount of cooling air is allowed to flow to the tip plate and atomiser tip.

It is important that the air check forms a tight seal otherwise thermal shock can damage the quarls when the burner is not in use The front plate is usually insulated , the complexity of the air control is related to the TDR .The steam jet types have the steam providing additional energy for the mixture of air and fuel.

- **see 'burners' for description of profiled registers**

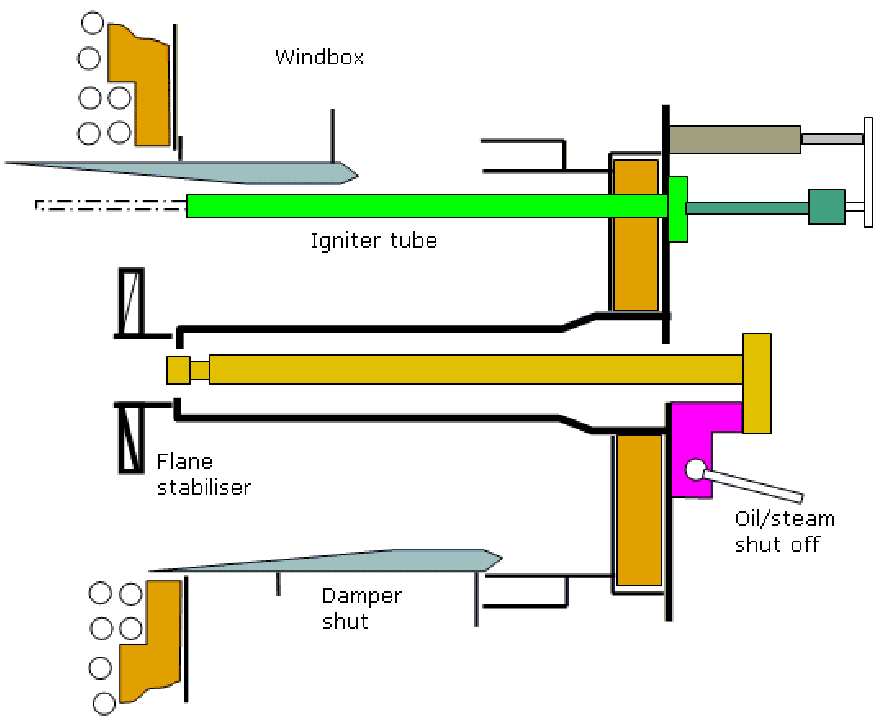
PREPURGING OF FURNACES

Furnace explosions caused by oil vapour and air present in furnace in explosive proportions. To a lesser extent a blowback is a furnace explosion. Prevention is by purging with air.

Usually adequate purging is provided within the combustion control however makers timings should be strictly followed.

N.B. This is particularly important with membrane wall boilers where the pressure wave is contained within a strong cell which if ruptured, has disastrous consequences.

Modern design



Superheater Temperature Control

Reason for superheating steam

Basically the control of temperature is to protect the superheater by preventing the metal temperatures reaching a dangerously high level reducing mechanical strength and leading to failure.

Water flowing through a tube conducts heat away much more effectively than steam due to its higher specific heat capacity. This means that tubes carrying water have a metal temperature much closer to the fluid passing through it.

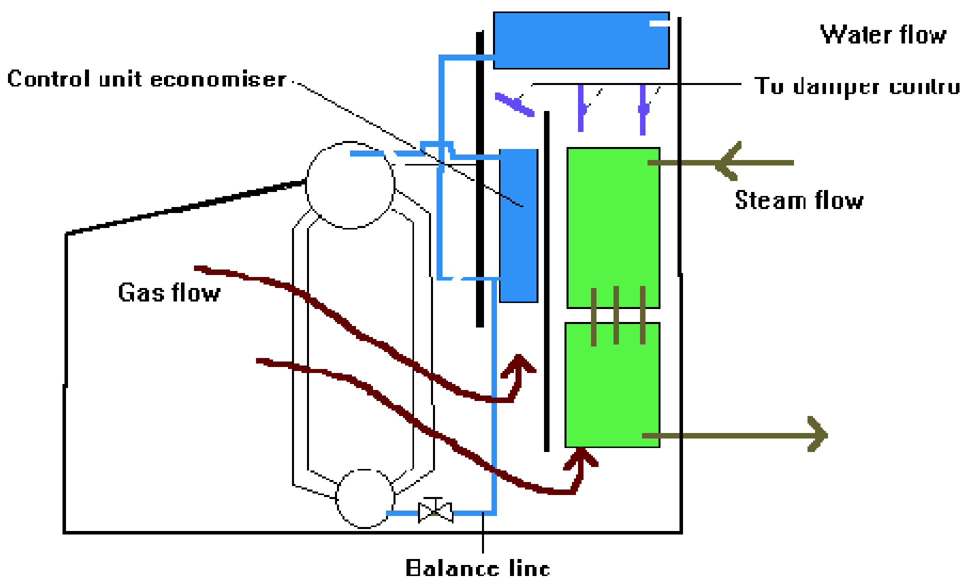
Where superheat temperatures up to 455°C are in use then the use of mild steel is not a problem, for superheat temperatures above this then alloys of chrome molybdenum steels are used (up to 560°C), difficulties in welding means that there use is restricted to only within the highest temperature zone and a transition piece fitted to connect to remaining mild steel tubing.

Superheat temperature control is there for fitted to ensure superheat temperature does not exceed design limits.

Methods of regulating superheat temperature

a, By regulating the gas flow over the superheater by means of dampers

FW ESD II

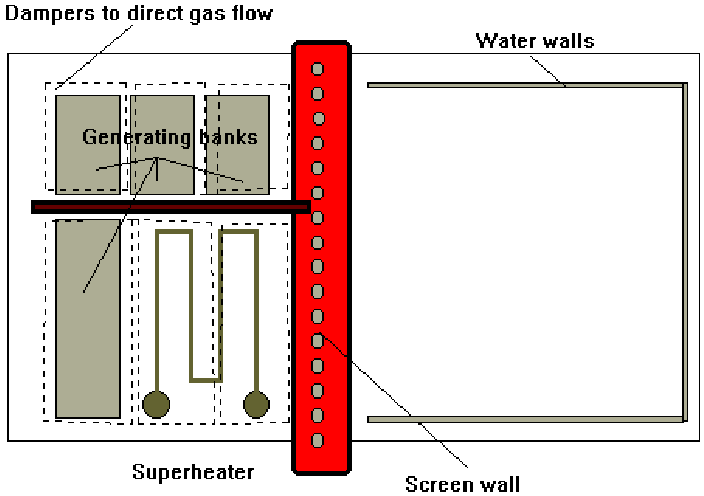


The balance line prevents any tendency for the control unit to steam under conditions of low feed flow say due to sudden load change or especially when flashing (several of these have been burnt out due to incorrect flashing procedure).

The control unit operates the linkages via a control arm, if the superheat is too high then gasses are diverted to flow over the control unit and less gas now flows over the superheat bank.

The control arms and the dampers were very susceptible to damage caused by operating in the hot gas path. Also this control was very sensitive to excess air which can raise the superheat temperature by increasing the heat energy removed from the furnace.

Babcock and wilcock selectable superheat



This design gave a wide range of temperature control, it operated in a similar manner to the Foster Wheeler ESD II. The gas path is separated by a baffle which has flaps located above the tubes operation of which can determine the superheat temperature, as the superheater only extends across one path it is made out of 'W' rather than 'U' tubes.

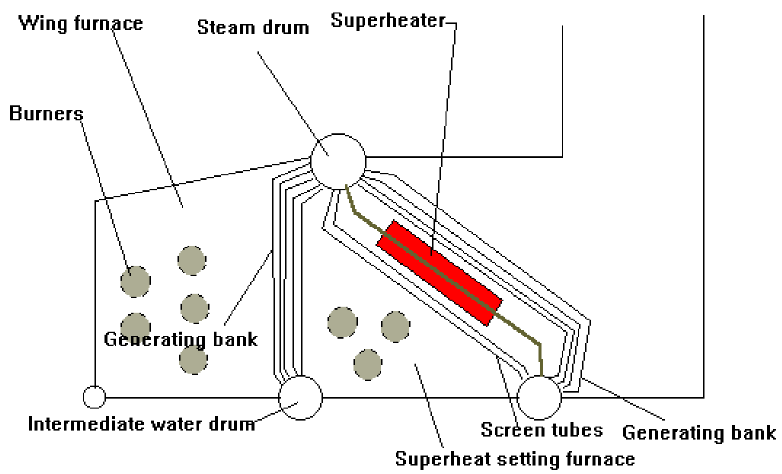
This design suffered from similar problems to the ESD II with regard to flaps and flap linkages susceptibility to corrosion.

b, By use of multi furnace boilers

Babcock and wilcock Controlled superheat)

The superheat temperature was regulated by changing the position of lit burners within the boiler, shutting off burners in the main furnace and replacing them with flames in the wing furnace had the effect of reducing the superheat temperature as the gasses are cooler when the reach the superheater bank. In this way the superheat temperature could be varied by 60°C.

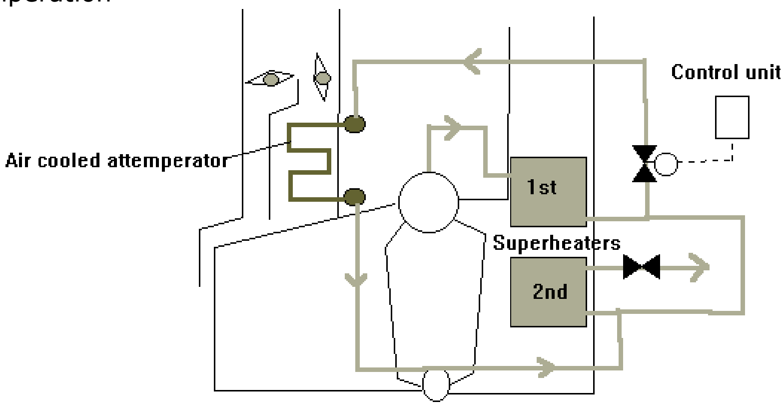
The advantage of this system was the superheat temperature could be maintained over a wide variation of load. To prevent reversal of flow in the intermediate generating bank a baffle plate is fitted in the water drum which allows the first two rows of the bank to be isolating from the rest and to be supplied by their own two downcomers. Difficulty was encountered in maintaining the correct air/fuel ratio during differential firing of the two furnaces. During flashing only the wing furnace is used to give better protection for the superheater.



c, Use of air cooled attemperators

Air cooling effect of the double casing is lost in this arrangement so additional insulation must be fitted to ensure that the casing temperature does not exceed safe handling limits.

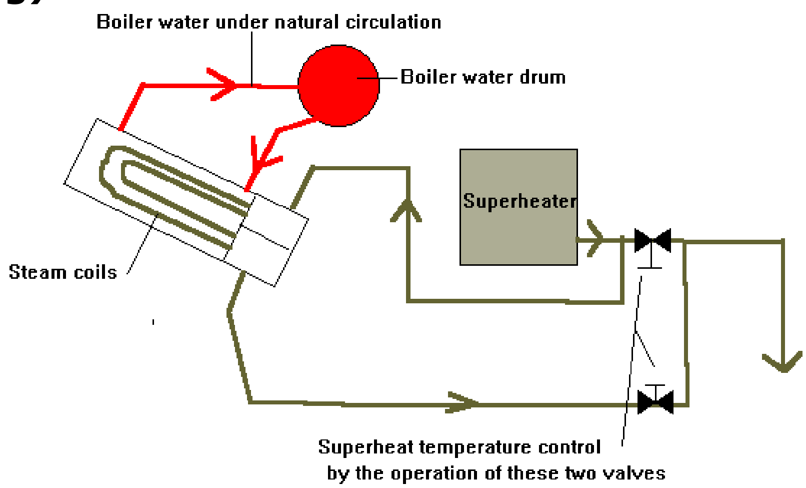
As air is a relatively poor cooling medium large attemperators are required allied to increased FD fan output required to overcome frictional resistance losses. There is an overall increase in weight, size and initial cost which led to the system being superseded by the regulated gas flow method and then by water or spray cooled attemperation



d, Use of separately fired superheater

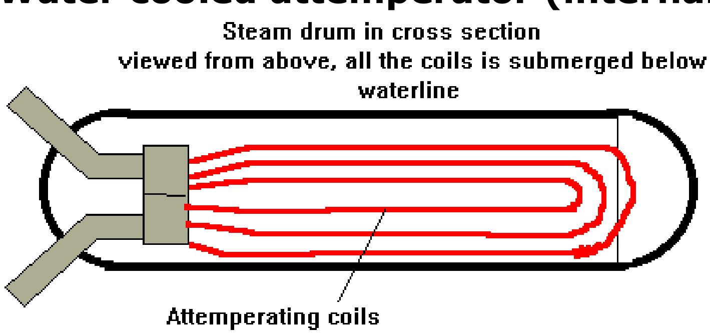
In very rare use, normally limited to tank boilers

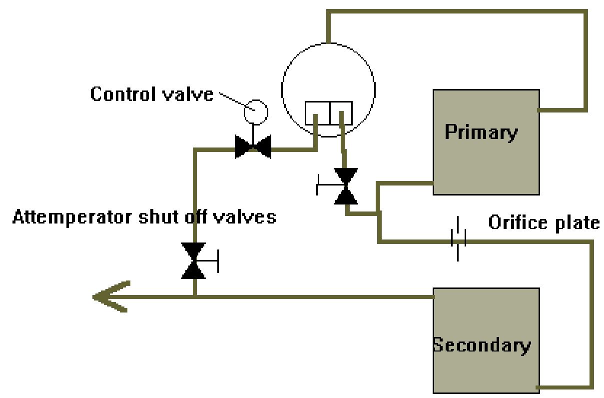
e, Use of boiler water attemperator (external mounting)



Superheat control is achieved by diverting a proportion of the steam through the simple tubular heat exchanger attemperator.

e, Water cooled attemperator (internal)



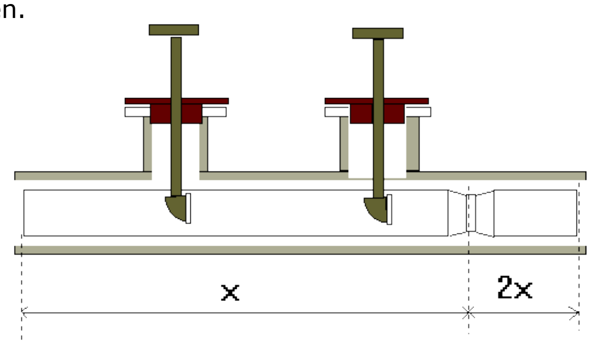


Shut off valves have to be fitted to the attemperator as in the event of tube leakage the boiler will empty in to the attemperator as it is at a slightly higher pressure due to frictional losses in the superheater.

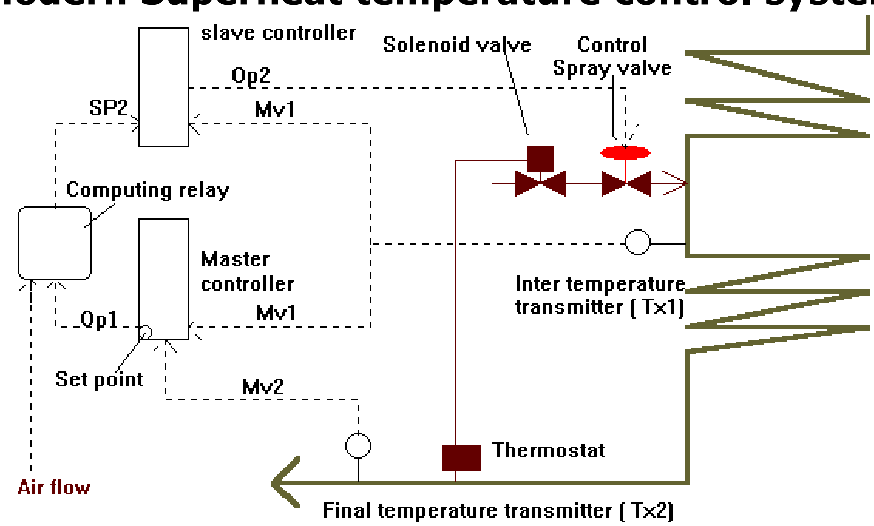
g, Water spray attemperation

This the most common form of attemperation in use, it consists of two spray nozzles which spray feed water into the steam as it passes from the primary to secondary superheaters. The water receives heat from the steam and thereby reduces the superheat of the steam. To prevent thermal shocking of the transfer pipe, a thin flexible inner tube is fitted.

The spray valves work in series with one reaching its maximum capacity before the second comes into use, the control system takes as its measured value both the outlet temperature and either steam or air flow (load). The spray valves are often designed to be of the air to open variety so in the event of air failure they will fail safe open.



Modern Superheat temperature control system



The main system components are a P+I+D Mater controller (reverse acting, hence output increases for measured values above setpoint) in which the desired final superheat temperature is set, working in cascade is a P+I slave controller whose output controls the spray attemperator control valve.

There is a temperature transmitter on the inlet to the secondary superheater (Tx1, fitted after the spray) and a secondary superheater outlet temperature transmitter (Tx2).

Tx1 output Mv1 is fed to both the master and slave controllers, in the slave controller this forms the measured value.

Tx2 output Mv2 is fed to the master controller and forms the measured value, here it is compared to the required set point entered. The output Op1 is sent to the computing relay.

Master controller Op1 = - (Desired set point - Mv2) (reverse acting)

In the computing relay the signal is added to the rate of change of air flow signal, as the air flow is taken from the combustion control circuit it forms a load signal. In this way the circuit has the ability to react quickly to load changes before they actually begin to affect the temperatures.

The output of the computing relay is fed to the slave controller as its set point Sp2 the set point for the slave controller now has the error of the final superheat and an amount by which the volume rate of air flow (and hence boiler load) would tend to change the superheat contained within.

The set point Sp2 is compared in the slave controller to the output from the secondary inlet transmitter Tx1 signal Mv1.

Slave controller Output Op2 = Setpoint Sp2 - Mv1

The use of the controllers in cascade speeds up response to system changes.

Computing relay Output SP1 = OP1 + d/dt (air flow)

It is necessary to add the air flow signal as this has a direct effect on the superheat temperature. If there was a load demand increase the combustion control would increase fuel and air to the boiler, this would cause an increase in the superheat steam temperature as there would be some lag until the steam flow increased due to the increased fuel . Once the steam flow has stabilised then the increased steam flow will match the increased gas temperature and so the temperature will reduce. It can be seen then that only during the transition period when the fuel/air has increased but the steam has not that the increased spray is required; this is why the rate of change of air flow rather than volume is used in the control system.

If the measured superheater outlet temperature drops then Mv2 drops, OP1 decreases (the master controller is reverse acting), this is fed through the computing relay and so the set point Sp2 for the slave controller decreases. The setpoint of the slave controller has now fallen below the measured value and hence its output will decrease. This signal OP2 is fed to the spray valve which will shut in increasing the superheat temperature.

If the load on the boiler increases the output of the computing relay increases and hence the set point Sp2 increases, the output of the slave controller Op2 increases and hence the spray valve starts to open even though the increased air flow and hence gas temperature passing over the superheater is yet to be detected in the superheated steam either Tx1 or Tx2, in this way problems of process and control lags can be negated.

The output of Tx1, Mv1 is fed not only to the slave controller but also to the master controller; its function here is to prevent the master controller from saturating and hence speeding its response under certain conditions. It does this by feeding the integral bellows via the integral restrictor in the controller rather than the more normal feedback arrangement of the output feeding the Integral bellows via the restrictor. In this way the master controller always takes account of the inter temperature.

With the normal layout in low load conditions, should Mv2 fall below the setpoint the Integral action will force the controller into saturation if the temperature fails to recover. This can happen as even with the spray valves shut there may not be enough energy in the flue gasses to heat the steam up to the required temperature in low loads.

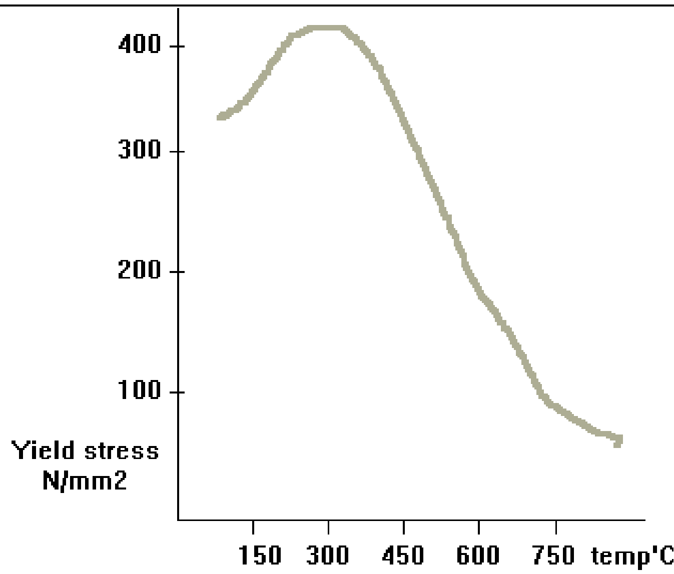
By using the output from Tx1, Mv1 then the controller will fail to go into saturation as the integral bellows will receive a signal Mv1 rather than its falling output Op1.

Other additional fittings

Shown on the diagram is a fitting sometime used to protect the system in the event of failure of the spray control valve, this takes the form of a thermostat set so that should the temperature fall below a certain value it will operate a solenoid valve fitted before the spray control valve to shut off the feed. It can be seen that in the event of loss of superheat control, and hence with the spray valve failed open, some form, albeit very coarse, of superheat control can be maintained by use of the thermostat and solenoid valve.

There are alarms fitted to both the inlet and outlet from the secondary superheater as well as a main engine trip due to high superheat temperature. A boiler trip may be fitted for low superheater outlet temperature.

External tube failure

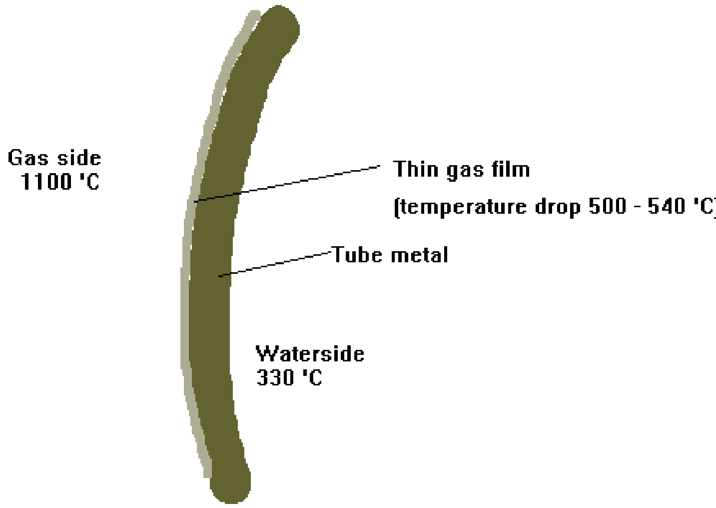


From the graph above for carbon steel, it can be seen that there is a rapid drop in strength above 430°C.

Long term overheating is a condition where the metal temperature exceeds the design limit for a long period. The mechanical strength is reduced as a function of the increase in temperature.

Deposits on the external surface and thin gas film layer aid in reducing the metal temperature. Deposits on the inside increase tube metal temperatures.

Temperature drop across the thin film gas layer



Bulging of many different forms tend to precede bursting.

Thermal oxidation

If the metal temperature exceeds a certain value dependant on the material rapid excessive oxidation can occur

This oxide layer can often form with faults, and can be exfoliated due to thermal stressing or vibration. The result is a thinning of the tube due to this cyclic thermal oxidation and spalling.

A failed tube suffering from this will have the appearance of tree bark.

Creep rupture

Plastic deformation due to metal overheating may occur. Microvoids form eventually leading to failure. Can be distinguished by a thick ragged edged fish mouth with small ruptures and fissures leading off.

Chain graphitization

Uncommon. Damage begins when iron carbide particles (present in plain carbon or low alloy steels) decomposes into graphite nodules after prolonged overheating (metal temperatures > 427^{o}C).

If the nodules are evenly distributed then these not cause a problem. However, some tomes the nodules can chain together and failure occurs along the length of the chain (as in ripping a postage stamp along the perforations).

Normally found adjacent to welds and determination as cause of failure requires examination under a microscope to observe nodules.

Short term overheating

Metal temperatures of at least 454^{o}C and often exceed 730^{o}C; failure may be very rapid. Not normally associated with a water chemistry problem rather than maloperation or poor design.

In very rapid overheating little bulging occurs and the tube diameters are unchanged in way of the fish mouthed failure (normally thick walled edge)

Under less arduous conditions some bulging occurs and the failure may have a finely chiselled edge

Multiple ruptures are uncommon.

care must be taken not to confuse a thick walled short term overheating failure with the many other possibilities such as creep failure, hydrogen embrittlement and tube defects.

Erosion

One of the most common causes of erosion within a boiler is sootblowing erosion. Especially those tubes adjacent to a misdirected blower.

Should the blower stream contain water then the erosion is much more severe. Ash picked up by the steam also acts as an abrasive. This is why proper warming through and drainage is essential

Other causes may be failure of an adjacent tube or to a much lesser extent by particles entrained in the combustion products

Internal water chemical causes

For a listing of the failures caused by water chemistry see relevant document 'Corrosion and failures in boiler tubes due to water chemistry'.

Oil Ash Corrosion

High temperature liquid phase corrosion phenomenon where metal temperatures are in the range 593^{0}C to 816^{0}C. Hence normally restricted to superheater and re-heater sections. It can affect both the tubes and their supports. May arise after a change of fuel with the formation of aggressive slags.

Oil Ash corrosion occurs when molten slag containing vanadium compounds form on the tube wall according to the following sequence

- **Vanadium and sodium compounds present in the fuel are oxidised to Vn_2O_5 and Na_2O.**
- **Na_2O acts as a binding agent for ash particles**
- **Vn_2O_5 and Na_2O react to form a liquid (eutectic)**
- **Liquid fluxes the magnetite exposing metal to rapid oxidation**

Catalytic oxidation of the metal surface by Vn_2O_5 occurs. The tube outer surfaces are thinned, stress increases in the inner layers and failure by creep rupture occurs

Corrosion of superheater by slag with a fusion temperature of 593 to 704^{0}C requires all utility boilers to have a steam temperature not exceeding 538 to 551^{0}C

Scale formation in the tubes leading to high metal temperatures can lead to this type of corrosion.

Elimination may require the chemical analysis of both the fuel and the slag to determine the corrosive constituents. The fusion temperature of the ash can be determined. Fuel additives may be used. Magnesium compounds have been used successfully to mitigate problems by forming a complex with Vn_2O_5 and Na_2O with a very high fusion temperature.

Low excess air retards the oxide formation.

Chemical cleaning.

Water wall fire side corrosion.

May occur where incomplete combustion occurs. Volatile sulphur compounds are released which can form sodium and potassium pyrosulfates. These chemically active compounds can flux the magnetite layer. This is more commonly found in coal fired boilers.

Uptake Fires

On break out of an uptake fire the priority is to boundary cool to contain the fire and give cooling effect.

Modern ship

An uptake fire generally starts when the load on the boiler is reduced. This is due to the quantity of excess air being very low at high loads.

Should a fire break out then the possibility of speeding up and reducing the excess air should be considered.

The amount of feed heating should be reduced to lower the inlet feed temperature and aid with cooling parts.

Where the possibility exists of damage to the superheater, then after first relieving pressure, it should be flooded.

Older ship

Where the excess air on older boilers is high even at high loads a different plan of attack must be used.

The flames should be extinguished and the air shut off. The amount of feed heating should be reduced.

The safeties should be lifted to keep a high steam flow and hence high feed flow requirements (the boiler is now being fired by the uptake fire).

Lifting the safeties give the added advantage of reducing the boiler pressure and hence corresponding saturation temperature of the water aiding the cooling effect.

Tackling the fire

If a direct attack should be made on hot non-pressurised parts then the nozzle should be set to solid jet and aimed at the seat of the fire.

This should not be carried out on hot pressurised parts due to the risk of a steam explosion.

Dry powder is a suitable extinguishing medium.

Disassociation

Under certain conditions an extremely destructive fire, commonly known as hydrogen or 'rusting' fire, may occur under high temperatures water will tend to disassociate to hydrogen and oxygen. The percentage amount increases with increased temperature. These will re-combust again liberating heat In a fire there is a danger that the use of superheated steam as an extinguishing agent (say sootblowers on an air heater fire) could in fact feed the fire and accelerate the growth. For example the displacement which occurs about 707°C.

Heat + Hot $3Fe + 12H_2O$ Ћ $3FeO_3 + 12\ H_2$

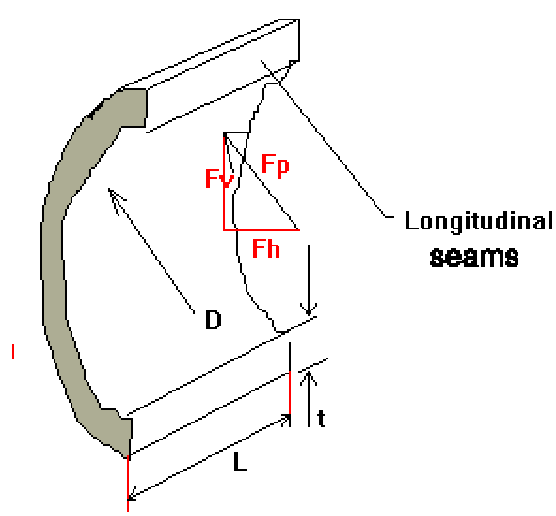
See Theory section for a more complete explanation

Tackling this type of fire is very hazardous and consists mainly of boundary cooling and shutting off water and air supplies as effectively as possible. Under no circumstances should steam smothering be considered.

A typical scenario for this fire is a badly cleaned uptake igniting leading to tube failure.

Stress in boiler drums

Circumferential



L=Length of cylinder

t= Material thickness

D= Diameter

F_p= Force acting on cylinder due to pressure

F_h= Resolved horizontal component of force

Equal forces act on all surfaces. If a vertical section is cut then the forces may be considered to be resisted by the longitudinal seam for the horizontal direction.

i.e. **horizontal forces to left=Horizontal forces to right = resisting force in seam**

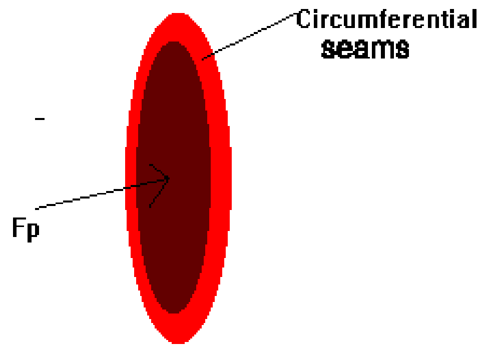
Pressure x projected area = stress x C.S.A of joint

By using projected area the horizontal component of the pressure force is automatically resolved

p x dia x L = stress x 2 x t x L

(p x dia x L)/ 2 x t= Stress (longitudinal joint)

Longitudinal



Similarly:

Horizontal forces to left = Horizontal forces to right

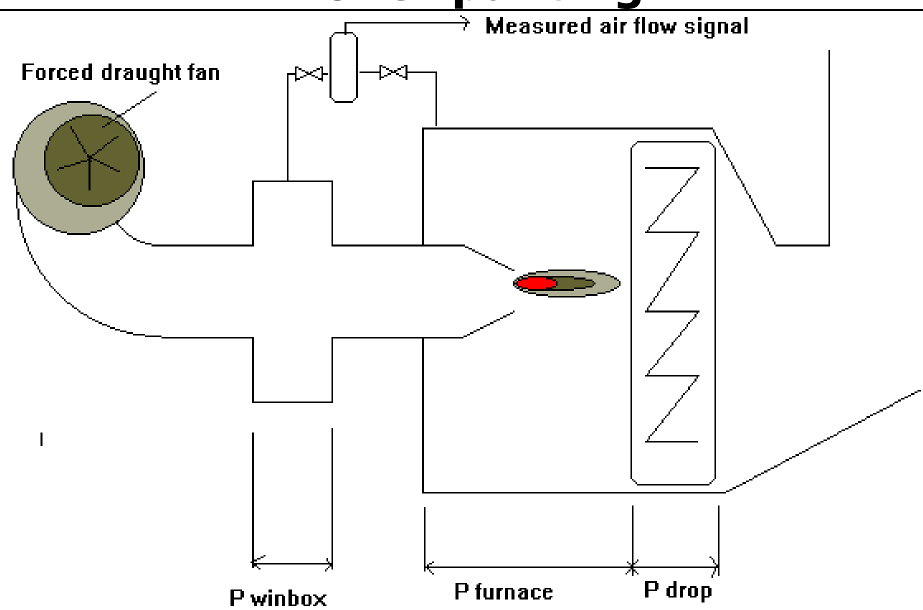
Pressure x end plate area = Resisting force in circumferential joint

P x (pi x d^2)/4 = stress x csa (circumferential joint) = stress x pi x d x t

(p x d)/ 4 x t = stress (longitudinal)

Hence, circumferential stress is twice that of the longitudinal stress and hence seams in the longitudinal axis must be twice as strong.

Boiler panting



If a boiler was open ended to atmosphere then boiler panting would not occur. However it is not, instead combustion products must flow over a whole range of items all of which contribute to a pressure drop indicated as P drop. For example, screen tubes, generating tubes, superheater tubes, economisers etc. All of these items cause a pressure drop which varies according to the combustion variations.

Mechanism of panting

The system shown above is considered to be in steady state. The windbox pressure is at a slightly higher pressure than the furnace pressure which is at a higher pressure than atmospheric.

If there was a sudden disturbance to the plant, for example, poor combustion caused by say low atomising steam pressure then combustion of the fuel would be less efficient. The pressure in the furnace will drop, the P drop increases and the mass/volume of the furnace gases increases. The actual volume of the gas has however reduced.

The furnace pressure drop will then cause increased air flow from the windbox (after some period allowing for inertia). The density of the air remains high and P drop remains high.

This in rush of air into the furnace aids the combustion process of the flame and also burns up any fuel products not completely combusted. This has the effect has the effect of reducing the density of the furnace atmosphere, increasing its volume, reducing P drop and increasing furnace pressure.

The flow of air from the windbox reduces as the pressure differential reduces. The poor combustion of previous is re-established and the whole process is repeated.

The cycle time will depend on the aggravating process i.e. in this case the poor combustion caused by the low atomising steam pressure., the volumes of the respective chambers as well as the size of the inlet for windbox air flow and also the amount of restriction caused by the elements forming the P drop.

This example only describes one possible scenario, in reality there may be many different sources all acting together or independently to cause the panting.

Probably the most common cause of panting is an uptake fire, others may be such as slagging of the tube stacks or even build up of the furnace floor on front fired boilers.

Effects

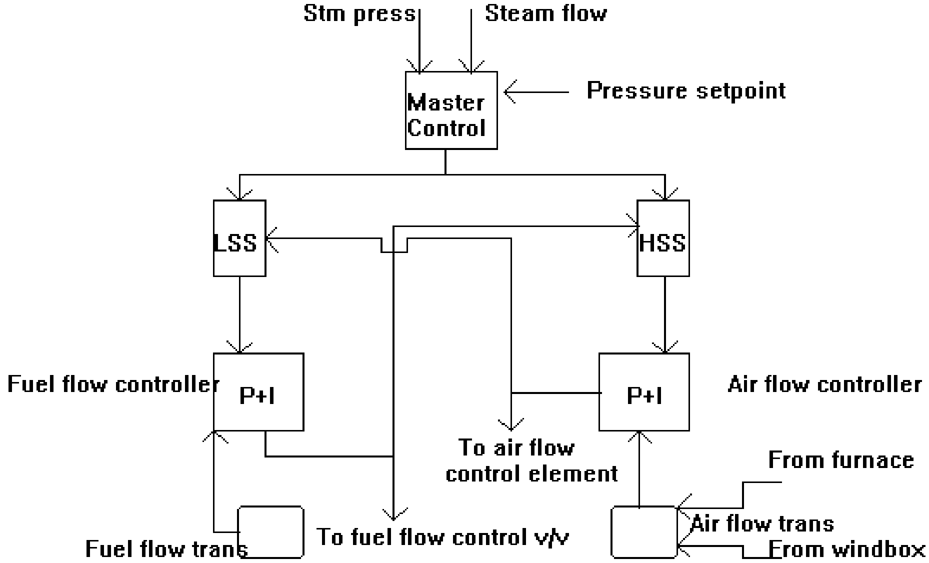
The effects of panting are too cause a low frequency (governed by volume/P drop criteria) oscillation of furnace spaces repeated to a lesser extent in the windbox and flue gas spaces.

For membrane boilers which are by design air tight the effect can be to cause heavy mechanical loading on all points especially on the drum connections, placing unwanted tensile stressing on welds. Other no less important effects are poor combustion leading to inefficient operation and choking of the tube stacks.

Remedies and remedial action

Modern combustion control equipment by their design inherently acts to prevent panting. When the drop in furnace pressure is detected by the air flow transmitter it is sent to the P+I controller as a reduced air flow measured value. The P+I controller acts to increase the air flow hence going some way to negate the cycling problem caused by the inertia of the air.

Should a boiler start panting during its life, the condition of the internal surfaces should be inspected and deposits removed.



Boiler Mountings

Definition - various valves and fittings are required for the safe and proper working of a boiler . Those attached directly to the pressure parts of the boiler are referred to as the boiler mountings.

Minimum requirements for boiler mountings

- **two safety v/v's**
- **one steam stop**
- **two independent feed check**
- **two water gauge or equivalent**
- **one pressure gauge**
- **one salinometer v/v or cock**
- **one blowdown/scum v/v**
- **one low level fuel shut off device and alarm**

Functions

SAFETY V/V - protect the boiler from over pressurisation. DTI require at least two safety v/v's but normally three are fitted ,two to the drum and one to the superheater. The superheater must be set to lift first to ensure a flow of steam through the superheater. These must be set to a maximum of 3% above approved boiler working pressure.

MAIN STEAM STOP - mounted on supherheater outlet header to enable boiler to be isolated from the steam line if more than one boiler is connected. V/v must be screw down non return type to prevent back flow of steam from other boiler into one of the boilers which has sustained damage (burst tube etc) v/v may be fitted with an emergency closing device.

AUXILIARY STOP V/V - similar to main stops but connected to the auxiliary steam line

FEED CHECK V/V'S - a SDNR v/v so that if feed p/p stops the boiler water will be prevented from blowing out the boiler. The main check is often fitted to the inlet flange of the economiser if no economiser fitted then directly connected to the boiler. The Auxiliary feed check is generally fitted directly to an inlet flange to the drum with crossovers to the main feed line. Usually fitted with extended spindles to allow remote operation which must have an indicator fitted.

WATER GAUGES - usual practice is to fit two direct reading and at least one remote for convenient reading.

PRESSURE GAUGES - fitted as required to steam drum and superheater header

SALINOMETER COCKS OR V/V'S - fitted to the water drum to allow samples to be taken. Cooling coil fitted for high pressure boilers.

BLOWDOWN COCK - used to purge the boiler of contaminants. Usually two v/v's fitted to ensure tightness. These v/v's lead to an overboard v/v.

SCUM V/V - These are fitted where possibility of oil contamination exists. They are designed to remove water and/or contaminants at or close to normal working level.

SAFETY VALVES

At least two safety valves have to be fitted to the boiler. They may be both mounted on a common manifold with a single connection to the boiler. The safety valve size must not be less than 38mm in diameter and the area of the valve can be calculated from the following formula

$$C \times A \times P = 9.81 \times H \times E$$

where

H= Total heating surface in m^3

E = Evaporative rate in Kg steam per m^2 of heating surface per hour

P = Working pressure of safety valves in MN/m^2 absolute

A = Aggregate area through the seating of the valves in mm^2

C = the discharge coefficient whose value depends upon the type of valve.

C=4.8 for ordinary spring loaded valves

C=7.2 for high lift spring loaded valves

C= 9.6 for improved high lift spring loaded valves

C= 19.2 for full lift safety valves

C= 30 for full bore relay operated safety valves

LIFT PRESSURE

The safety v/v must be set at a pressure not exceeding 3% of the approved boiler working pressure. It is normal to set the super heater safety below that of the drum to ensure an adequate flow of steam for cooling purposes under fault conditions. Similarly the superheater should be set to close last.

10% ACCUMULATION OF PRESSURE RULE.

With all the flames in full firing the steam stop is closed, the boiler pressure must not increase by more than 10% in 7 minutes for water tube of 15 min for tank boilers with the safety lifted. this is normally wavered for superheater boilers. Instead calculations and previous experience used.

BLOWDOWN

The pressure drop below the lifting pressure for a safety v/v is set at 5% by regulation although it is more normal to set v/v's at 3% to prevent excessive loss of steam. For boilers with a superheater it is important that the superheater v/v not only lifts first but closes last.

Adjustment of the blowdown may be necessary following adjustment of the popping setpoint (Increasing set point lengthens blowdown). Adjustment is achieved by altering the height of the 'adjusting guide ring' on the full lift safety valve design shown below. Over raise adjustment of this ring can lead to mal-operation with the valve not fully opening

SETTING

Must be set with the surveyor present except when on the waste heat unit. A chief engineer with three years experience may then set the safety valve but must submit information to surveyor for issue of certificate. Superheated steam safety valves should be set as close to operating temperature as possible as expansion can alter the relationships between valve trim and guide/nozzle rings which can effect the correct operation of the valve.

a. Two safety valves- each set independently

b. Each safety valve must release entire steam flow in pressure accumulation test

c. Surveyor uses specially checked gauge

d. One valve gagged

e. valve initially set to approximately the correct position then steam pressure increased to set pressure

f. adjust valve to lift

g. raise and lower pressure to check

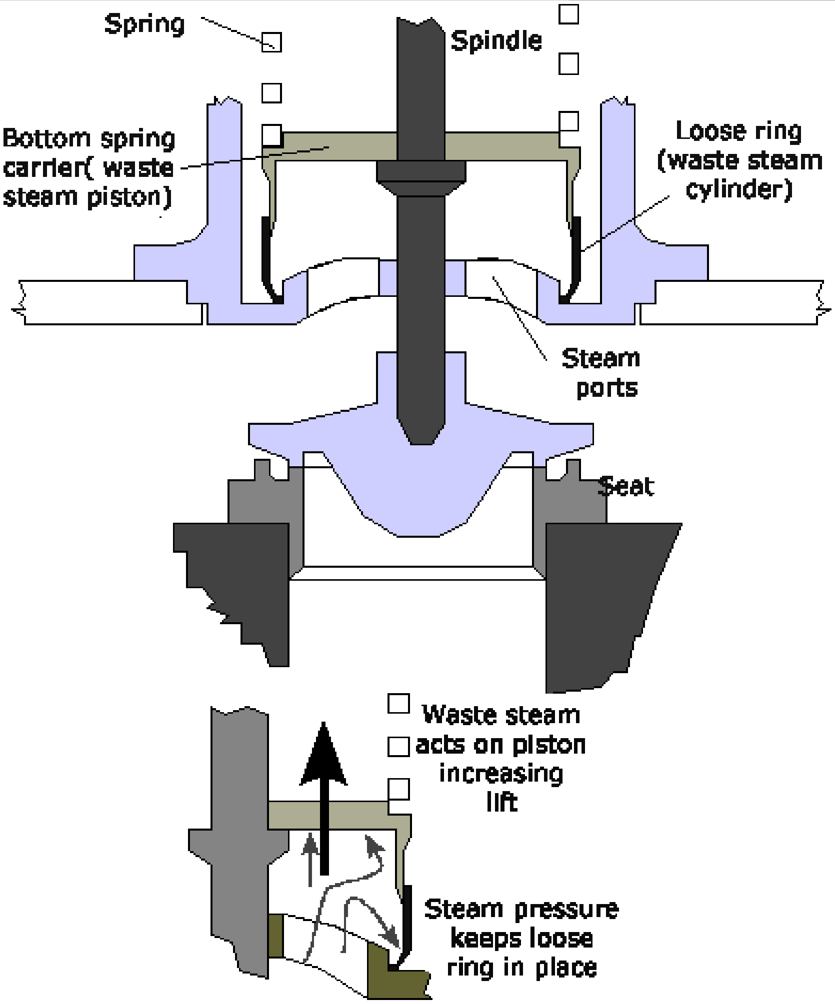
h. fit locks to both valves on completion

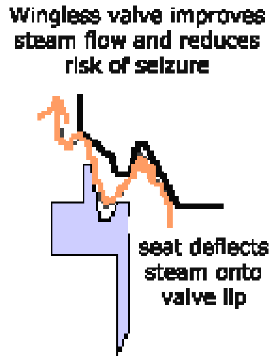
Easing gear to be checked free before setting valves. Steam should not be released as this can damage seat.

Improved high lift safety valve

Differences in the ordinary and high lift designs

Ordinary	High Lift	Improved high lift
Winged valve	Winged valve	Wingless valve
No waste piston	Waste piston	Waste piston
	No floating ring	Floating ring





For superheated steam the aggregate area through the seating of the valves is increased, the formula is

$$As = A(1 + Ts/555)$$

Where

As = Aggregate area through the seating of the valves in mm^2 for superheated steam

A = Aggregate area through the seating of the valves in mm^2 for sat steam

Ts = degrees of superheat in ^{o}C

As is greater than A due to the higher specific volume of superheated steam requiring more escape area.

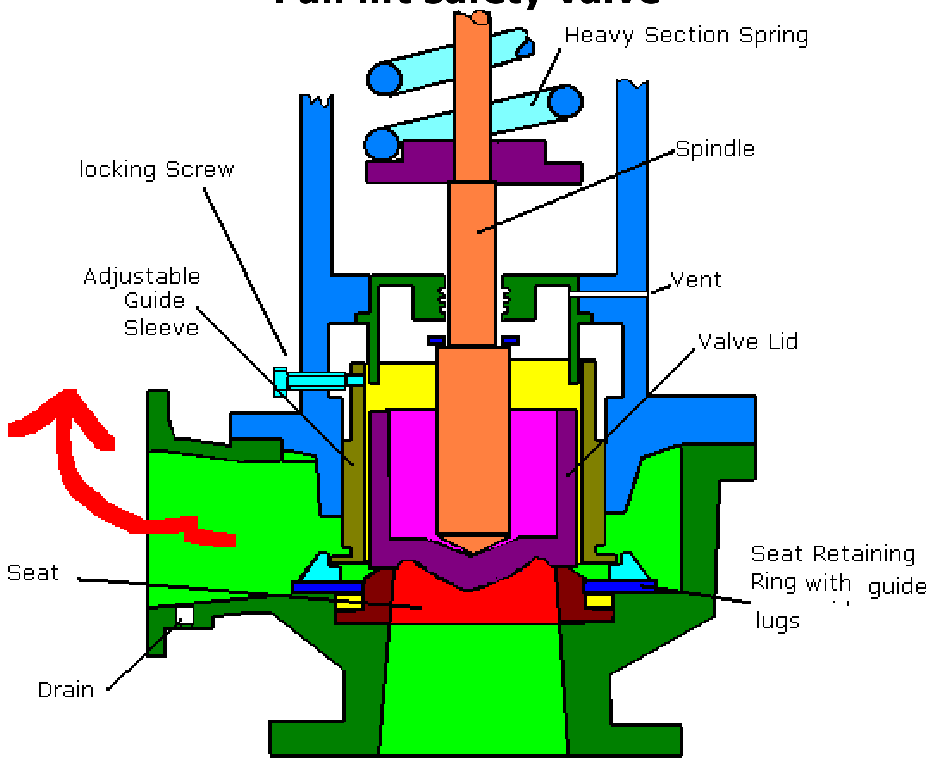
The manifold pipe must have an area equal to at least H of A; the exhaust must have a diameter dependent on the type of valve but up to 3 x A for a full bore relay operated valve.

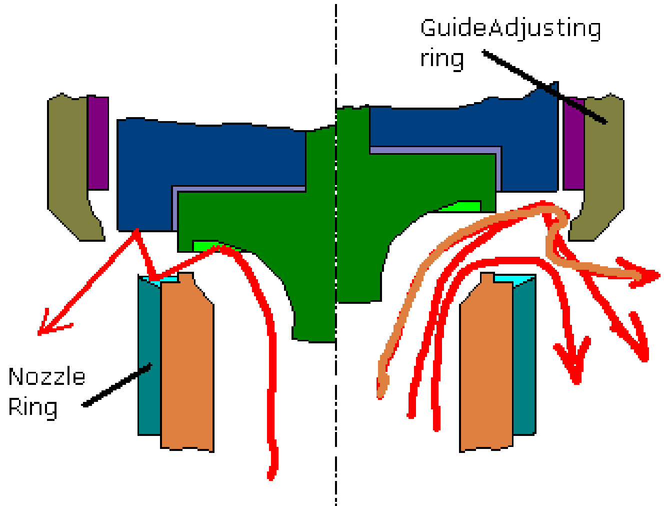
A drain pipe must be fitted to the lowest part of the valve; it should have no valve or cock and should be checked clear on regular occasions.

Materials

Materials for all parts must be non corrodible. Common materials are Bronze, Stainless steel or Monel metal, depending on the conditions of service. The valve chest is normally made of cast steel.

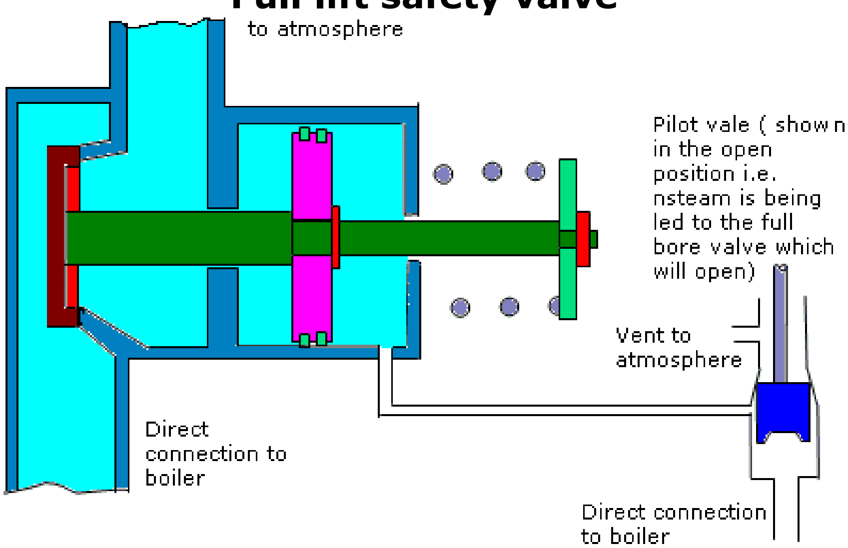
Full lift safety valve





This is a modern version of the high lift safety valve incorporating the piston and reaction force effects to improve valve lift. In addition the inlet pipe is tapered to give a nozzle effect increasing the reaction on the lid. The initial lift is produced when the steam pressure under the disc exceeds the spring pressure. As the valve begins to open a thin jet of steam escapes and is deflected by a small angle on the nozzle ring. As the lift increase the steam begins to react against upper guide ring increasing to 'full bore' lift. **Full Bore** lift is defined as that point where the area of the nozzle, rather than the lift, limits the discharge capacity of the valve. The form of the valve offers an increased area to the steam jet stream and the design allows for a piston effect of the valve trim assembly as it enters in the guide ring cylinder, both these effects increase lift and improve action of the valve. The guide sleeve is adjustable allowing alteration of the blowdown. With boiler pressure dropping the valve begins to close. When the lid just exits the guide sleeve there is a loss of the reaction and piston effect and the valve tends to snap shut cleanly. Blowdown adjustment is achieved by altering the height of the adjusting Guide Ring. On some designs a second adjustable ring is mounted on the nozzle, this allows adjustment of the 'warn' or 'simmering'period and increases the popping power. Adjustment of this ring is critical to operation, after factory setting it is generally unnecessary and no attempt should be made to remove slight 'warn'.

Full lift safety valve



Seen fitted to large high pressure boilers.

This design offers several advantages over simple high lift valves

- **Complicated design to achieve high lift is obviated**
- **Pilot valve may be mounted on the drum and the main valve maounted on the superheater thus making the system more sensitive to load changes (over pressurisation will first be seen in the steam drum before the superheater. In addition the pilot valve and main valve piston arrangements are subject to lower steam temperatures**
- **Boiler pressure will assist to close the main valve rapidly leading to very small blowdown**

Easing gear

This is fitted to safety valves to allow manual operation of the valve in an emergency.

Gauge glasses

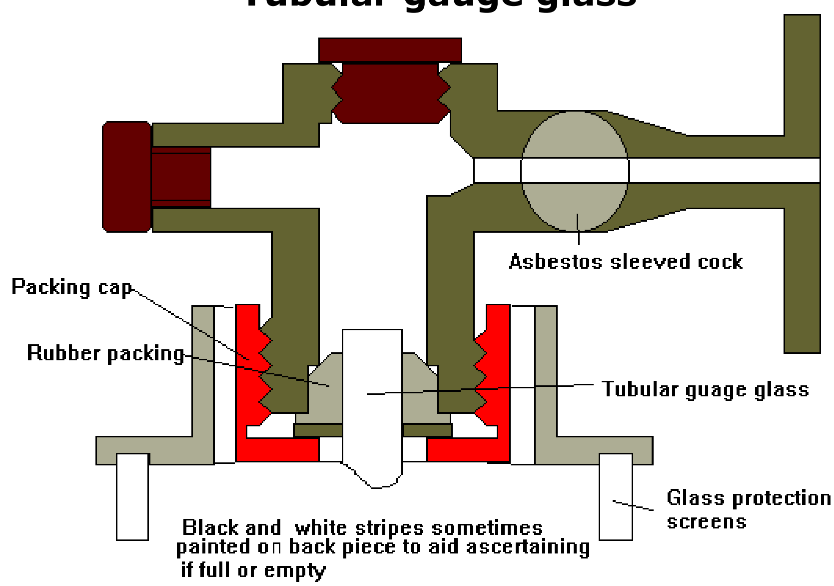
General

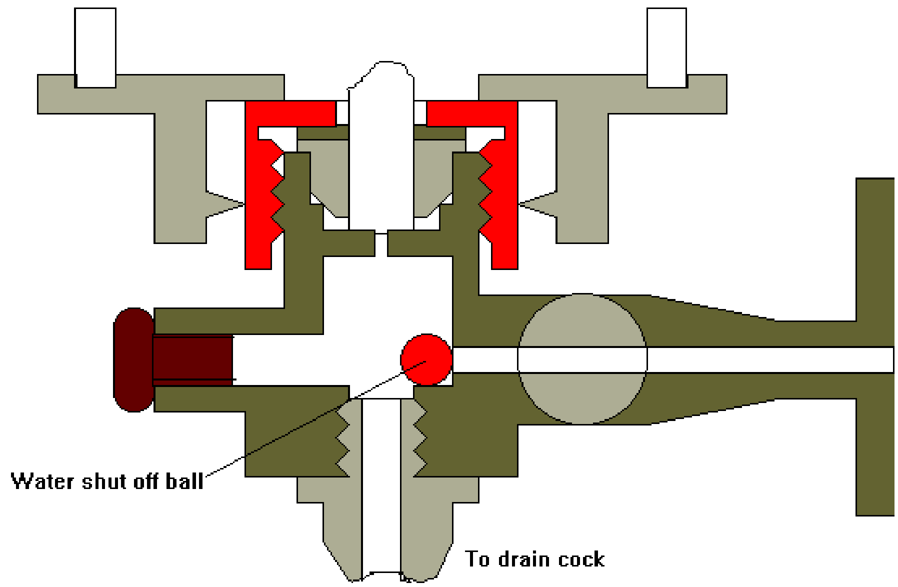
The requirements are that there must be two independent means of reading the boiler water level. Normal practice for propulsion plant boilers are the fitting of two direct reading level gauges and remote display readout.

Low pressure boilers (up to 17.5 bars)

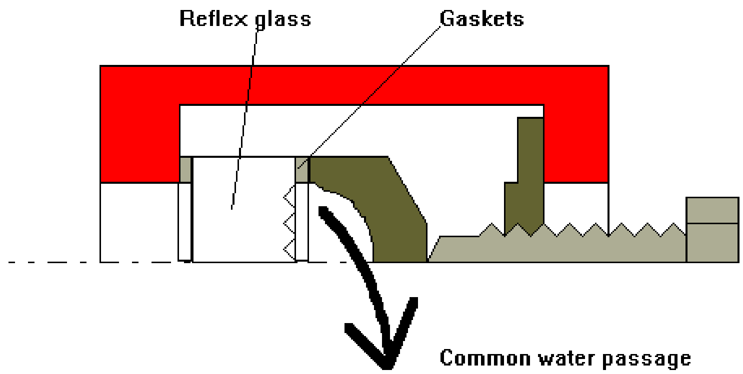
Small vertical boilers may be fitted wit a series of test cocks to ascertain the level; this is deemed unsuitable for boilers above 8.2 bar and/or 1.8m in diameter.

Tubular gauge glass



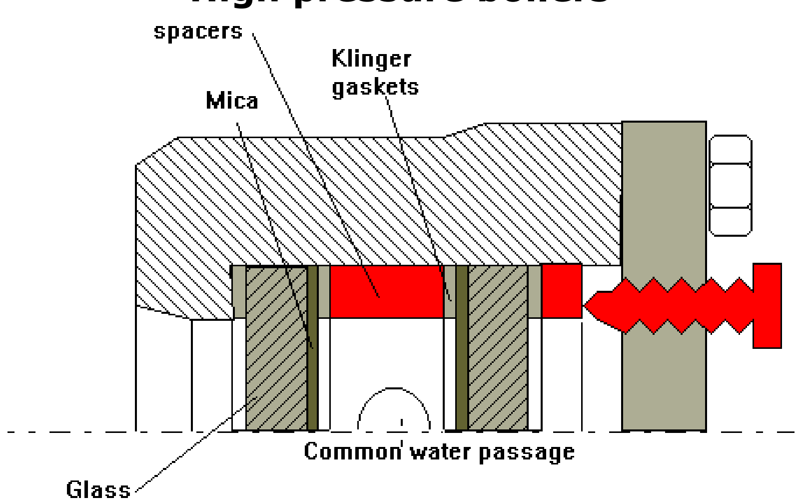


Medium pressure boilers



Reflex glass is used due to the fact that light falling on the glass is reflected by the steam but not by water, and so the glass appears bright where there is steam and dark where there is water.

High pressure boilers

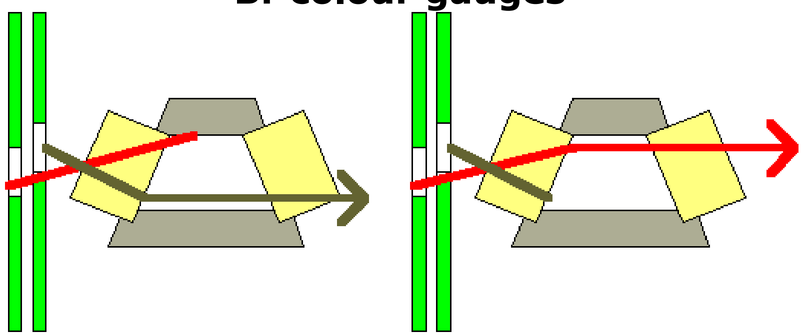


A ball is located in the water side to prevent large quantities of water entering the engine room in the event of the glass failing and the subsequent large expansion of the water as it flashes off to steam. An orifice restrictor is fitted to the steam valve. Mica is placed on the water side of the glass to protect against erosion and chemical attack of the high temperature water.

General gauge glass faults

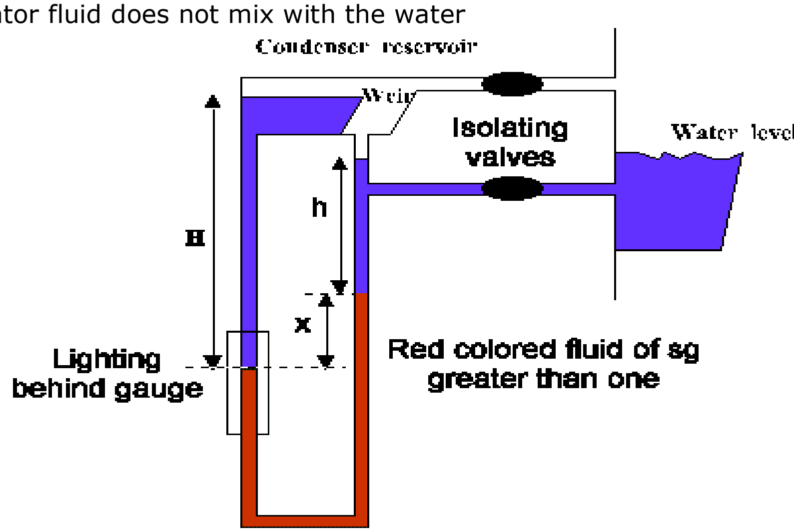
Due to the evaporation of water leaking through the cock joints a build up of deposits can occur. This leads to restriction and eventual blockage of the passage. If this occurs on the steam side then the level tends to read high as the steam condenses. Another reason for blockage is the cock twisting, hence the cocks are all arranged so that in their normal working positions, i.e. steam/water open, drain shut, the handles are all pointing downwards. Possibility of the sleeving rotating on the cock has led to the use of ribbed asbestos sleeves which must be carefully aligned when fitting. For tubular gauge glasses the length of the tube is critical and should be checked before fitting

Bi-colour gauges



"Igema" remote reading indicator

Fitted in addition to gauges required by statute and not in place of them. The red indicator fluid does not mix with the water



Equilibrium condition is when $H = h + rx$ where r is the specific density of the indicator fluid.

If the water level raises h increases and x reduces. Therefore H will be reduced and water will flow over the weir of the condenser to maintain the level constant. If the water level were to fall h would be reduced, x increase and H would be increased. Water therefore must be made from condensing steam in order to keep the condenser level constant.