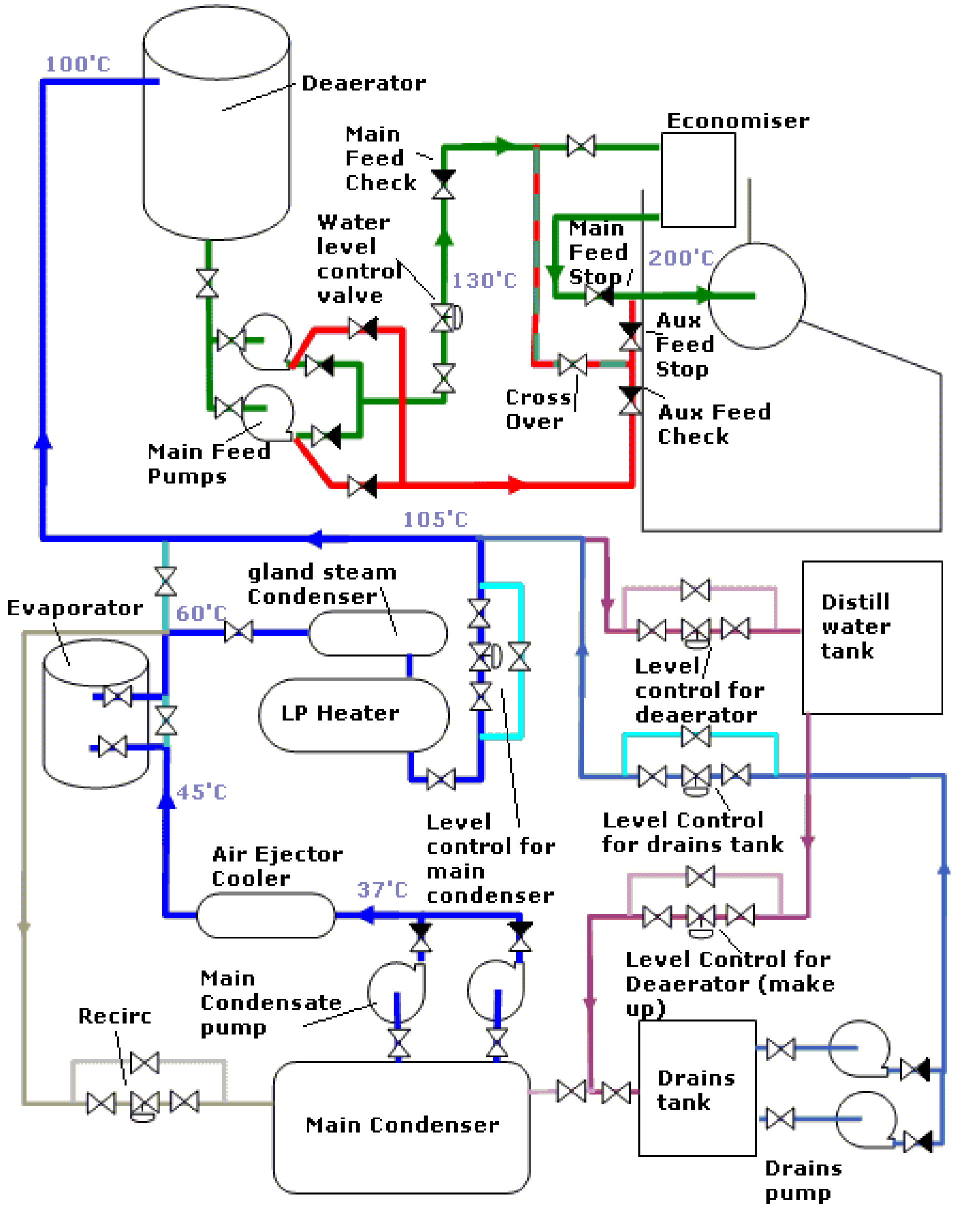
Feed system



Shown above is a typical feed water system for a modern steam plant. Water is pumped from the main condenser by special centrifugal pumps having an inducer to allow suction from the very low pressures without vaporisation of the water. The water passes through the air ejector cooler to the Condensate cooled evaporator. A recirculation valve is available to return some condensate to the main condenser. The purpose of this is to increase the overall flow though the evaporator cooler thereby increasing water production as well as to ensure a minimum flow through the condensate pumps.

The water passes via the gland steam condenser and LP heater which in this case are shown as a combined unit on to the Main Condenser level controller. This prevents the level in the condenser falling below a set level thereby causing the main condensate pumps to run dry.

Some times mounted after this is a deioniser and feed filter before the water is passed to the de-aerator.

The de-aerator is mounted as high as possible in the engine room increasing the suction head for the feed pump preventing vaporisation in the suction eye of the pump. Not shown is an automatic recirculation valve fitted to the main feed pump outlet to ensure a minimum flow through the pump. The boiler water then passes via the boiler water level controller to the economiser and then through to the boiler steam drum.

An second supply is available for use in emergencies to the drum either via or by passing the economiser.

The drains tank condensate is pump via the drains tank level controller into the main feed system.

System level Control

Control of the amount of water in the system is by level control of the de-aerator. One of the purposes of the de-aerator is to act as a reserve capacity of high quality feed for the boiler. Water may be spilled to the feed tank or made up to the drains tank. An emergency filling valve is available for the main condenser the use of which is avoided as it introduces large quantities of gasses into the condenser reducing efficiency.

Boiler economisers

Purpose

The purpose of the economiser is to increase plant efficiency by removing heat that would otherwise be lost in the flue gas and use it to indirectly feed heat the water. By heating the feed water it is also helping to prevent thermal shock as the water enters the steam drum.

Description

The flow of water is general counterflow. The exception to this is in the radiant heat boiler where the economiser is mounted immediately above the superheaters. The water flow in these so called 'Steaming economisers' is then parallel flow to decrease the tendency for the economiser to steam excessively above the design limits and lead to steam blockage , this is why these economisers are bare tube with

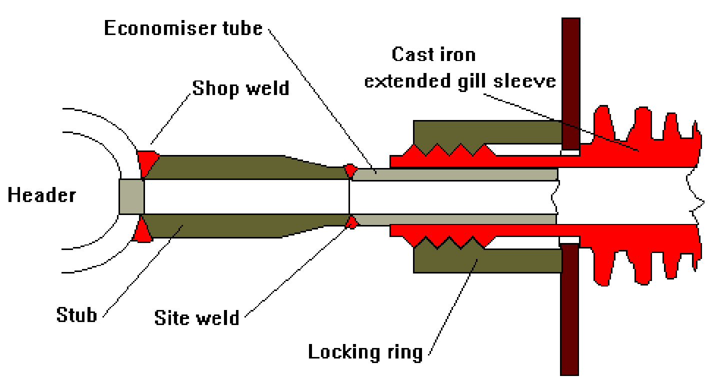
no extended heating surface. Vent and drains are fitted to header where isolating valves are fitted a safety valve must also be added.
The modern design involves the fabrication of the header and stub tubes which can then be heat treated. The tubes are then site welded to the stubs. The previous use of expanded joints has now fallen out of failure due to the requirement of a multitude of hand hole doors with associated joints and hence possible area of leakage. The materials used are governed the materials susceptibility to cold end corrosion (see later notes), any metal having a surface temperature below the dew point will tend to have acidic deposits forming on its surface caused by the water absorbing sulphur trioxide and dioxide from the flue gases. Some metals are more resistant to this form of corrosion at lower temperatures; choice of material will initially depend on the minimum metal surface temperature and is calculated as the feed water temperature that is passing through the economiser plus 5°C.

For temperatures greater than 138°C solid drawn mild steel tubing is used. Fitted to these are welded on extended surface steel fins or studs. For temperatures between 115°C to 138°C shrunk on/or cast iron gills must be used. The temperature should not be allowed to fall below 115°C as this can lead to heavy fouling as well as corrosive attack.

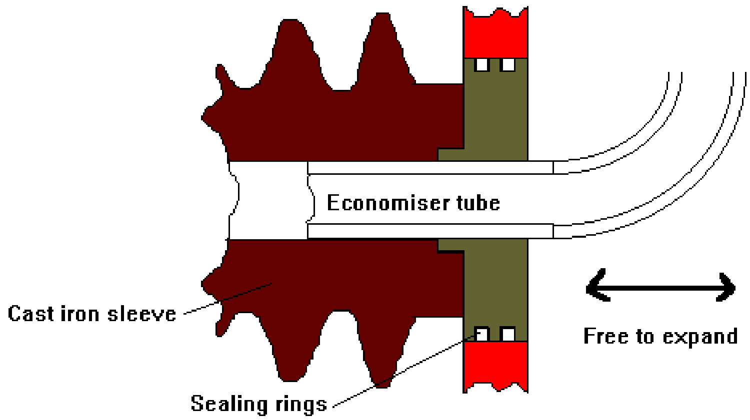
Efficient sootblowing is absolutely essential to ensure that surface are kept clear of combustion products which can not only lead to heavy corrosion and a drop in efficiency , but also to the possibility of an economiser fire with potentially disastrous consequences. With this in mind it is not unusual to find provision for water washing, something which is carried out on a very regular basis on a Motor ship with waste heat recovery.

If due to failure it is required to run the economiser dry then the maximum gas inlet temperature should be limited to about 370°C, vents and drains should be left open to ensure that there is no build up of pressure from any water that may be still located in the tubes.

Cast iron extended gill economiser - Inlet end



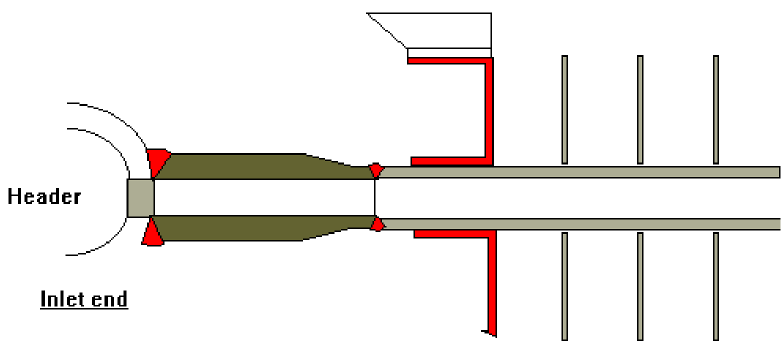
Return end

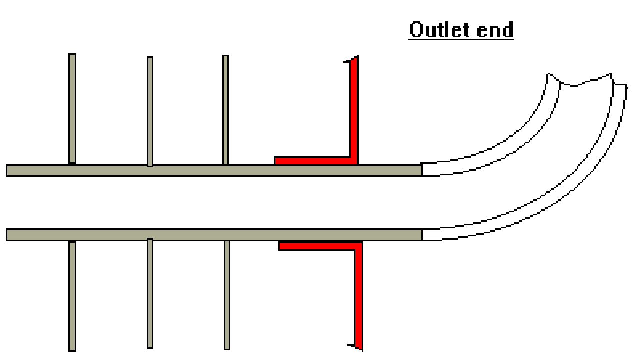


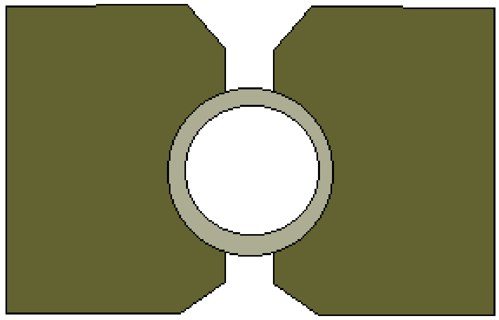
The unit is of the multiple pass 'melesco' style, the sleeves may be slid on before the bends are welded on.

The header is made out of mild steel.

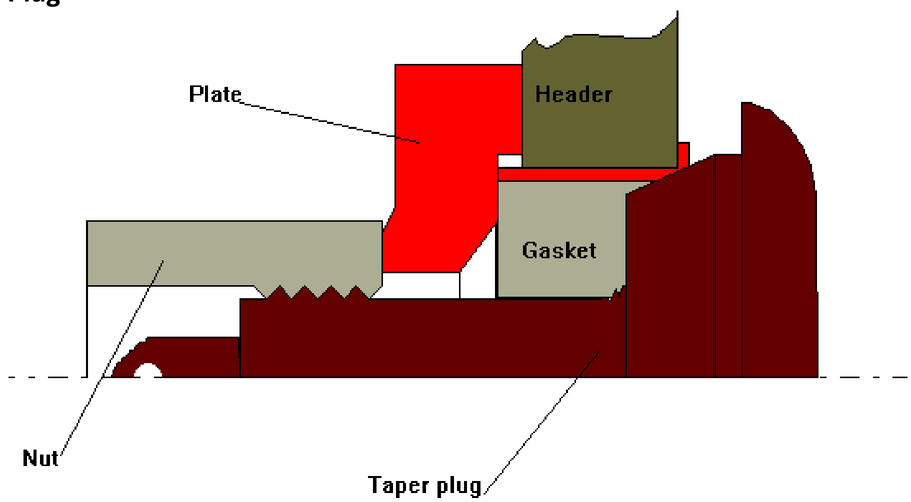
Mild steel fin extended surface economiser





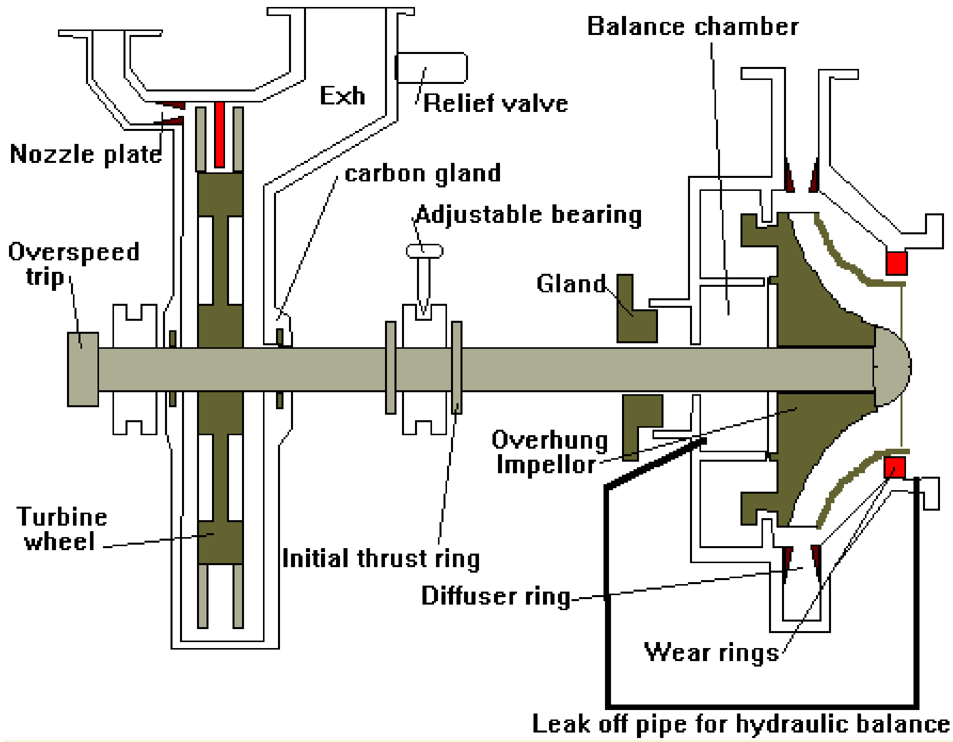


Plug



Boiler feed pumps

High speed, multistage centrifugal pumps are the preferred type due to their ability to supply large quantities of water and to provide it at steady flow avoiding shock loads on pipe lines and valves.



Materials

- **Nozzle plate- Creep resistant steel**
- **Blades-Stainless iron**
- **Bearings-White metalled (oil lubricated)**
- **Turbine glands- Carbon**
- **Turbine casing- Cast steel**
- **Turbine wheel- Stainless steel**
- **Shaft- Nickel Chrome steel**
- **Wear rings- Leaded bronze**
- **Impeller-Stainless steel or monel**
- **Diffuser ring- Aluminium bronze**

The impulse Curtis wheel (velocity compounded) rotates at speeds of around 7000 rpm. Velocity compounding means that there is very little pressure drop across the stages reducing the need for fine clearances. This allows the turbine to be run up quickly from cold.

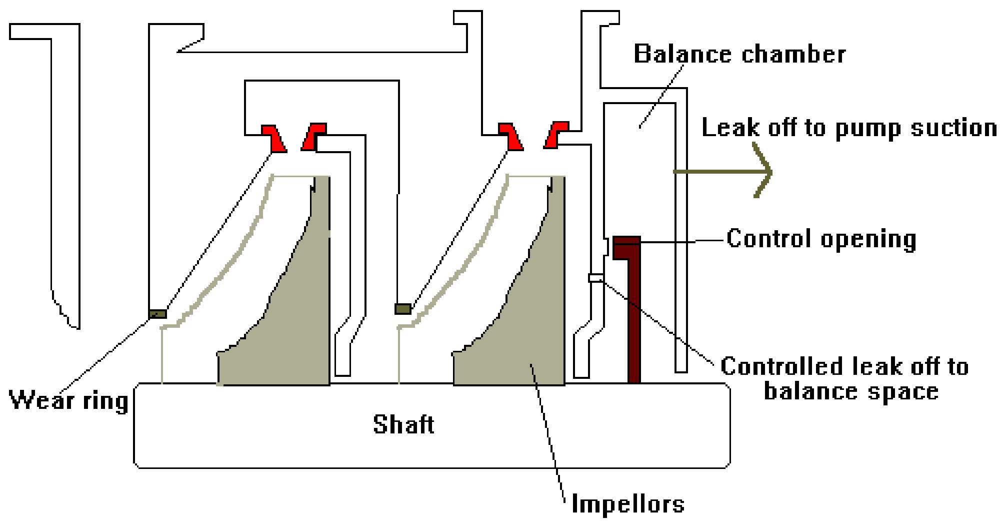
The balance chamber must have a diameter greater than the suction wear ring. If the pump is designed to be super-cavitating hard metal inducers are fitted which screw into the water. Any cavitations occurs on this which is made sacrificial.

Inlet steam pressure around 60 bar, outlet around 3 bar. Expansion down to lower pressures would require excessively large casings and would lead to problems of centrifugal stresses due to the larger blading required.

Carbon seals are used instead of labyrinths for simplicity and to keep the length of the unit down to a minimum. Due to the different coefficients of expansions between the carbon and the steel a madrill must be used to set the correct running clearance. For multistage pumps an extra end bearing is required and hence additional packed gland.

The pump is dynamically balanced by means of the balance chamber leak off to the suction eye, and the dam edges on the back of the impeller

Balancing of two stage pumps

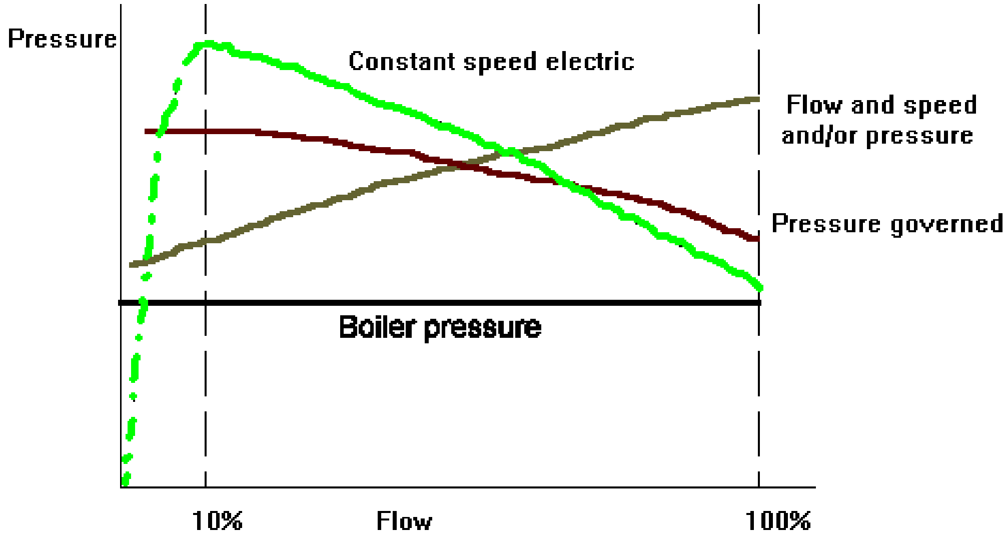


Feed pumps of this type of balance are best started against either a closed or spring loaded discharge v/v to ensure rapid build up of pressure

Bearings

Water lubricated bearings- Steel backing onto which is sintered a layer of porous bronze impregnated with PTFE (0.025mm thick). This PTFE is transferred to the shaft so providing very low coefficients of friction
Bearings operate at 115°C with water supplied at 5.5bar 70°C.
Bearing clearance- 0.15 mm
Max - 0.25mm must be replaced
Danger - 0.3 mm severe damage will occur
The bearings should also be replaced if less than 75 % shows on the surface.

Flow characteristics of controlled feed pumps

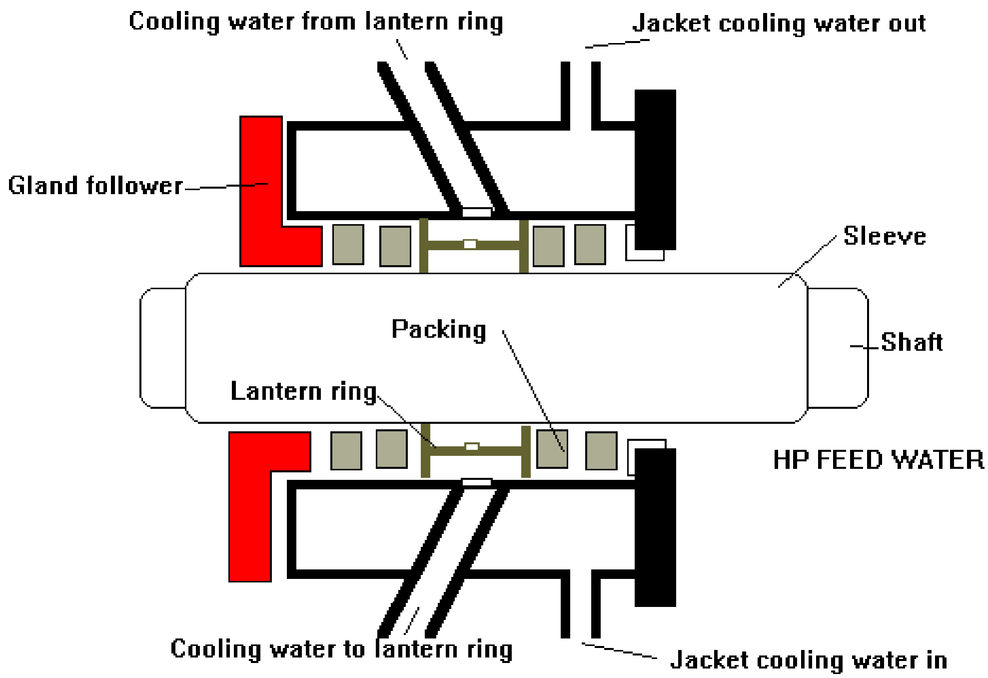


Constant speed (electric) - Below 10% turbulence becomes so great that the pump operates very inefficiently and must not be worked in this range. Hence, a recirc valve must be used. At full flow pressure is only just sufficient to feed the boiler

Pressure governed - Pressure droop designed in to give stable control.

Flow + Speed and/or Pressure - The extra element must be added with the flow otherwise the system becomes unstable. Characteristic can be level or slightly rising giving low pressure at low flow rates conserving energy and preventing water being forced at high pressures through partly open feed control valve.

Gland
Can be operated at very low flow rates due to reduced speed.



De-arators

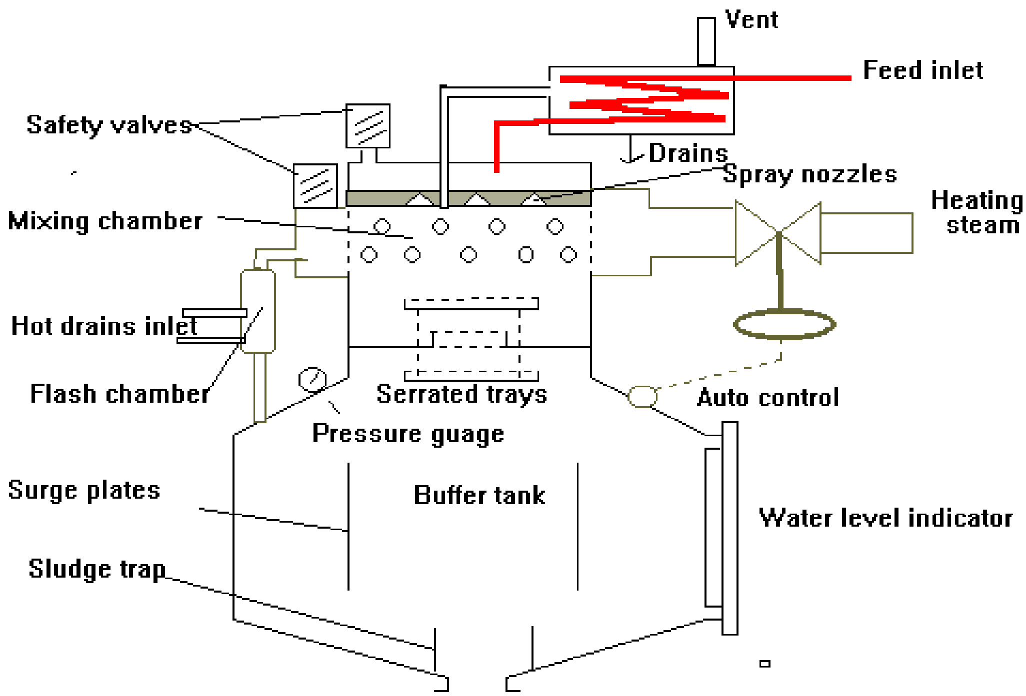
The need for de-aeration

In marine water tube boilers it is essential to keep water free of dissolved gases and impurities to prevent serious damage occurring in the boiler.
In a closed feed system the regenerative condenser removes the bulk of the gases with a dissolved oxygen content of less than 0.02 ml/l.
However, it is recommended for boilers operating above 30 bar and essential for those operating above 42 bar that a de-aerator be fitted.

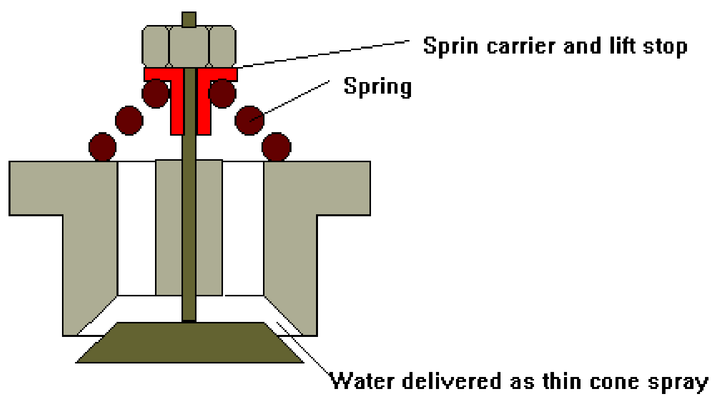
Purpose of fitting a De-aerator

There are four main purposes;

- **To act as a storage tank so as to maintain a level of water in the system**
- **To keep a constant head on the feed system and in particularly the Feed pumps.**
- **Allow for mechanical de-aeration of the water**
- **Act as a contact feed heater.**



Feed water enters the de-arator via the vent cooler, here the non condensable gasses and a small amount of steam vapour are cooled. The condensed water is returned to the system. The feed water is sprayed into the mixing chamber via nozzles, for systems with large variations of flow, two separate nozzle boxes may fitted with two independent shut off valves to ensure sufficient pressure for efficient spray. Alternatively, automatic spray valves may be fitted.



By varying the spring tension the pressure at which the nozzles open can be set at different levels.

The water in a fine spray, and so high surface area to volume, is rapidly heated to corresponding saturation temperature in the mixing chamber by the heating steam. This steam is supplied from the exhaust or IP system and is at about 2.5 bar.

The heated water and condensed steam then falls onto a series of plates with serrated edges, the purpose of these is to mechanically remove any gas bubbles in the water improving the efficiency of the process.

Finally the water falls into the buffer tank, before exiting to the feed pumps; as the water is now at saturation temperature any drop in pressure (such as in the suction eye of the impeller) will cause vapour bubbles to form. Hence, the de-aerator must be fitted well above the feed pumps or alternatively an extraction pump must be fitted to supply the feed pumps.

Hot water drains are led to the de-arator where they are allowed to flash into steam adding to the heating steam.

The non condensable gas outlet is limited so that there is only a small flow of water from the drain of the cooler. This water should be discarded as it contains not only high quantities of oxygen but also ammonia.

Requirements for efficient operation

- **The minimum temperature increase is 28°C**
- **The minimum heating steam temperature is 115°C which corresponds to a pressure of 1.7 bar; this is to prevent deposits forming on the economiser. To prevent cold end corrosion on cast iron protected economisers this temperature rises leading to the common practice of using steam at 2.5 bar**
- **The water at inlet should have an oxygen content of not more than 0.02 ml/l**

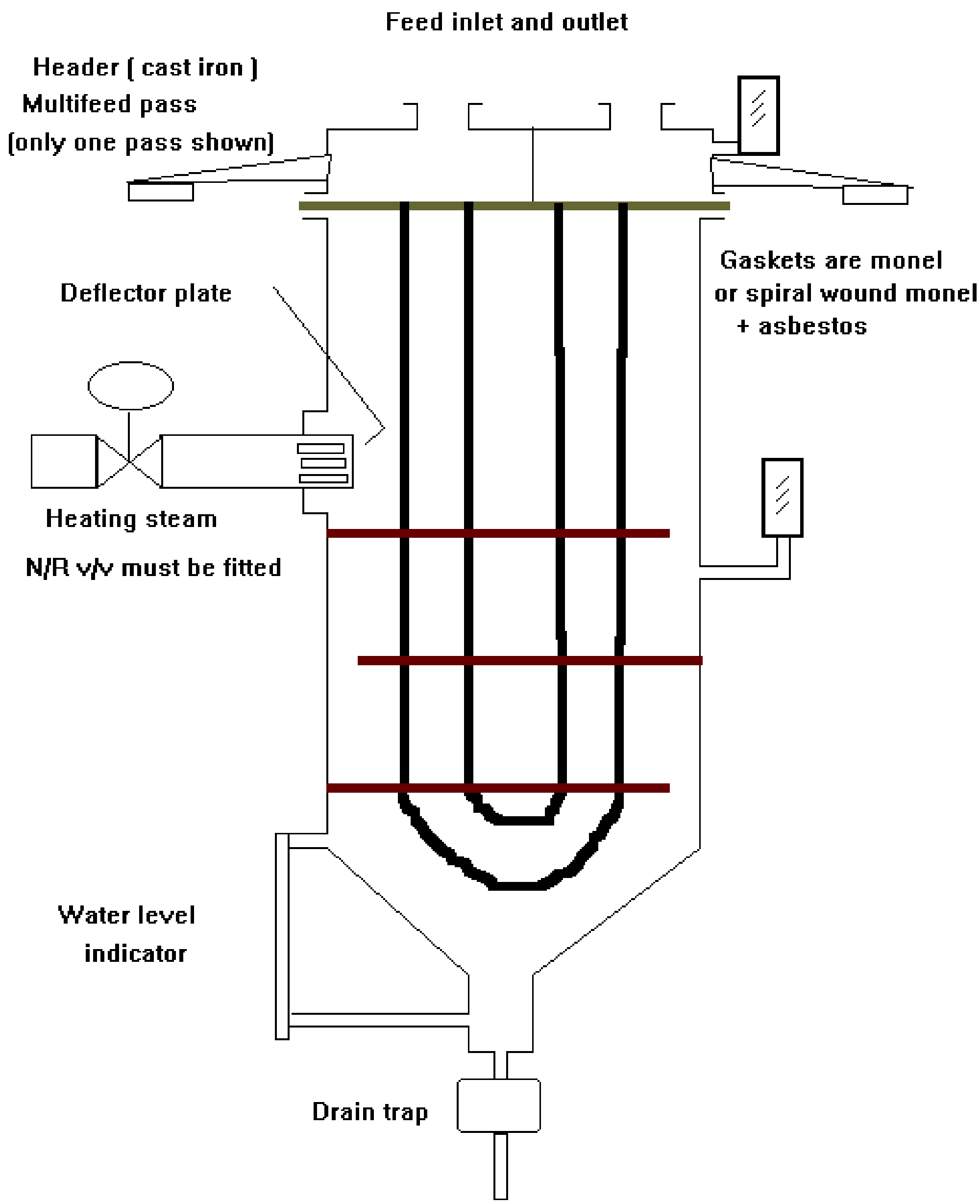
With these parameters met the water at outlet should have an oxygen level of not more than 0.005 ml/l.

A thermometer is fitted to the shell; the temperature should be kept to within 4°C of the saturation temperature of the pressure indicated on the pressure gauge. This can be governed by the quantity of heating steam added. If the difference is always greater the partial pressure due to the non-condensable gasses is high and the possibility of re-dissolving increases. Where fitted the valve on the air outlet should be opened more to limit of too much steam being lost up the vent.

The fitting of vent condensers is not universal and it is not uncommon to see the vent led up the funnel where a small wisp of steam can be seen when correctly adjusted.

HP feed heater

HP feed heater as fitted to cascade feed heater system instead of economiser



- The high pressure tubes are made of copper nickel or steel.
- The casing is made of mild steel

For efficiency it is important that the bottom of the heater does not become flooded.

As a large difference in pressure can be accommodated between the feed and steam, this type of heater can be fitted on the discharge side of the main feed pumps; in a cascade feed heating system this replaces the economiser and the heat in the flue gas is recovered by a regenerative air heater (Lungstrom). This system allows the feed to be heated to a high temperature

The change in temperature is normally about 30^{o}C

The heater, when new, must be able to withstand either or both of the following;

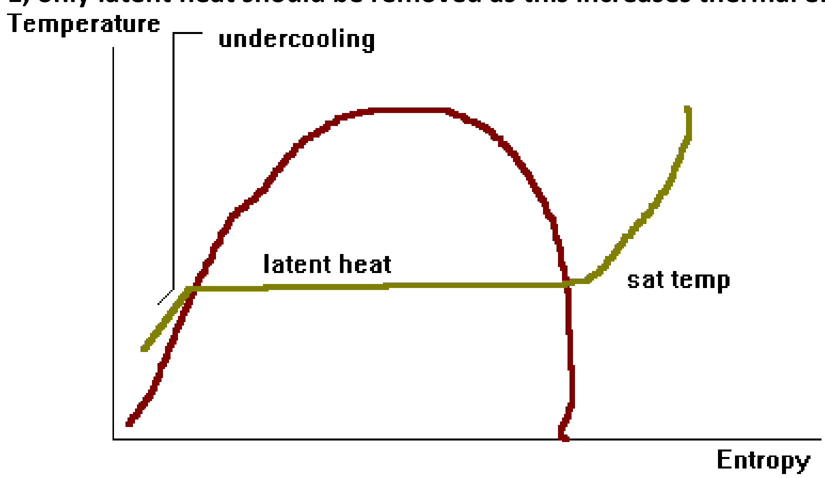
- **2 x boiler press + 20%**
- **125 % feed press continuously**

Condensers

BASIC FUNCTION

1. Remove latent heat from exhaust steam and hence allowing the distilled water to be pumped back to system
2. Create vacuum conditions assisting flow of exh steam and also allowing for low saturation tempo and hence increasing recoverable heat energy from the steam
3. De-aerate

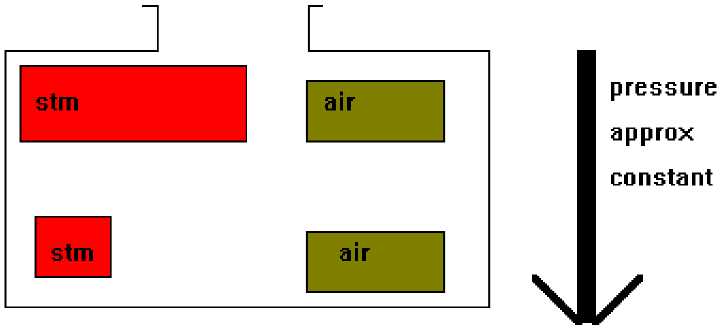
1, only latent heat should be removed as this increases thermal efficiency



Even when the steam is expanded to vacuum conditions some 60% of the initial enthalpy at boiler conditions is thrown away in the condenser.

3, Air must be removed from the condenser because;

- **-it dissolves in water**
- **-it destroys the vacuum**
- **-poor conductor of heat and forms a thin film on pipes**
- **-increases under cooling due to the following circumstances**



The steam quantity reduces and hence it is responsible for less of the total pressure. Hence it is at a lower pressure, has lower saturation temperature and so is undercooled with respect to the actual pressure within the condenser (that is to say the condensate should be at a higher temperature equal to the saturation temperature at the pressure measured in the condenser.

Daltons law of partial pressure

Each constituent of a gas mix exerts a partial pressure equivalent to that if it occupied the space alone.

Condensate falling through the lower cooler regions containing the high air content is further cooled and re absorbs gases.

DESIGN

Must have large surface area available for cooling . Hence large number of small diameter tubes.

Cross flow is adopted for ease of manufacture, this allied to the change of state gives a cooling efficiency approaching that of counterflow

Taking into account tube material ,
max sea water flow rate should be maintained so as to;
a. maintain a sufficient steam/ coolant tempo difference across the material along the tube length
b. prevent silting

Circulating system should offer no undue resistance to flow and supply water equally to all tubes.

The tube batches should be so arranged so as to provide no resistance to the flow of steam. There is normally a narrowing inlet space within or surrounding the bank so as the passage area remains constant as the steam condensers.

Failure to provide even flow leads to ;
a. reduced efficiency

b. pockets on non-condensable gasses being formed in the tube banks.

Allowance in the design should be made for some expanding arrangement.

PROTECTION OF CONDENSERS

Avoid low water speeds which causes silting.
Too high a speed leads to erosion.
Cathodic protection for plates and tubes by using soft iron/mild steel anodes. The effect can be increased with the use of impressed current using anodes of larger size and different material.

Alternately coating of the tubes with a 10% ferrous sulphate solution.
Rubber bonding of water boxes.

Marine growth prevention

- **-chlorine dosage**
- **-Electro chlorine generator making sodium hypochlorite (switched off when dosing with ferrous sulphate)**

Erosion protection

- **-Inlet of tubes streamlined to smooth flow by expanding and bell mouthing**
- **- the fitting of plastic ferrules**
- **-for aluminium-brass inserts fitted and glued**

When laying up the following procedures should be carried out to prevent damage;

- **-Drain sea water side**
- **-If ferrous sulphate has been used then the SW side should be refilled with fresh water to maintain film**
- **-Where it is not practical to drain then the SW should be circulated daily**

CONDENSER CLEANING

Before draining ensure no special chocking arrangements are necessary to prevent loading on springs or damage to the LP exhaust inlet gasket.

Waterside

- **General inspection before cleaning**
- **Place boards to protect the rubber lining**
- **Use water jets or balls blown by compressed air through the tubes**
- **Only brushes or canes as a last resort**
- **When plastic inserts are fitted work from the inlet end**
- **Test for leaks on completion**
- **Clean or renew the sacrificial anodes**
- **Remove the boards and prove vents and drains clear**

Steamside

- Inspect the steam side for deposits, clean with a chemical solvent where required
- Examine the baffles, tube plates and deflectors
- Look for vibration erosion damage of the tubes
- Inspect for possible air leakage
- Box up and remove chocks.
-

Leakage

The indications that a leak is in existence is that of high salinity measured in the condensate and boiler combined with a rapid drop in pH.

The first aid should be the injection of sawdust followed by a shut down at the soonest possible time.

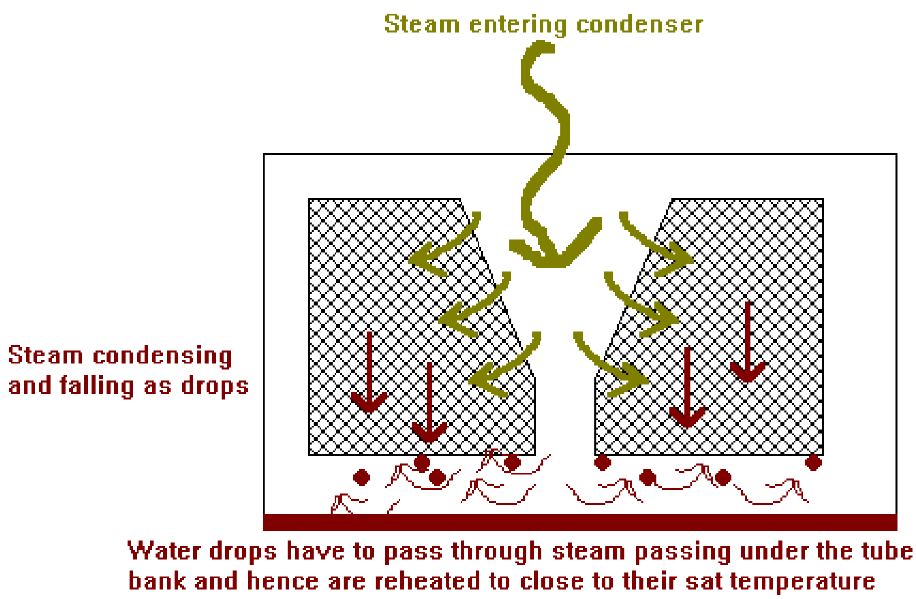
There are three methods for leak detection:

Ultrasonic - Here, electric tone speakers are fitted in the steam space, and a microphone passed down the tubes. Alternately, instead of speakers a vacuum can be drawn with the microphone picking up air leakage.

Fluorescent - The water side is cleaned and dried, chocks are fitted and the steam side filled with water containing a quantity of fluorescence. A UV lamp is then used on the water side.

Vacuum test - Draw a vacuum and cover the tube plate with plastic or use the ultrasound microphone.

Regenerative condensers



With the regenerative effect the water is heated to within one degree of the sat temperature so releasing dissolved gases which may have been re-absorbed as the drops where falling.

The dissolved oxygen content should be less than 0.02 ml/litre.

At the air ejector take off for the gasses, a cooling space is so arranged so a to ensure that there is no reheating of the gasses which would lead to expansion and reduce the efficiency of the process.

Drains which are led to the condenser are led to the top so the water is reheated/de-arated before extraction.

The increasing use of scoops has led to the single pass condensers with SW velocities of 2 - 4 m/s being the ideal with minimum's to prevent silting of 1m/s.

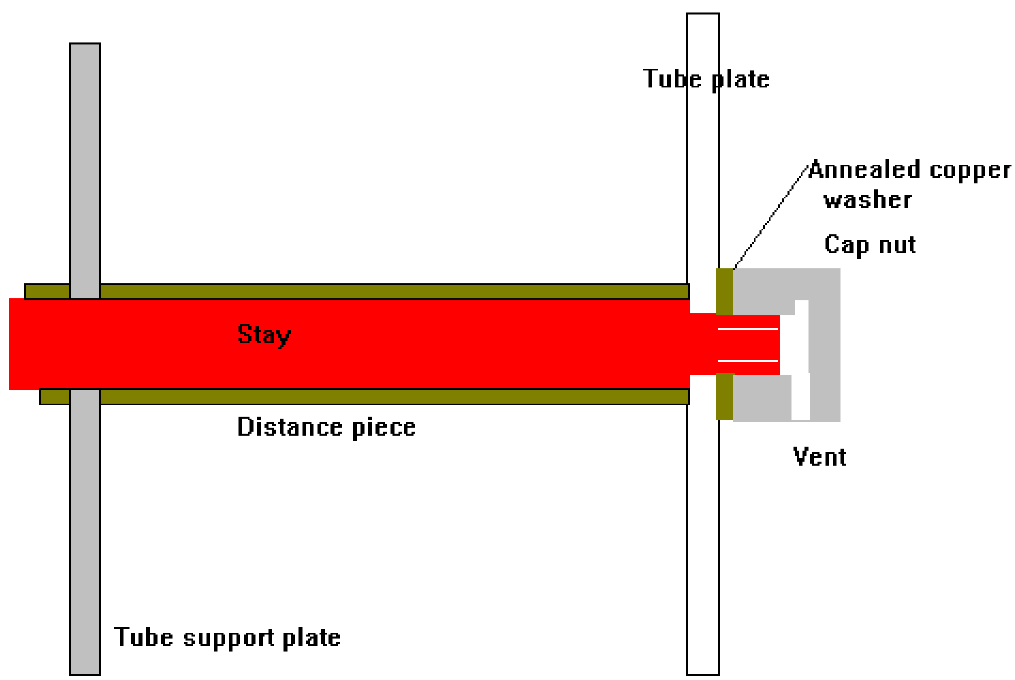
Material of tubes

Cheap aluminium brass has a low allowable flow speed of 5 m/s; cuprum-nickel has a higher flow of 10 m/s but is dearer and a poorer conductor of heat.

Tube fitting

This is by expanding and bell mouthing or with by ferrules and alternately fibre and metallic packing at the other end,

Stays



Tube stays cannot be used where the tubes have been expanded at both ends, the tubes must support themselves.

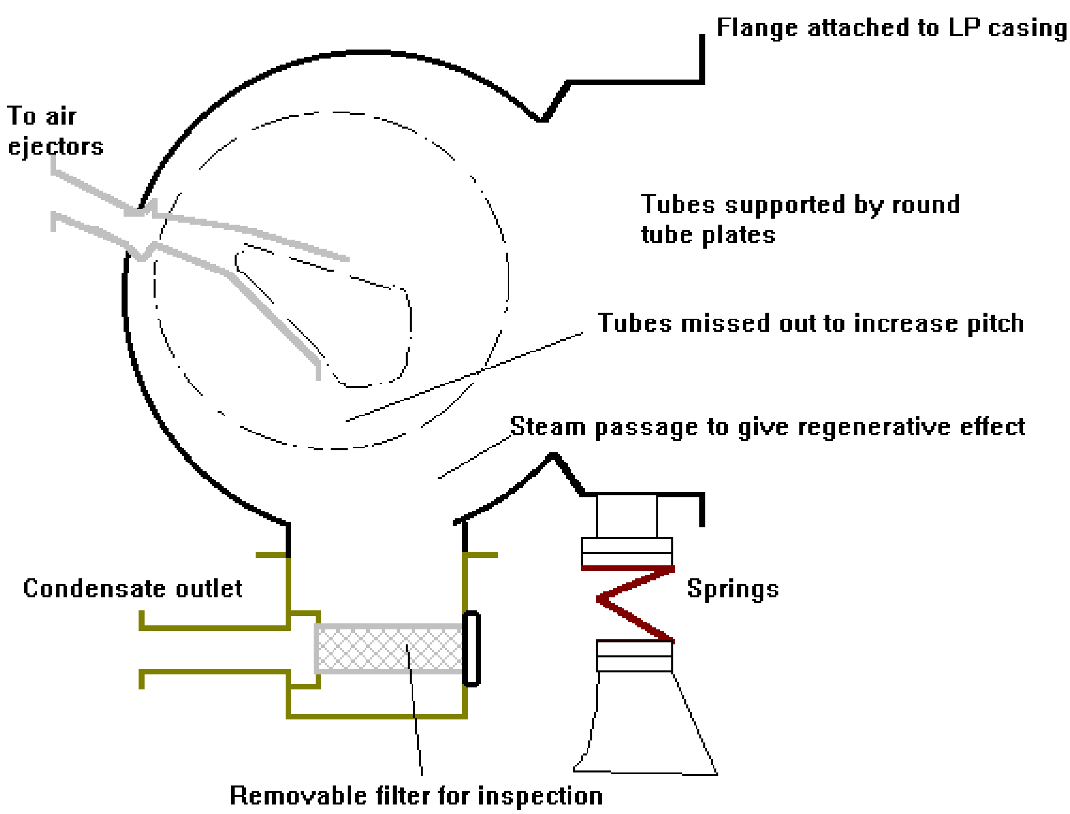
Advantages of the different designs of condenser
Underslung

This provides a short path for both the ahead and astern steam, however the steam must turn through 90^{o} before entering and hence there is a possibility of increased windage losses. Windage loss is where the ahead steam is picked up by the astern turbine which recompresses it and heats it up leading to a loss of efficiency, reduced vacuum and heating up of the astern turbine.
The length is reduced but at the cost of increased height. The fitted support springs under the condenser carry two thirds of the weight and allow for expansion.

Axial plane (radial flow)

Reduced height at the expense of length. The ahead and astern both exhaust in the same direction so reducing the chance of windage. As the turbines are situate lower and inline the alignment to the tailshaft is simpler. The big disadvantage is that the condensate level is critical and must not be allowed to spill out.

Axial plane condenser as fitted to the Stal-Laval AP Plant



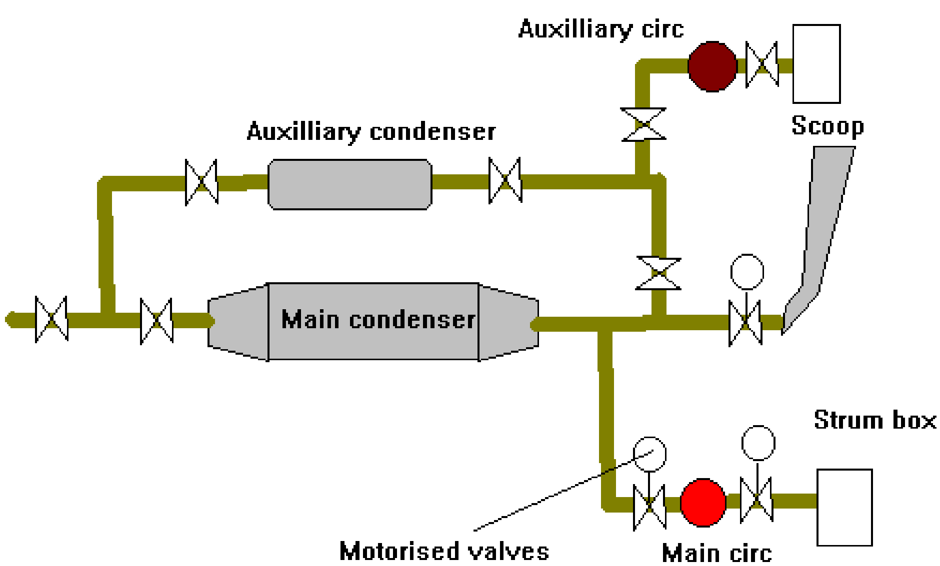
The tube pitch at the bottom of the tube stack is increased by leaving out alternate tubes over the final three rows. This helps to encourage the regenerating effect. A

cooling pack of coarse pitched tubes is fitted within the bellmouth for the air extraction to prevent re-expansion of any gases and removal of vapour
The condenser is a dry bottom type with a low water level in the hot well being maintained by the super cavitating pumps

Scoop systems

This single plane design of condenser is of the single pass type and is well suited to use with scoop systems. This is were cooling water flow to the condenser is supplied from an angled inlet pipe on the ships side. For this to operate the engine has to be travelling at a certain speed to give the correct flow of water. Below this speed the scoop must be shut off and a centrifugal main circulating pump in use. The advantage of this system is that the main circ can be of a much smaller size than would be required if it had to supply cooling water requirements for full engine load conditions. In this case it would be normal to fit to pumps of 50% capacity.

Scoop System layout



Air Ejectors

FUNCTION

Air ejector units are generally of the steam jet type. Although electrically powered units offer the advantage of ease of installation and slightly improved operating efficiency their maintenance requirements has ensured that the most common type on larger installations are steam powered Their primary function is to remove non-condensable gases from the condenser.

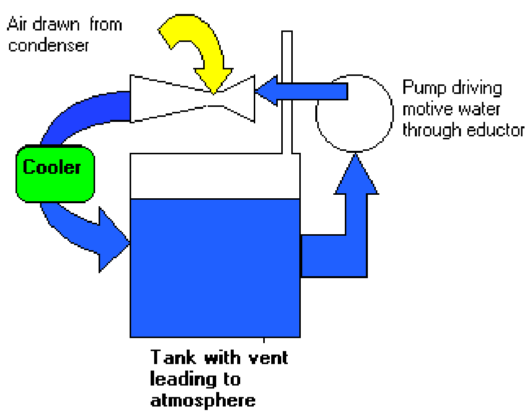
After passing through the nozzle the high velocity stream jet entrains air and vapour, compresses it, and the mixture passes to a condenser section were it is cooled. The air with any uncondensed steam and vapour passing to the second stage were further compression of the air takes place.

Depending upon the number of stages of the air ejector, the air is now discharged to atmosphere or to a final stage and then to atmosphere. The condensers are of the surface type and are cooled by condensate, in this way acting as a feed heater.

Either, two complete units or two ejectors mounted on one condenser are used , nozzle diameters are very small typically 1.2 to 4.7 mm and are liable to wear, abrasion and blockage.

When manoeuvring or at rest provision must be made to ensure that there is adequate flow of condensate through the condenser to provide cooling. This is achieved by means of a recirculating v/v which leads condensate from the outlet of the air ejector condenser outlet (and other low pressure feed heaters such as an evaporator) back to the main condenser. The opening of this v/v should be limited as it leads to a loss of plant efficiency.

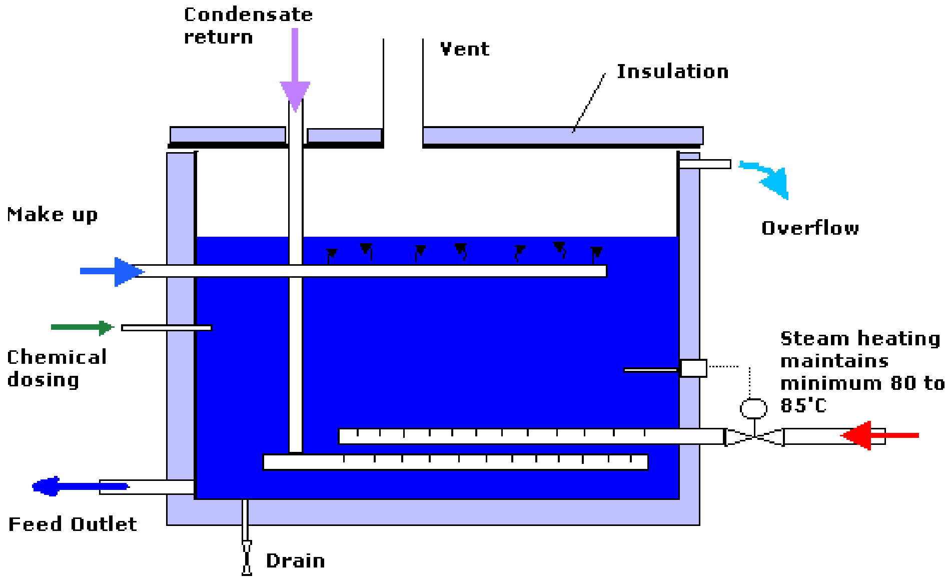
Electric Powered



The position of the cooler can vary; either as shown, incorporated into the tank or on the suction side of the pump.

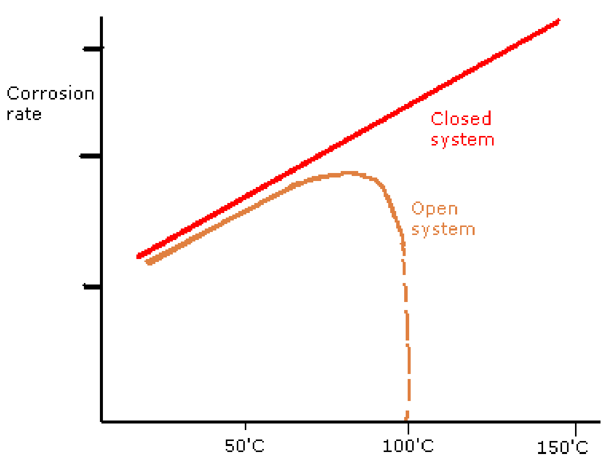
Feed Tank Design

A well designed feed tank should be designed to minimise the oxygen within the feed system. This is especially important with open feed systems.



The following are taken as parameters for a well designed tank

- **Adequate ventilation with on or more vent pies determined by the volume of water**
- **Condensate enters as low as possible via a slotted sparge pipe**
- **Cold water make up enters at highest point**
- **Sufficient tank volume to cope with transient flows from normal operations without necessitating spilling back to feed tanks or overflows.**
- **Tank to have sufficient volume of water at normal working level to allow for 1 hours operation at maximum demand.**
- **Take off to feed pumps to be at least 75mm from tank bottom**
- **Tank to be located to provide head requirements at normal working level for feed pumps**



As a rule of thumb chemical reaction rates double for every 10^0 C rise in temperature. For feed system this remains true up to about 80^0 C for open system. After this due to reducing solubility of oxygen the rate of corrosion reduces. Thus steam heating on the open feed tanks have thermostats set at 85'C or higher.