Module BESTT MS3

The Marine Steam – Water System

Aim

This unit explains why a marine steam plant has a much more complex water supply system than a locomotive or traction engine. We will consider how water is pumped to the boiler, how the exhaust steam is dealt with, and how suitably clean water can be resupplied to the boiler.

INTRODUCTION

Why marine steam vessels need to condense

Feedwater pumps

The types of condenser

The hotwell and oil separation system

The Feedwater system

Water impurities and Corrosion control

One might think that water supply for a boat is a rather silly topic to consider, but The Rime of the Ancyent Marinere '*Water, water every where, nor any a dropp to drink*' was quite right for steam ships as well as shipwrecked sailors. If a steam ship simply took seawater into the boilers, it would only take an hour or two for the boiler to completely fill with salt: the water evaporates but leaves an increasingly concentrated (and quickly crystallising) residue.

Smaller steam launches, particularly when sailing on fresh water, tend to exhaust steam which has been used by the engine either directly overboard or through the funnel to atmosphere like a railway engine. Fresh water to replace that used from the boiler is generally drawn in from the river or lake through injectors with the aim of maintaining a constant water level in the boiler. Although the freshwater from the river or lake can easily be used it is also important to frequently remove detritus especially if the water is silty.

Some larger launches and larger vessels, particularly those sailing on salt water in general recycle the used steam by condensing it and pumping that condensate back into the boiler. In a steam engine the used steam goes out from the engine into the Condenser where it passes over tubes filled with cold river or lake water. The cooling water is pumped through the tubes by a Circulating Pump and then discharged back overboard. The cooled steam turns back to water (known as condensate) and is sucked through the Air Pump into the Hot Well from where it is then pumped back into the boiler.

There are two significant reasons for condensing:

- Firstly, the water can be used again. This avoids having to carry sufficient water for the whole journey (as most railway locomotives did), or using the water you are floating on, and makes it easier to control the water quality. But it does mean having to install equipment to remove cylinder oil (if used) from the feed water, and you can no longer use the exhaust steam to ‘puff’ – draw air through the fire by directing it up the funnel.
- Secondly, if the condenser is suitably sealed, the pressure in it can fall significantly below atmospheric pressure, essentially adding to the pressure difference available to the engine, and increasing power. Some of the extra power has to be used to pump the condensed water back to atmospheric pressure, but thermodynamic theory shows that there will still be a net gain. Most compound engines are designed to be used with a condenser.

Learning Outcomes

LO 1:

Feed Pumps and Other Engine Room Pumps

1. Why must supply be maintained?
2. Types of manual (hand) pumps
3. Advantages of engine feed pumps
4. Engine feed pump designs
5. Monitoring output of engine feed pumps
6. Other engine room pumps
7. Pump fault finding

There must be at least two methods of supplying the boiler with water and many operators will prefer to have three. The water may be pre-heated or supplied cold - both have advantages in different circumstances. Failure to maintain the water level can result in catastrophic failure of the boiler.

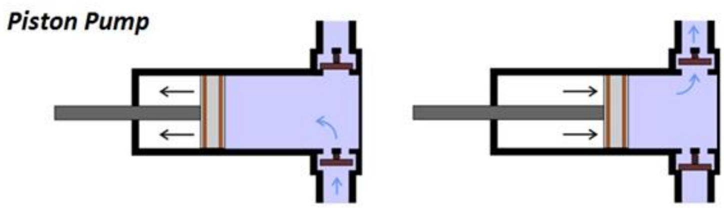
Supplying pre-heated water, particularly while running, will improve the efficiency of the plant; the energy required to raise the water to boiling point will be reduced and so less fuel will be required to maintain the same level of steam output. Systems for transferring this heat to the feed water could be an economiser or an exhaust feed water heat exchanger.

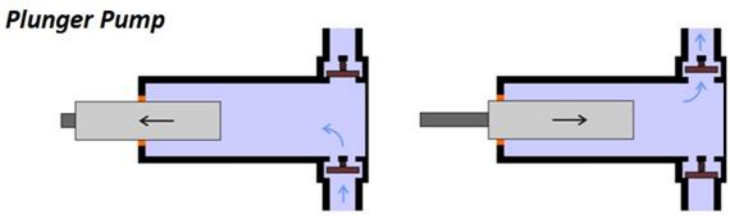
Supplying cold water might be beneficial to reduce the pressure in the boiler for specific reasons, for example, when drawing alongside a quay or entering a lock. By adding cold water to the boiler the pressure will fall, or be kept constant, in the absence of steam demand, and so the pressure relief (safety) valve will not operate. If steam is exhausted through the relief valve it is wasted energy. When additional water is added to the boiler it increases the 'thermal mass' which can then be exploited when demanding steam again.

Manual (Hand) Pump

Many small and medium sized steam launches have a hand operated feed pump. This can be valuable to raise the level of the water in the boiler while there is no or little steam pressure and when starting from cold. It can also be useful in conducting cold water hydraulic tests of the pressure system. The capacity of these pumps tends to be small (perhaps 3cm^2 bore and 10cm stroke) and they will frequently have a detachable lever/handle to provide sufficient leverage to pump against the boiler pressure.

The designs will often be a piston-type or plunger-type and will feature inlet and outlet valves. These do not need to be rated for steam as these pumps will only operate with cold or warm water.





https://www.michael-smith-engineers.co.uk/resources/useful-info/positive-displacement-pumps

It will be easy for the operator to be confident that the pump is working because there will be a reassuring back pressure on every stroke of the pump. The pump could be further tested by closing the isolation cock adjacent to the boiler and the operator can satisfy themselves that there is no movement of the pump handle at all, indicating a leak-proof hydraulic system.

Engine Driven Feed Pump

It is common practice for the steam plant to have a feed pump which is driven by the engine or propeller shaft. Commonly these will be small piston or plunger pumps which may be driven directly from an eccentric and strap, via a gear-mechanism at reduced rpm from engine speed, or linked to the reciprocating cross-head.

A slow-moving piston is advantageous in a feed pump as a small-bore long stroke pump will have a greater tendency to cause cavitation and the bubbles which result can reduce or even stop the effective working of a water pump: the air can be compressed on each stroke rather than forcing the movement of water by positive displacement.

The engine driven feed-pump has the desirable property that the output is directly proportional to engine speed, and as such there is an element of self-regulation in matching the flow rate and the demand. This is an over-simplification as the steam working pressure, the loading of the vessel, and the water conditions all influence the steam demand per rpm substantially.

Typically, the engine driven feed pump will be designed to be slightly oversized to account for additional engine demand, plus the use of other ancillaries such as the whistle. To regulate the supply a bypass valve is fitted between the pump and the boiler. This may be a needle valve or a full closure valve. The water will always flow via the path of least resistance so when the bypass valve is open the output will be diverted back to the supply (hotwell) and when closed the water goes to the boiler. This valve may be manually controlled but in many small launches it is linked to a float valve in the hotwell which will automatically regulate the water level. There are more complex systems which can link the bypass valve operation to the boiler water level.

As with the hand feed-pump, because these valves are operating with cool water, domestic plumbing fittings are often sufficient in this application.

The first sign that the boiler feed pump is not working will usually be that the water level on the boiler has dropped unexpectedly. It could also be noticed that the boiler pressure rises too - as a result of the lack of cooler water being introduced to the system. Water tube boilers are common on steam launches due to their light weight and rapid steaming, however they often carry a smaller water volume than fire tube boilers and hence will react more quickly to a feed pump fault. Usually there is a valve or cock to bleed the boiler feed pump which can be used to release trapped air and prime the feed pump to make it pump again. If the boiler feed pump has completely failed and cannot be restarted then there is a need to pump water into the boiler in other ways either from the Hotwell or the make-up feed tank. On ships there will be a General Service Pump which can pump water from the hotwell, or the make-up tank, or in dire circumstances from directly overboard in dire emergencies. Small launches may have a hand-feed pump for this purpose.

For the safety of the boiler it is advantageous to discover the feed pump failure as soon as possible so that remedial action can be taken. Some steam launches will have systems to assist. The simplest is in systems where there are bronze clack valves or steel ball bearings as non-return valves and these can tap or click with each pump stroke providing an audible signal that all is well. Where 'silence is golden', nitrile balls or rubber-seated one way valves eliminate this signal method, so a pressure dial on the feed system may be included. As long as this is pulsing at a pressure just above the boiler pressure, then there is the continuous reassurance that the boiler is receiving water. A further signal that the feedwater pump is not operating may also be that the 'hotwell' overflows however the hotwell may not be in a conspicuous location within the launch.

Auxiliary Pumps

Engine rooms of ships would often have one or two auxiliary pumps (sometimes known as Donkey Pumps) which could be used for all manner of purposes in addition to pumping additional water to the boiler such as circulating water through an inboard condenser, rebalancing shipboard water tanks, firefighting, sluicing the decks, pumping bilges, etc. 'Donkey Pump' is a generic term for a hard-working engine/pump combination and there are a wide variety of types.

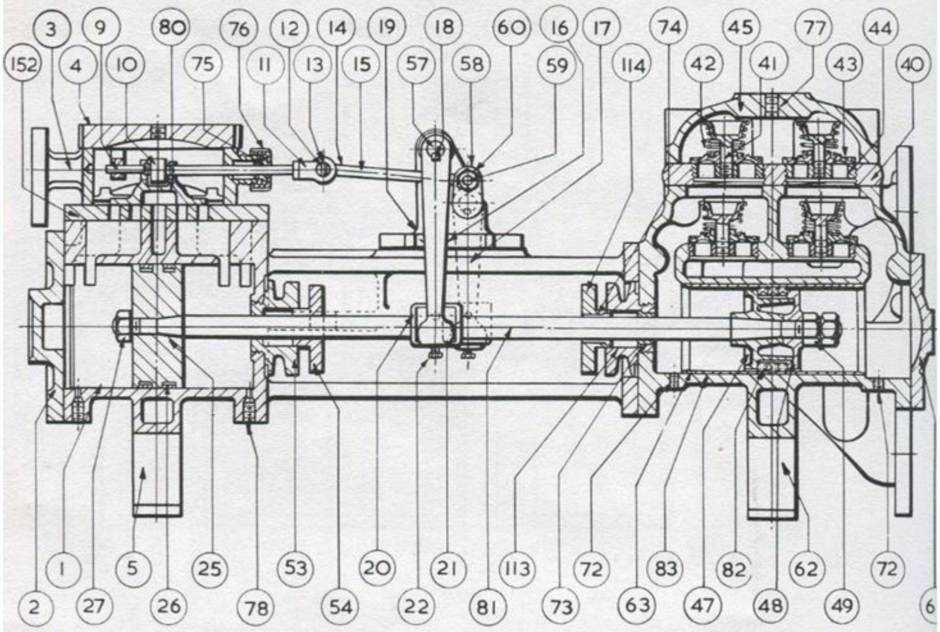
Circulation pumps for supplying cold water to a condenser are either a reciprocating pump or a steam driven centrifugal pump and will need to deal with a large volume of sea water but will not run at high pressure. Corrosion control and debris clearance will be the important issues here. There will be sea cocks on the inlet to allow the pump to be serviced without flooding the ship.

Pumps for supplying high pressure water for boiler feed will have an accordingly small sized water cylinders and the gland seals will need to work very effectively.

A Mumford 'Banjo' type of Donkey Pump

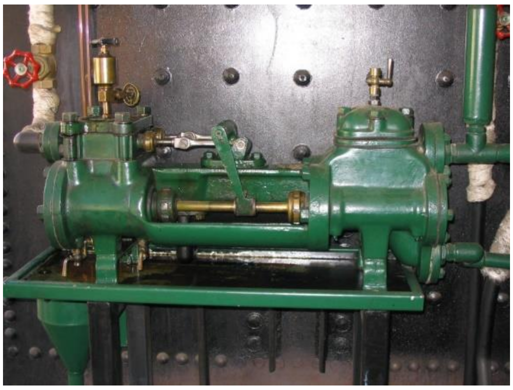
is fitted to K.C.

TYPICAL SECTION AND LIST OF PARTS FOR PUMP SIZES
6 x 4 x 6 6 x 5¾ x 6 7½ x 5 x 6



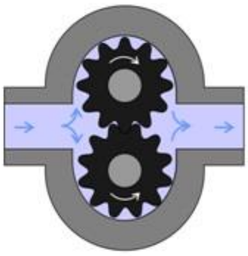
No.	Name of Part
1	STEAM CYLINDER
2	STEAM CYLINDER HEAD
3	STEAM CHEST
4	STEAM CHEST COVER
5	STEAM CYLINDER FOOT
9	VALVE ROD
10	VALVE ROD NUT
11	VALVE ROD HEAD
12	VALVE ROD HEAD PIN
13	VALVE ROD HEAD PIN NUT
14	VALVE ROD LINK, LONG
15	VALVE ROD LINK, SHORT
16	ROCK SHAFT LEVER, LONG
17	ROCK SHAFT LEVER, SHORT
18	ROCK SHAFT KEY
19	CROSS STAND
20	SPOOL
21	SPOOL PIN
22	SPOOL SET SCREW
25	STEAM PISTON
26	STEAM PISTON RING
27	PISTON ROD NUT (STEAM END)
40	VALVE PLATE
41	LIQUID VALVE GUARD
42	LIQUID VALVE GUARD SPRING
43	LIQUID VALVE
44	LIQUID VALVE SEAT
45	FORCE CHAMBER
47	LIQUID PISTON BODY
48	LIQUID PISTON FOLLOWER
49	PISTON ROD NUT (LIQUID END)
53	STEAM CYLINDER STUFFING BOX
54	STEAM CYLINDER STUFFING BOX GLAND
57	UPPER ROCK SHAFT
58	LOWER ROCK SHAFT
59	CRANK PIN
60	CRANK PIN NUT
61	LIQUID CYLINDER HEAD
62	LIQUID CYLINDER FOOT
63	LIQUID CYLINDER LINING
72	LIQUID CYLINDER DRAIN PLUG
73	LIQUID CYLINDER STUFFING BOX NECK BUSH
74	LIQUID CYLINDER STUFFING BOX GLAND BUSH
75	STEAM CHEST STUFFING BOX GLAND
76	STEAM CHEST STUFFING BOX NUT
77	AIR COCK
78	DRAIN COCK
80	SLIDE VALVE
81	PISTON ROD
→ 82	LIQUID PISTON RINGS, ROCKHARD
83	LIQUID CYLINDER
113	LIQUID CYLINDER STUFFING BOX
114	LIQUID CYLINDER STUFFING BOX GLAND
152	PORT PLATE (Not fitted on size 7½ x 5 x 6)

A typical Worthington Circulating Pump which will pass water continuously through an inboard surface condenser.

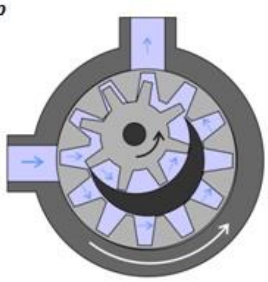
 

On older vessels these auxiliary pumps will be reciprocating pumps. Newer vessels may have additional electric powered pumps for specific purposes or for emergency use, or when steam is not raised – gear pumps, sliding vane or impeller but these are not common.

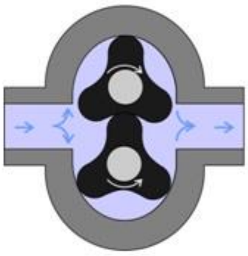
External Gear Pump



Internal Gear Pump



Lobe Pump



Vane Pump

https://www.michael-smith-engineers.co.uk/resources/useful-info/positive-displacement-pumps

Fault Finding

There are few reasons for failure with reciprocating pumps. If the O-rings or gland seals degrade there will usually be a progressive reduction in performance and leaking will be the conspicuous symptom. A total cessation of pumping will most likely be caused by the failure of one or both valves. Displacement pumps may have ball valves (gravity or spring-loaded), gate valves, or spring-disks (which often have rubber seals). Most of these valves can be easily dismantled and the foreign object which is preventing proper seating can be removed, or the corrosion or soiling causing ‘sticking’ of the valve can be cleaned. Installing an in-line filter before the pump can reduce the likelihood of failure.

It is good practice to install a steam-pressure rated check valve between the feed pump and the boiler, as close to the boiler as possible, to reduce the possibility of steam blow-back should a non-return valve in the pump fail.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO1 1	Manual Pumps	Sketch the design and valve arrangement of displacement pumps	Classroom	
LO1 2	Servicing reciprocating pumps	Strip down, assess bore and valve faces, service and reassemble a reciprocating pump	Workshop	
LO1 3	Engine room pumps	Be able to identify and explain features of different engine pumps	Workshop and in situ	
LO1 4	Electrical pumps	Explain the benefits of electrical pumps over steam-driven pumps	Classroom	
LO1 5	Pump fault finding	Dismantle, clean and reassemble a reciprocating pump including assessment of valve condition	Workshop	
LO1 6	Engine feed pump monitoring	Describe and demonstrate ways that the operation of an engine feed pump may be confirmed	Classroom and in situ under steam	

Learning Outcomes

LO 2:

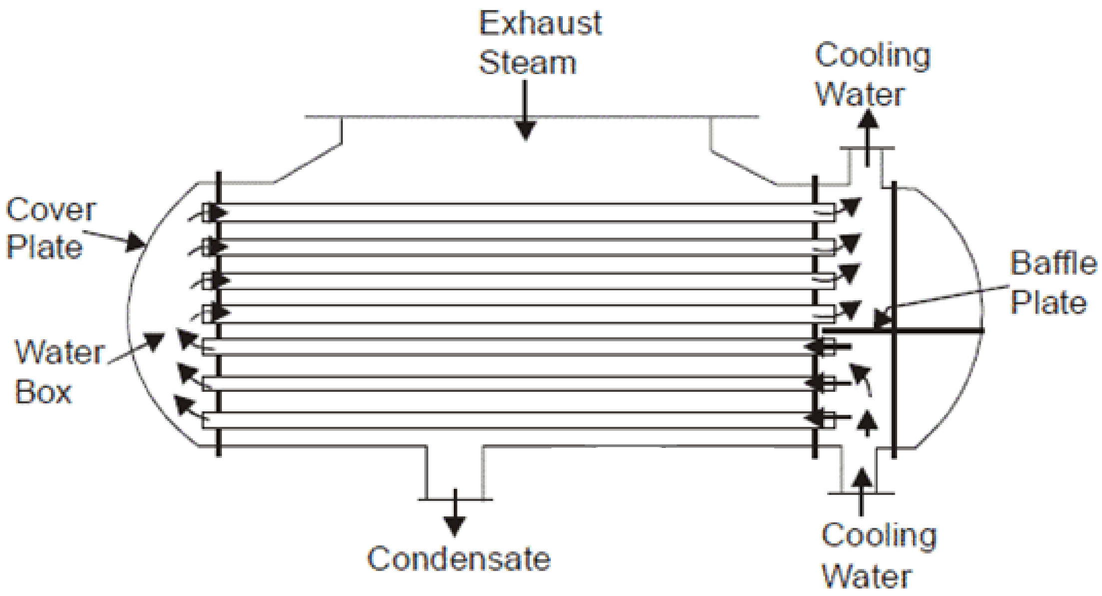
The Condenser

1. The keel condenser
2. Inboard condensers
3. Air pumps
4. Leaks
5. Servicing

Condenser Types

In small steam boats, the condenser is usually cooled by an external water flow, although in some other applications an air flow may be used (in a similar set-up to a car radiator), and in others a jet of cold water is injected into the steam. The simplest arrangement is the keel-cooler: one or more pipes running under the hull, often close to the keel or a bilge keel (for protection from mechanical damage resulting from underwater objects such as rocks or faulty recovery of the boat onto its road trailer), and cooled by the passing river water flow. A typical small launch installation might have about 4 m (13 ft) of tubing, around 25 mm (1 inch) diameter.

The alternative arrangement is the inboard condenser, often called a 'surface condenser' and these are commonly found on ships. Cooling (or *circulating*) water is pumped into a heat exchanger which is inside the hull. This system is heavier and more complicated than a keel cooler, requiring an auxiliary circulating pump, but is less vulnerable to accidental damage. In addition, it may be possible to adjust the temperature of the returning condensed water by altering the flow rate of the circulating pump. The only way to adjust the temperature of returning water from a keel condenser is to experimentally adjust the cooling surface area. Even then, the effective cooling is still inconsistent due to the ambient temperature of the sea/river/canal.



Ideally, the condenser will return water at atmospheric pressure and just below boiling point. Any colder, and heat is being wasted. But this is not at all easy to achieve.

The condenser is usually the lowest part of the steam circuit, and when the plant is shut down, it usually fills with water. This needs to be removed before winter lay-up, to avoid frost damage. Inboard condensers will have a drain. External condensers will need to be emptied by disconnecting one end and employing a syringe type arrangement, or by disconnecting both ends and using a blow of compressed air.

If the water level in the gauge glasses rises, then this means that the boiler is somehow ‘making water’. The most likely cause of this will be pin prick holes having formed in the condenser tubes allowing the circulating sea/river water to contaminate the fresh water of the condensate. This cannot be addressed with the engine in motion so there would be a need to find a safe haven to moor or to go to anchor. Then the end cover can be taken off the condenser and it can be subjected to a pressure test using water pumped through it either from a shore side hose pipe or sea water provided by the General Service Pump. Examining the inside of the condenser whilst the water is being passed through it will show any tiny holes. Where holes are found in any condenser tube then that tube should be sealed off at both ends usually with hammered in taper plugs. Condensers usually have very many tubes so sealing some of them where they are damaged will have little overall effect on the condenser’s operation.

Pin prick holes in a condenser may just be the result of old age but they can be caused by overheating of the condenser if, for example, the Circulating Pump stops working for some reason and is not noticed for a time thereby allowing the inside of the condenser to overheat with steam.

The cooling water inlet should have a coarse filter which can and should be checked and cleaned frequently. This protects the circulating pump which on larger ships is likely to be a centrifugal pump.

Extraction Pumps (aka Air Pumps)

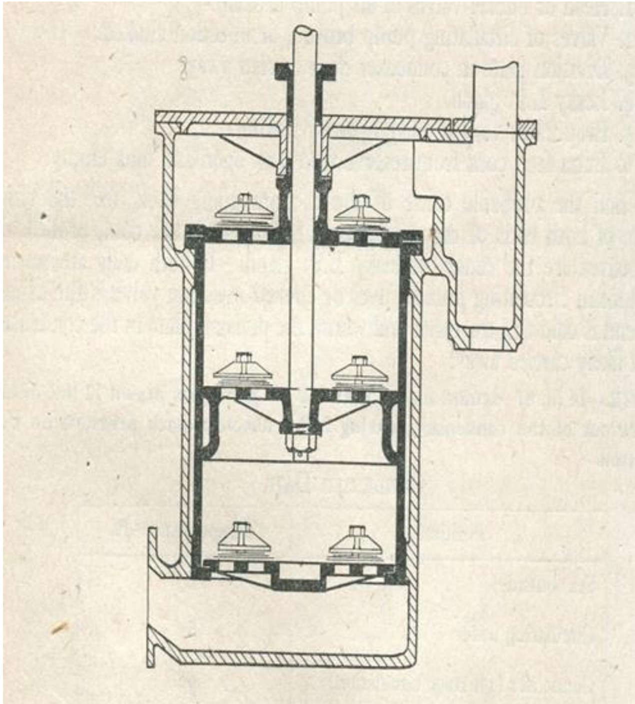
In the simplest of systems, the water is removed from the condenser by the pressure from additional condensing water. While this allows a plant to recycle the water, it does not gain the maximum benefit from the condenser. If the water can be mechanically removed then the vacuum benefit of the system is achieved. This can offer the equivalent of one atmosphere of pressure (1 Bar, or about 15PSI). In most cases slightly less than this is practically achievable but it is still a substantial benefit to the efficiency of a steam plant. This is especially the case with compound engines.

The pump which removes the water from the condenser is strictly termed the *extraction pump*. However, the water volume is very small, and there is usually a considerable quantity of air (arising from leaks such as the LP cylinder gland, or from air dissolved in the water) to remove as well. The pump is designed to be capable of both duties simultaneously, and is called the *air pump* (although some large installations do use a separate air pump).

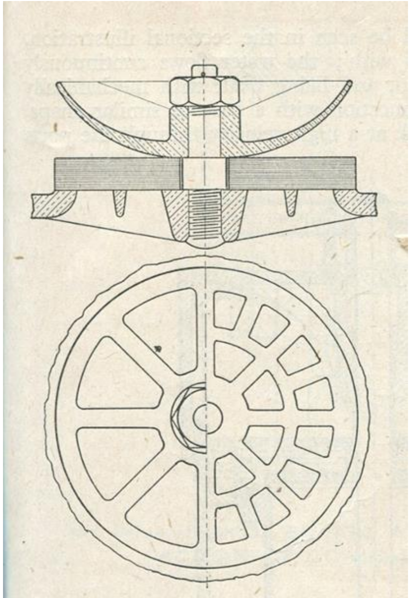
To maintain a good vacuum in the condenser you need an extremely well-sealed condenser and air pump. Since the volume of the water you are pumping out is only about 1/2000th of the volume of steam going in, pinhole leaks (leaky gland packing, leaky drain, or poorly seated valve) can be very detrimental. Vacuum is usually measured in terms of head of mercury below atmospheric – 75 mmHg (3 inches) of mercury is about the same as 0.1 bar (1.5 psi). A reasonable level of vacuum to aim at is 400-500 mmHg (16-20 inches) of mercury.

Like the feed pump, the air pump may be driven from a crosshead link or from a separate eccentric. Usually, a piston type is used.

There are different sorts of Air Pumps but the most common are the bucket type single acting which removes water, air and vapour and the rotary which consists of a steam-driven wheel fitted with peripheral vanes. The bucket type single acting pumps are fitted with rubber diaphragms inside them which can perish or split thereby losing their seal. Changing diaphragms is straightforward but requires the engine to be stopped. To change diaphragms the top of the Air Pump needs to be lifted off, which in larger vessels is likely to require the use of a chain block, and the rubber diaphragms at various positions within the pump can be removed and replaced. Flexible leather diaphragms should not be used as these tend to bake themselves solid thereby losing their ability to provide a seal.



No. P42.—BUCKET AIR PUMP.

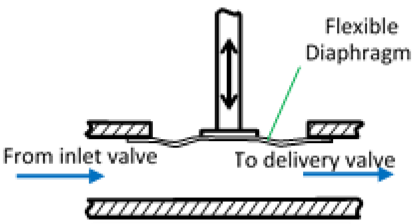


No. P43.—AIR PUMP VALVE.

(Indiarubber type.)

The plan shows the holes formed in the valve guard (left half) through which the air pressure forces the valves back on to their seats. The right half of the plan shows the holes in the grating through which the vapour and water passes. The lift is about $\frac{3}{4}$ in. at the outer circumference of the valve.

Diaphragm pumps are also favoured for air pumps on small boats, because they completely eliminate leakage at the piston gland.



Diaphragm Pump

On average, the air pump pumps a little less water than the feed pump (it only handles exhaust from the engine, not from the safety valve, whistle, Windermere kettle, stack blower, etc.). But it also handles quite a lot of air, so it actually needs a higher volume capacity than the feed pump. A rule of thumb is that it should be about 1½ to 2 times the capacity of the feed pump.

The returning condensed water may contain oil: if cylinder lubrication oil is used in the engine it will be carried through the system with the steam, or if 'wet steam' lubrication is deemed sufficient, there may still be traces of oils from lay-up periods. This oil must be removed before the water is returned to the boiler because oil deposits in boilers reduce efficiency dramatically and may even lead to localised overheating.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO2 1	Keel condenser arrangements	Inspect a keel condenser for damage	Workshop	
LO2 2	Inboard Condensers	Open inspection ports and clean an inboard condenser	Workshop or ship	
LO2 3	Extraction pump operation	Strip and service an extraction pump or air pump	Workshop	
LO2 4	Efficiency	Explain why pinhole leaks are a serious concern in condenser systems	Classroom	
LO2 5	Lay-Up	Prepare a condenser for overwinter lay-up	Workshop	

Learning Outcomes

LO 3:

The Feed Water Systems.

1. The journey of the water
2. The hotwell
3. Oil separation
4. Regulating water supply
5. Open Feedwater systems (common)
6. Closed Feedwater systems (special cases)
7. Cleaning

In this section we are considering the condensing plant, and the recycling of water in a feed system. Water has been being evaporated and condensed since the beginning of time, moving between ocean and sky, cloud and rain, stream and river. We borrow it for a short time in our steam plant for a slightly more controlled journey. Steam evaporating from the boiler transfers the energy from fuel into movement energy in the engine. From the engine exhaust the water passes into a condenser to cool and return to water known as condensate. This water is then pumped into a hotwell where it rests and is filtered. A further pump forces the water back into the boiler (possibly via a heater) to begin the cycle again.

It is interesting to consider that a typical large watertube launch boiler producing 300lbs of steam per hour might be completely recycling its water 4 times per hour. A monotube boiler will have a much higher turnover still.

When the water has been withdrawn from the condenser it is passed into the 'hotwell'. This tank of water gains its name because the water which it contains is still warm when it comes from the condenser. A big benefit of inboard condensers is that the rate of flow of cooling water can be adjusted so that the returning condensed steam (condensate) is as hot as possible (less energy needed to turn into steam again). The only way this hot returning water can be achieved with a keel condenser is the adjustment of the length of the condenser tubes – however it is not possible to account for the varying temperature of ambient seawater.

There is disadvantage with excessively hot condensate as the hotter the condensate, the lower will be the maximum vacuum that can be obtained; hence a balance has to be struck to achieve the maximum efficiency of the plant.

Oil contamination

When the water is recycled any oil which is introduced to the steam in the engine to lubricate slide valves and pistons will be scoured from the surfaces by moving steam and carried through the system. This can get into the boiler with the recycled feedwater and it will remain there as the oil evaporates at far higher temperatures than the water. The presence of oil in the boiler may sometimes be evident in the gauge glass where the lighter-than-water oil forms a layer above the water. This can be cleared by blowing the gauge glass down. Some boilers are fitted with a surface skim blow-down which will allow heavy deposits of oil to be partially removed. However it is far better to prevent any oils entering in the first place.

It should be noted that in large commercial marine applications the use of cylinder oils is highly controlled to prevent feedwater oil contamination

Steam oils are formulated so they will not emulsify with water (turn to a cloudy gel which has little lubricating effect). Oils for compounding engines are particularly formulated to remain as oil droplets to assist in their separation from condensed steam.

When the extraction/air pump has removed the water from the condenser it is usually delivered to a hotwell. The hotwell is a reservoir tank which will contain filters (some used horse hair or terry towelling, although new evidence suggests that human hair is the best material for absorbing oils!) to catch small oil droplets and form (coalesce) them into larger drops that separate from the condensate more easily. In a small launch the oil is dealt with by means of absorbent mats floated on the surface of the hotwell. Any filters need to be changed regularly. The outlet of the hotwell should be at the bottom because any oil present should float to the top. Some hotwell designs feature a series of baffles to ensure the water spends as long as possible in the reservoir to let the oil drop coalesce. The hotwell is the reservoir of water which is drawn from to feed the boiler. On larger ships the hotwell has a water level gauge glass so that abnormal changes in the water level can be readily seen by the engineer.

Regulating boiler water level

Many steam plants have a float valve in the hotwell to automatically regulate the supply of water to the boiler. If the water level in the hotwell is low, the inference is that the boiler is full and so the flow rate to the boiler is reduced, and vice versa. General steam leaks, use of the whistle, blower, kettle etc will remove steam from the system and so it will be necessary to periodically add more water. This is done via a 'make-up valve' which permits water to be fed in using gravity or an ancillary pump.

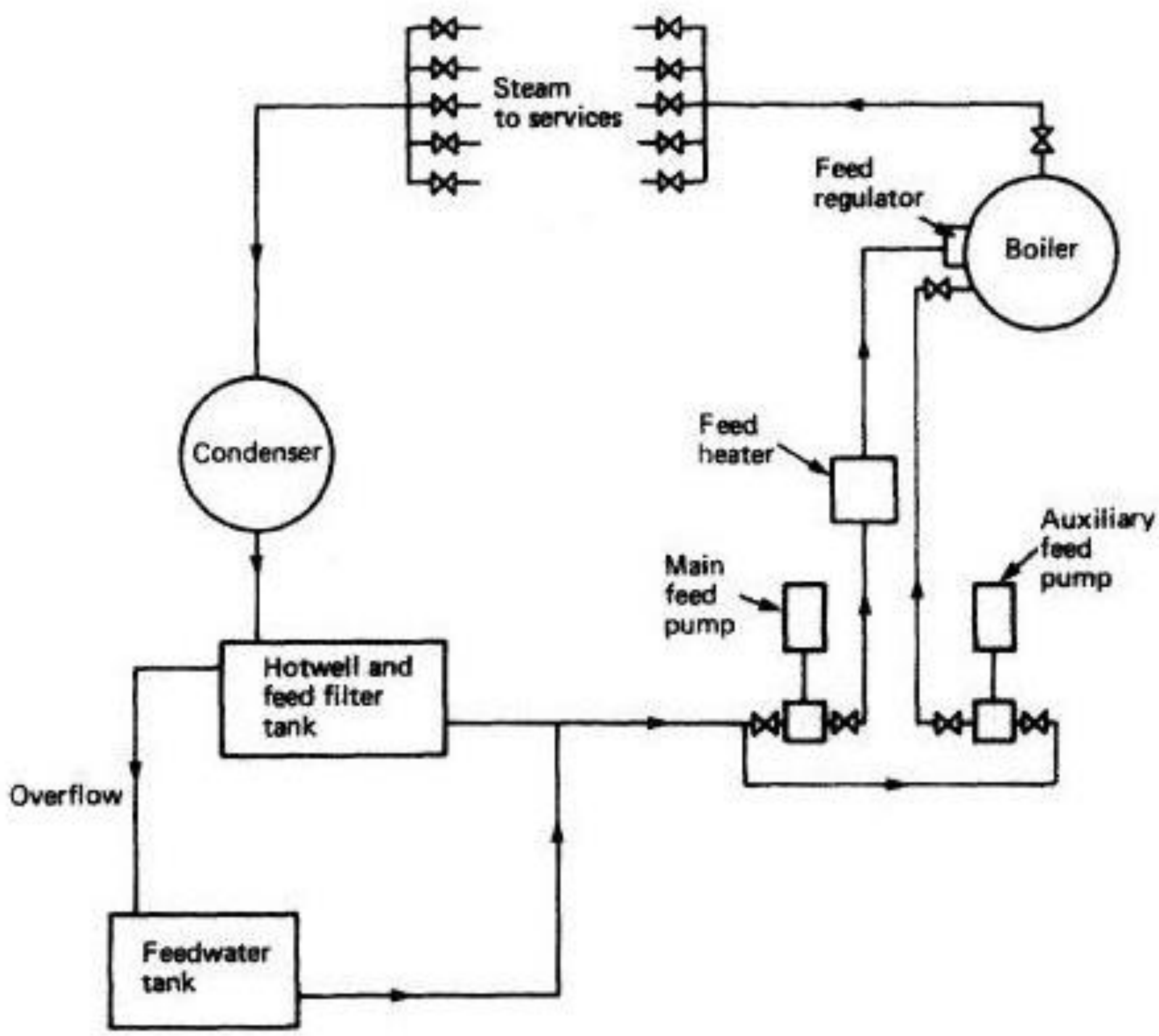
Feed water systems

Feed water systems are commonly broken down into two groups; either open or closed systems.

Open feed water systems are typically used with boilers operating up to 250 psi (17.5 bar). Scotch, Vertical, Packaged, Low Pressure Water Tube will all be operating with an open feed system. These boilers would normally operate with makeup water being fresh water or occasionally distilled or base exchange (Base exchange works by swapping the mineral salts naturally present in the water, responsible for causing hard water, with other minerals that cannot lead to scale formation and thus the water is ‘softened’.). It is not unknown historically for these boilers to use raw sea water.

Closed feed systems are used for higher pressure and temperature plants where it is important to keep contaminates out of the system. These boilers would normally operate on base exchange or distilled water; rarely would raw fresh water be used.

Open Circuit System

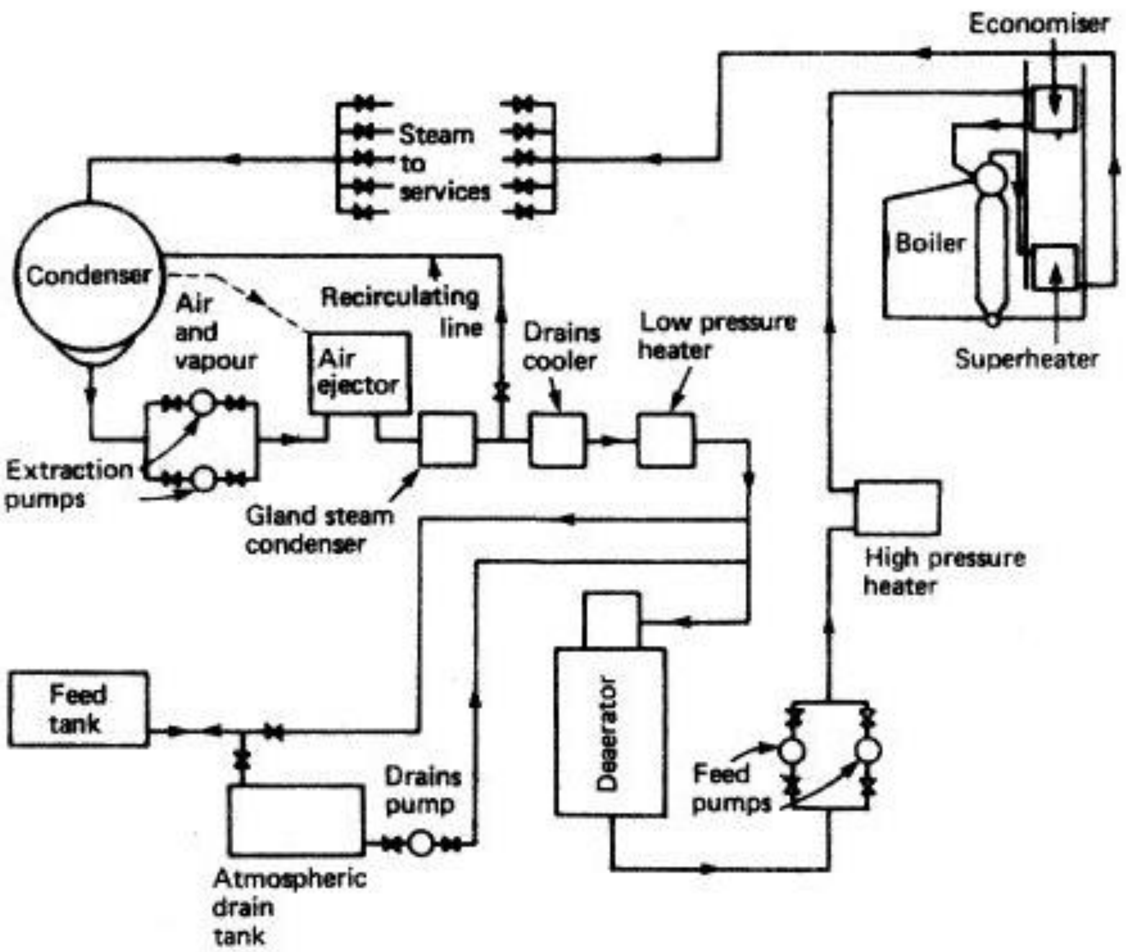


Open feed water systems are generally used for auxiliary or small systems and is not pressurised. Condensed steam from engines maybe gravity or pump fed to an open hotwell other various steam service or drains are also fed to the hotwell.

The hotwell being open to atmosphere allows for the easy addition of chemicals to the system and for visual inspection. This system is not suitable for high-pressure systems with highly controlled water treatment regimes.

Open feed systems are what you would expect to find on smaller steam systems with boiler pressures of 250 psi or below.

Closed Circuit System



The diagram of the closed feed system is included for clarity. This type of system is used solely for "Clean Steam Systems". Being applied to main systems which are oil and other contamination free. Steam from main engines and generators is condensed and extracted from the condensers and pumped to the deaerator via coolers and heaters. Feed make up is via the feed and atmospheric drain tanks.

The closed feed system has a deaerator which acts as a feed water storage tank after steam is used to help remove free oxygen from the condensed water. It should be noted however that the main condensers are normally of the regenerative type which, with the help of the air ejector, creates a vacuum and removes a large proportion of the free oxygen from the feedwater.

Most large steam systems (ship size) will have a closed feed water system for the main plant with an open feed system for all auxiliary or dirty systems such as oil fuel heating, laundry or deck steam.

On the open system (small vessels) it will be noted that there is the capacity to feed cold water into the boiler whereas this facility is not shown on the closed system (it may well be present in many ships though). Consider though, larger vessels will tend to run for many days at constant speed and load, whereas smaller vessels will be manoeuvring much more frequently and so it may be beneficial to reduce boiler temperature/pressure in response to temporary reduced boiler demand.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO3 1	Supplying water	Create a flow diagram to show the journey of water in a condensing plant	Classroom	
LO3 2	Open Feedwater systems	Draw up a table to compare advantages and disadvantages of an open feedwater system	Classroom	
LO3 3	Closed Feedwater systems	Explain why closed feedwater systems are beneficial on large ships	Classroom	
LO3 4	Hotwell oil filtration	Assess the condition of a hotwell filter and service as necessary	Workshop	

Learning Outcomes

LO 4:

Impurities and Feedwater Treatment

1. Contaminants which may be present in water
2. What is water 'hardness'?
3. Why is Blowing Down important?
4. The importance of Feedwater Treatment
5. Health and Safety

Water falls to earth in the form of rain and from the outset starts to become contaminated as the air that it falls through contains gases which will readily dissolve into the pure water. Such gases are.

1- Oxygen. It should be noted that this dissolved oxygen is completely separate to the oxygen contained in water (H_20) and is very corrosive to ferrous components inside the boiler as well as in attached pipework.
2- Nitrogen Dioxide in the atmosphere was in the old days attributed to lightning activity in the atmosphere but is more truthfully attributed to the combustion of fuels. The action of this gas on water is to produce nitric acid.
3- Sulphur Dioxide as with nitrogen dioxide will dissolve into the water form a sulphuric acid (H_2SO_4).
4- Carbon Dioxide which again will readily form carbonic acid (H_2CO_3)

These gases should be considered to be the main water contaminating agents and are common in air throughout the world.

So, before the water hits the earth it has become a cocktail of corrosive chemicals all be it at low levels. On hitting the earth, the water hits either sea or land.

Water Sources

Sea water contains a cocktail of chemicals into which the rainwater is consumed. The makeup of sea water includes Sodium Chloride, Magnesium Chloride, Magnesium Sulphate and Calcium Carbonate. This mixture by weight adds 31.3g to a litre of pure water (5 oz to a gallon of water). The action of the boiler at work will cause a great percentage of these impurities to come out of solution as a scale or sludge thus having an adverse effect on the boiler including corrosive effects. It should be noted that the average pH value of seawater is 8.1 so neutralising the slightly acidic rainwater.

Water hitting the land: the condition of rainwater after it has hit land is something very much to be considered on an area by area basis. It very much depends on the makeup of the soil or rock. The slightly acidic water arriving on land will react with mineral rocks such as limestone and chalk which consist mainly of calcium carbonate causing the water to dissolve these minerals. This makes the water hard (denser) with chemicals that will come out of solution when heated. There is however the opposite situation to this where the water hits acidic land such as peat rich soil which are very acidic again could cause corrosion within the boiler.

In addition to the previous statement consideration must be given in addition to water hitting the land as to where it hits the land.

River and Lake Water is difficult to describe as the formulation of this water depends greatly on the area of land that it passes through. Consideration must include additional contaminates such as rotting vegetation or animal excrement. Water originating from Dartmoor or in the Port of Glasgow area are very pure and ideal for boiler feedwater use. However, water originating in peat moor areas are normally very acidic and will in a short period of time cause sever corrosion to the boiler's water side.

Canal and Industrial River Water should be avoided as boiler feedwater as even today levels of contaminates from past industrial discharges can cause problems to the water side of a boiler.

Towns Mains Water Supply is variable depending on water source. However, this supply is normally adequate for most boiler uses with suitable chemical treatment. It is advisable to ascertain with the water companies the chemical composition of the water. It must however be noted that water companies are dosing the mains supply with Phosphoric Acid to clean up its pipework and prevent sludges discolouring water at the taps. This chemical addition to the water however can be easily overcome by suitable chemical treatment of the feed water.

Water 'Hardness'

It can now be appreciated that a cocktail of chemicals can be present in the raw feed water all of which have the ability to effect boiler operation. The inclusion of these contaminates are often referred to as water hardness which maybe Temporary or Permanent.

Temporary Hardness is caused primarily by calcium salts being dissolved into the raw water. When subjected to the boiling process carbonate salts are formed from bicarbonates which then precipitate out of solution forming scale. This scale may easily be seen at home in the kettle if living in a calcium/chalk 'hard water' area.

This form of hardness can and does cause problems before the water gets to the boiler and can block feed water pipes and other feed water fittings if the water is being heated **before** entry to the boiler. It should be noted that this precipitation is often not noticed due to the velocity of the water stopping the scale salts settling.

Permanent Hardness is the remaining mineral content of the water that cannot be removed by boiling. It is usually caused by the presence of sulphates particularly of calcium and magnesium which will form very hard scales at higher temperatures.

Total Hardness is a term sometimes seen in water chemistry which is the sum of both temporary and permanent hardness levels.

The above notes are intended to give an overview of commonly used raw feed water sources. It is normal to have a chemical analysis of the raw waters so that the correct chemical treatments can be used.

In industry over the years there has been more written, discussed and fought over regarding feedwater treatment than any other engineering discipline with at least four or five ways to do the same thing. So, lets us consider the discipline.in the following way.

1- What are we trying to achieve?
    a. Stop the formation of scale
    b. Reduce corrosion of the boiler plates to a minimum
    c. Increase boiler operation times between washouts
    d. Prevent priming or any form of carry over
    e. Ensure the safety of all that may be harmed
    f. Ensure that water is safe when discharged for washout or maintenance.

2- How is this achievable?
    a. What pressure and temperature does the plant operate.
    b. Expected steaming periods
    c. Suitability of feedwater
    d. What treatment regime is to be imposed.
    e. Type of boiler plant.

It is important to impose a safe feedwater treatment regime with regard to the operating conditions. Chemicals that are commonly used are highly alkaline and must be handled with care with operatives being trained and protective clothing and other safety considerations being adhered to. This will involve, as a minimum, suitable gloves, goggles, overalls and good ventilation. However it is important to read and understand the hazardous chemical labelling on all these chemicals. If in doubt, seek expert advice.

In industry boilers would be brought into service and continuously steamed for many months. In preservation or tourist use this is not so with boiler plants being in service for relatively short periods. So, the following considerations must be made.

1. Type of boiler
2. Time in steam

3. Amount of water evaporated.
4. Washout period
5. Effects of feed treatment.
6. Is the operating system condensing or is the exhaust to atmosphere?

Marine systems are normally condensing so that the introduction of raw makeup water is only to replace lost water lost through leakage glands, safety valves or auxiliary loss.

The raw water introduced into feed system enters the boiler and gives up its dissolved impurities, it then mixes with the rest of the boiler water system picking up its characteristics, it will then turn into steam and pass via pipework to the steam system. The addition of this water will dilute the action of any added treatment chemicals. Monitoring of the systems water will enable the addition of more chemicals to be made on a regular basis.

Traditionally in the marine environment low pressure steam systems on steam ships such as trawlers tugs and some small coasters little or no feedwater treatment as used.

The use of continuous blow down as stated would help to control the sea water which highly contaminated with salts. These highly concentrated salts in the boiler would be on the point of coming out of solution as scale or sludge which then blown into the sea. Scale formed in the boiler heating surfaces would greatly reduce the boilers efficiency and cause corrosion of the boiler's plates.

It is estimated that scale on heating surfaces increases fuel usage as follows.

Thickness of Scale	**Estimated Increase in Fuel Consumption**
1.5 mm (1/16")	15 %
6 mm (1/4")	60%

The system of boiler operation with continuous blown down is effective up to a point, with the following comments

1. It is expensive, (a lot of heat energy wasted),
2. It reduces the amount of dissolved solids in the boiler water,
3. It has no effect on corrosion of boiler plates as the salts which cause corrosion would still be present.
4. It helps to reduce priming (carry over of water in the steam).
5. It is only effective for short periods.
6. It was normal for ships operating in this way to return to port after several weeks for boiler cleaning where scale and sludge would be removed by the wheel barrow loads.

Therefore feedwater treatment should be considered. The basic idea of feedwater treatment is very simple to change the water into

1. A non-corrosive liquid thus protecting the boilers plates.
2. Water able to restrict the formation of sludge and scale and be able to keep any sludge so produced in a fluid state.
3. Water able to limit priming (carryover of boiler water). Water carry over in the steam reduces efficiency and can damage engines. Another problem with carry-over is that salts within the boiler water can be carried over and deposit themselves in superheaters and pipework to no ill effect until the boiler is shut down when condensation occurs causing highly concentrated solution to be created which can cause severe corrosion in localised areas.
4. Water that is at a pH of around 11 (pH of neutral water is 7) which will minimise the corrosion of steel plates in contact with hot water.

Studies of water chemistry have shown that the addition of certain chemicals along with a blow down or water freshening regime can greatly improve boiler operation and life. Boilers operating on pure sea water feed water had greatly reduced life, probably in the region of 15 years, whereas boilers operating in properly controlled freshwater and chemical regime would normally have a life expectance in excess of 30 years.

Chemical Feedwater Treatment

For the purpose of this document a basic chemical treatment regime is described.

Chemicals Commonly Used in Boiler Water Treatment.

Alkalinity Builders – The most commonly used chemical is Soda Ash (preferred) or Washing Soda. These chemicals are ideal for boiler use and can be introduced directly into the boiler in liquid form before steam is raised or directly into the hot well when steam is up. An alkalinity level of around pH 10 to 11 would give good results.

Oxygen Scavenger –Free oxygen is or can be a major factor in boiler and steam pipe corrosion and can often be spotted in steam valves with the internal surfaces looking like an aero chocolate bar. This is known as Oxygen Bubble pitting. To prevent this, and deep pitting of boiler plates, the addition of Tannins in liquid form has proved to be highly effective in removing free oxygen from the boiler water. It should be also noted that Tannin will form a thin corrosion resistant film across the boiler internal surfaces. The correct application of this treatment will lead to the boiler water in the gauge glass taking on the colour of weak tea.

Sludge Conditioners – Corn Starch or Potato starches are added to boiler feed treatments to control the growth of crystals and disperse precipitates, These starches help to keep soft sludges produced in the boiler water in suspension so that they can be removed by blowing down or draining from the bottom of the boiler.

With addition of the chemicals listed it is now possible to operate boiler in such a way to restrict corrosion and cut down the formation of scale. The boiler water however will build up dissolved solids which must be controlled. This build-up of dissolved solids is normally referred to as the boilers TDS (total dissolved solids). The level of TDS for class one boilers should be no more than 3,500 parts per million. This level will be considerably lower for miniature boilers.

When these levels are exceeded it is likely that the boiler will prime causing problems to the attached steam plant.

Blowing Down

For boilers operating on high days only such as small steam launches it is true to say that blowing the boiler down should be avoided as the boiler water can be easily changed and treated between events.

For boilers operating on a regular but not continuous basis blowing down can be avoided by what is known as freshening the boiler. This is done by allowing the boiler to cool so that there is no steam pressure and the resultant movement of water in the boiler to cease with the heavy dissolved salts being allow to start to drop to the bottom of the boiler shell. The boiler water can then be drained to bilge. <u>It is normal to drain a full gauge glass level of water at this time</u>. This will have the effect of draining out dissolved salts within the water and the added advantage of not reducing the boiler waters alkalinity by very much. The boiler will then have to be topped up with raw water. This top up should be done <u>just before steam is raised</u> to reduce problems with the fresh water's free oxygen; **filling the boiler with fresh water and then leaving the plant dormant increases the rate of corrosion**.

For boilers in continuous service the boiler water should be controlled by monitoring with the addition of chemicals and blowing down as required.

Blowing down is an operation which should be undertaken with care as over the years a number of persons have been badly injured during this operation which must be undertaken in the following way

1. Monitor the boiler water level continuously during blow down period.
2. Open the ship or boat side valve
3. Carefully open the boiler blow down valve. This valve may only need partial opening.
4. On completion, close boiler valve then ship side valve in that order
5. Ensure that the boiler water level is stable and correct.

The reason for this sequence is that the pipe between the boiler and ships side is susceptible to corrosion and full boiler pressure may cause a fracture. It is normal practice to inspect and hydraulically test these pipes at every dry docking.

Further information on safe boiler blow down procedures maybe found in Combustion Engineering Association (CEA) Guidance note BG03 which supersede guidance note PM60 covering blow down systems and their safe operation.

Additional Notes

Feed water treatment and control is a very complicated subject which the author has tried to simplify giving an operable overview. The state alkalinity and TDS levels are quoted for guidance only.

The following points should be considered.

1. Steam space in normal commercial steam boilers is enough to deal with a certain amount of priming. In miniature and highly forced boilers it may not be enough so a lower alkalinity and TDS may need to be maintained.
2. Tube spacing in normal commercial boilers is enough to allow for steam production around the hot surfaces of the tubes without it being affected by the steam production in the adjacent tubes. This will cause foaming resulting in priming. It should be noted that railway engines are prone to this problem.
3. High firing rates forcing high steam output may also cause priming.
4. Operating with too high a water level may also cause problems.

Blowing the boiler down during operation has been covered at length but other blow down considerations must be noted.

In the operation of steam reciprocating engines, it is normal to use cylinder lubrication. These oils pass from the engine to the condenser then onto the hotwell filters where often they are not fully removed. The oil contaminated water is then fed back into the boiler forming a scum at the water level. The oil breaks down into fatty acids and is nothing but a problem. In the past, boilers were fitted with scum pans so that the water about the water level can be blown out to sea or river. These devices were commonly fitted to Scotch and Cochran type boilers.

Suggested simplified Treatment Plan

In conclusion, adherence to the following rules will greatly help in efficient boiler operation and safety.

1. Never leave a boiler for a period of time standing with raw un-boiled water in it.
2. Before raising steam add to the boiler the required amount of chemical.
3. Raise steam slowly taking care to ensure that the correct water level is maintained.
4. Check the water for alkalinity and dissolved solids daily and treat or blow down accordingly.
5. For boilers in high day and holiday service change the boiler water regularly.
6. For boilers in regular service ensure that a regular logged regime for the boiler and its water is in place.

7. Never add to much chemical. The old rule of thumb for the use of Soda Ash was initial charge of 0.5 kilos to every 1000 litres of water (approximately 1 lb of chemical per ton of water).
8. Take care and use the appropriate personal protection when handling chemicals.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO4 1	Water contaminants	List the contaminants which may be present in water from different sources	Classroom	
LO4 2	Hardness and scale	Explain what is meant by water hardness, and how it can effect boiler performance	Classroom	
LO4 3	Blowing Down	Describe the precautions which should be taken when blowing down a boiler	Classroom	
LO4 4	Feedwater treatment	Calculate the correct amount of treatment to use for a given boiler	Workshop	
LO4 5	Health and Safety	Read and interpret the Hazchem labelling on water treatment. Demonstrate correct safe handling	Workshop	

BESTT Marine steam maintenance and repair Module MS3

Assessment Record for: Training Centre: Year:

LO1	1	2	3	4	5	6
Supervisor Initials and date when completed						
LO2	1	2	3	4	5	
Supervisor Initials and date when completed						
LO3	1	2	3	4		
Supervisor Initials and date when completed						
LO4	1	2	3	4	5	
Supervisor Initials and date when completed						