Module MS 5

Marine Steam Boiler Fittings and Auxiliary Systems

Aim

This unit will describe the roles and operations of the essential and optional control systems and valves associated with steam launch boilers. Some consideration is given to design options and the more common faults and remedies are described.

INTRODUCTION

Pressure ratings of boiler fittings

Injectors

Assessing boiler water level

Pressure relief valves

Improving the efficiency of the steam system

Ancillaries

The majority of historic steam launches and small steam ships have been made or assembled on an individual basis, unlike railway locomotives where a number were built to the same design, and frequently a company would have common design features across a whole fleet of locomotives. As a result there are seldom any two steam vessels which are alike in their construction except in the Royal Navy. However, there is more commonality than the casual observer may realise upon initial inspection. As with all steam plant, a steam boiler requires the same three key features: a way to introduce water to the boiler against a positive pressure, some means of assessing the level of water in the boiler, and a means of withdrawing steam from the boiler with some degree of regulation. In addition there must be a failsafe system of venting steam to ensure the pressure cannot rise above a safe level.

This unit describes and explains the most commonly seen solutions to the three requirements above and also introduces the faults which may be encountered with the systems which are employed in steam launches. In a vessel with well-designed components and which are in regular use, these faults should be few and far between. The majority of steam launch owners will relate that sticking ball valves or weeping gland packing are more frequently encountered following a period of 'laying up' than at any other time. Thus, on the first steaming up after a lengthy shutdown, extra time should be allowed in anticipation of rectifying minor issues before they develop into major problems during a voyage.

Many owners and operators of steam vessels get great pleasure from the regular attention which the steam plant requires during normal running. With the correct choice and arrangement of the boiler fittings and ancillaries this should be a straight-forward experience for the operator. The boiler water level should be easily visible and remain relatively constant, and should it vary the operator should be able to control the water reliably and in a timely manner.

With these two factors securely under control, the operator can begin to refine the experience and maintain a consistent boiler pressure even with varying engine demands by using some of the ancillaries available. Steam plant was never efficient, but small gains may be made which can improve the power output of a steam launch or reduce the quantity of fuel used.

An extract from the Edinburgh Encyclopaedia from 1832 illustrates the value in paying good attention to the boiler fittings in any vessel encountered:

"About six years since, a new copper boiler of one of the ferry boats plying between New York and Pawlus Hook, New Jersey, burst in consequence of the safety valve having been fitted too neatly, so that when heated by steam it expanded and stuck. The boat had made several trips that morning and no steam had been observed to pass for several hours. The boiler was turned upside down and flattened

"In another boat on the Delaware, the escape pipe for the safety valve was of conical form, the greatest diameter of which was below, so that when the valve raised, it closed the pipe and prevented the steam from passing off. The defect was, however observed and an explosion prevented.

The report goes on to describe how the weights on the safety valve were increased in order to increase the performance of the steam ship.

".... vexed at not being able to overcome the rapidity of the current as completely as he had hoped for, the engineer fastened down the safety valves of all four of the boilers; three of them bust almost simultaneously.

"The Norwich (English) steamboat exploded in part from the same cause. The attendant engineer seated himself on the safety valve, on order to give his comrades the spectacle of the oscillating motion that he would undergo, as he said, as soon as the vapour should be strong enough to lift him. The valve did not open, but the boiler burst and killed or wounded a great number of persons."

Sadly there are many more similar reports from the 'Golden Age of Steam'

Learning Outcomes

LO1 Identifying fittings suitable for steam pressure

LO2 Engine room pumps

LO3 Injectors,

LO4 Boiler water level gauges

LO5 Pressure Relief Valves

LO6 Pressure gauges

LO7 Efficiency: feed water heaters, economisers, super heaters

LO8 Launch Ancillaries: kettle, bilge ejector

Learning Outcomes

LO1:

Fittings and Pressure Rating

1. How elevated temperatures reduce the strength of metals
2. Suitability of commercially available brass fittings
3. Recognising indicated ratings of fittings
4. Why small leaks must be taken seriously
5. Arrangement of fittings close to the pressure vessel

It goes without saying that all fittings on boilers must be rated for the correct pressure, but it is also important to take account of the elevated temperature of steam at pressure. A fitting rated for water or gas at 150PSI is not the same as rated for steam at the same pressure. As steam pressure rises, so does the temperature, and some metals, most notably copper and copper alloys suffer a significant reduction in strength at these elevated temperatures. Hence it is unlikely that any conventional plumbing fittings will be suitable for use with steam.

Steam Pressure		Temperature
BAR	PSI	^{o}C
5	72	159
10	145	184
15	217	201
20	290	215

Valves, cocks and taps suitable for steam use will not contain plastic or rubber components (although may contain solid ptfe or correctly selected o-rings). They will have been designed to withstand the higher loads and more extreme conditions than might be expected in a domestic central heating system. Original vintage components may not have any markings on, and expert advice should be sought to assess whether these are safe to continue using. Old components may be marked in various non-standard ways and care should be taken in interpreting these marks (e.g. 300 WOG, or 250C).

More modern steam fittings are clearly marked either on the body or with a thin printed metal disk on the top. Most common is the PN rating which stands for Pressure Nominale and prefixes the pressure rating in Bar when cold, e.g. a PN16 flange is designed to operate up to16bar at room temperature, but this safe working pressure drops substantially at higher temperatures.

Diligence is needed in selecting the correct ratings for a given steam application and it is always best to err on the side of caution. As a guide, the following information may be valuable, but it is essential to seek the advice of a competent person for each specific steam application.

	Maximum pressure	Notes
PN16	7 Bar at 170°C	100 PSI is below the commonly used range of pressures in steam launches. **Unsuitable.**
PN25	10.5 Bar at 186°C	152 PSI may be suitable for some lower pressure steam plant say, up to 120PSI, but **not recommended**.
PN32	14 Bar at 198°C	200 PSI gives a suitable safety margin and this rating will be found on steam launches operating up to 175PSI
PN40	20 Bar at 260°C	290 PSI will exceed the rating required for all but a very few exceptionally high-pressure steam launch systems

It is not uncommon to encounter the American ANSI standard which refers instead to a pressure/temperature rating termed 'Class'.

For example, an ANSI Class 150 flange is rated to approximately 270 PSI at ambient conditions, 180 PSI at approximately 400°F (200°C).

All fittings must be regularly assessed for their integrity: a tiny crack, a poorly fitting flange, a threaded connection onto iron or steel which may have corroded can all lead to a leakage of steam. Whilst this may not affect the performance of the plant it has three very serious implications.

Firstly, steam can erode surfaces very quickly, and a small leak can develop into a large one over a short period of time.

Secondly, the leak may be the early sign of a rupture which could occur without any additional warning.

Thirdly, the escaping steam will be invisible: at temperatures over 100°C the steam will be a pure gas and will be invisible but will scald extremely badly. The white clouds we can see are the condensed water droplets which have fallen below 100°C. This can be seen by inspection of the spout of a kettle as it boils - notice that the first 2 or 3cm of the steam plume is invisible but, do not be tempted to test it, as it is the hottest part.

Fittings on boilers will usually fit into one of three categories: adding water to the boiler, indicating the level of water in the boiler, withdrawing steam from the boiler.

It is good practice that every route into or out of the boiler has an isolator which will allow steam to be immediately shut off from that component in the event of a failure. This isolation should be as close to the boiler as possible. For water feed routes into the boiler it is good practice to have a clack valve adjacent to this isolator cock. This is in addition to the one-way valve on the pump outlet.

There is one important exception – the pressure relief valve (safety valve) must not have any such system. There must be no way that the pressure relief valve could be inadvertently closed off under any circumstances.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO1 1	Pressure and temperature	Describe the relationship between temperature and pressure	Classroom	
LO1 2	Strength at high temperatures	Explain why domestic brass fittings are unsuitable for steam	Classroom	
LO1 3	Pressure rated fittings	Correctly identify rating markings on bronze fittings and recognise which are suitable for different applications	Workshop	
LO1 4	Inspection of fittings	Explain why conscientious inspection of fittings is important. What is being looked for?	Workshop	
LO1 5	Arrangement of fittings	Identify the locations of isolation cocks and clack valves adjacent to the boiler on a selection of launch steam plant	Workshop & in-situ	

Learning Outcomes

LO 2:

Injectors

1. Injector types
2. How does an injector work?
3. Injector operation under steam
4. Injector fault finding

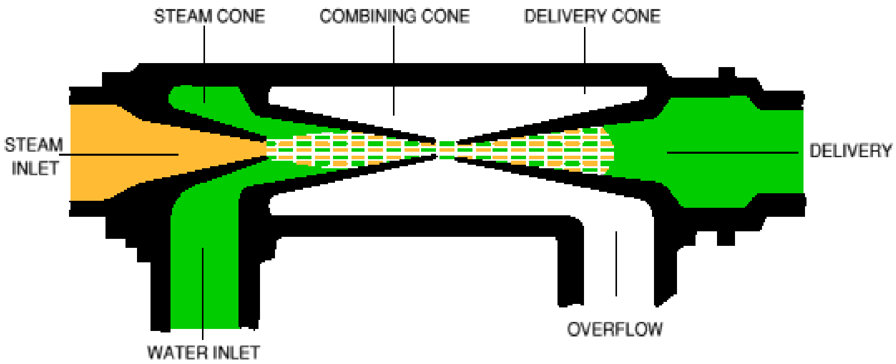
The injector appears to defy logic on first inspection as it uses steam from the boiler to force water into the boiler at the same pressure. This break in logic is explained by considering the energy changes. The steam is not only at high pressure, but also contains heat energy. The steam transfers this heat component into movement energy and is thus able to force the cooled condensed steam plus extra cold water back into the boiler.

There are 3 main manufacturers which are likely to be encountered and it will be useful to become familiar with the differences in the orientation of the inlet and outlets between the designs. Injectors are also available in many different sizes.

Some of the injectors have integral clack (one-way) valves but in the same way as the feed pumps, it is important to fit a steam-rated one way valve between the injector and the boiler in addition to the isolation cock on the boiler.

We will consider the rudimentary designs here, but in the realms of locomotives there are many more elegant and elaborate designs. Although there are two groups of injectors - lifting and flooded, on steam launches the flooded is far more common.

In the simple form the injector consists of 3 cones. The steam cone, the combining cone, and the delivery cone.



The steam cone directs high temperature steam at high velocity into the assembly. It has a small bore at the tip which restricts the amount of steam coming through. This means that once started, the injector can usually be allowed to run with the steam inlet cock fully open. As the steam passes along the steam cone, a proportion of the heat energy is transferred to giving the steam a high velocity.

As steam leaves the small nozzle it meets a flood of cold water. This combination of fast-moving steam and cold water merge and the steam is condensed. This is why it is essential that the injector feedwater is as cold as possible. The steam and water interaction takes place in the combining cone and this fast-moving warm water is ejected through the nozzle of this cone into a void – the 'overflow gap'.

The final part of the injector is the delivery cone. The fast-moving warm water is forced into the narrow orifice at the tip of the delivery cone, and the diameter gradually increases. As it does so, the velocity of the water reduces and the pressure and energy increase sufficiently high to overcome the boiler pressure.

It is essential that the injector has an associated non-return valve on the output side otherwise the boiler back pressure would vent through the delivery cone when steam supply is shut off. It is also worth noting that the feedwater inlet also requires a control valve: when the injector is not running or feedwater would just dribble out of the overflow continuously.

Operation

It should be noted that injectors made by different companies behave differently, so no hard and fast rules can be laid down, but the following guidance will often apply:

The injector should be mounted such that there is a positive head of feedwater and the combining cone can be flooded. It will also be more reliable in starting if it can be cold, i.e. mounted away from intense boiler heat.

1. Open the feedwater supply valve and ensure water is free-flowing from the overflow
2. Open the steam supply fully
3. When running correctly there will be no water running from the overflow, and most injectors make a characteristic 'singing' or 'murmuring' sound.
4. To test if the injector is running, inspection of the pressure gauge may show falling pressure in response to the introduction of cold water, or alternatively with great care, assess the temperature of the clack valve adjacent to the boiler. If it remains hot then the injector is not delivering cool water and it should be switched off and restarted.

Fault Finding

The relative dimensions of the cones are critical. Any damage, corrosion or contamination will prevent running.

The injector requires an uninterrupted supply of cold water and any bubbles in the water can prevent the condensation of the steam happening continuously. Similarly, there should always be an excess of water as a shortage can interrupt operation. Hence it is important to have a supply line to the injector which is a wide bore and which does not also feed a reciprocating pump which has the potential to introduce bubbles to the supply.

It is good practice to occasionally clean the injector nozzles. Most injectors are designed for easy dismantling, but great care should be taken so the nozzles are not replaced in reverse positions. Visual inspection will be enough to assess condition, and any cleaning should be done without scoring the brass surfaces. A soak for a few minutes in citric acid followed by a rinse is often sufficient. Citric is one of the weakest acids and can be bought in powder form from wine making shops or some catering suppliers. This will gently remove surface oxidation and any scale formation and restore the inner faces of the cones to the smooth condition which maximises delivery.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO2 1	Injector types	Recognise common injectors and identify inlets and outlets	Classroom and in situ	
LO2 2	Injector design	Sketch the arrangement of cones and explain operation	Classroom	
LO2 3	Injector operation	Initiate an injector and confirm correct operation visually and audibly	In situ under steam	
LO2 4	Injector fault finding	Dismantle, clean and reassemble an injector	Workshop	

Learning Outcome

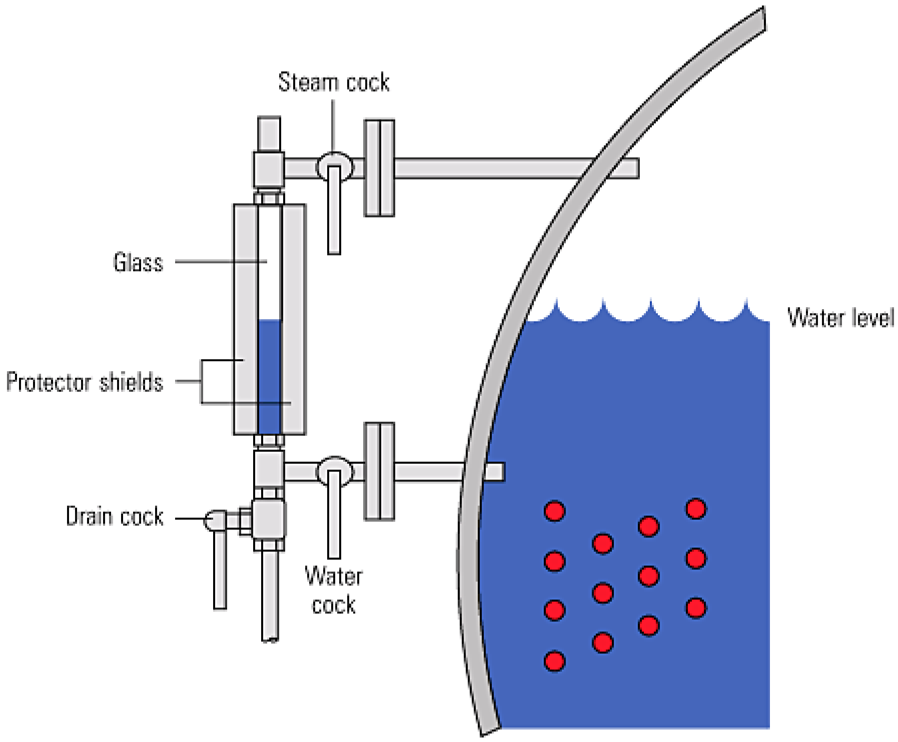
LO 3:

Water Level Gauges

1. Water gauge designs most commonly found on launches
2. Water gauge cocks, their roles and operation
3. Reading and misreading of a gauge glass
4. Water gauge fault finding
5. Servicing of gauge glass protector
6. Servicing of gauge glass

On steam launches there are two basic types of water gauge employed. The most common is the sight glass style. There are also many with the 'Klinger' or reflex style. Both work in the same way and maintain a water level equivalent to the water level inside the boiler.

Note that when fitted correctly the 90° cocks have their heavy handles hanging downwards (open for the steam and water cocks, closed for the drain cock). This is so that gravity will assist in keeping the cocks in the correct position. This convention is the opposite of the convention for other cocks, where the handle points in line with the pipe to indicate open.



The water gauge should be mounted such that it can be easily seen by the boiler operator. On large steam plant such as rail locomotives or passenger carrying steam launches there will need to be two water gauges fitted, but most leisure steam launches only have a single water gauge. The position of the gauge in the boiler pressure vessel should be such that when the water level is at the bottom of the gauge glass the firebox crown or the water tubes will still be submerged. In commercial vessels there are regulations which stipulate dimensions for this.

On some steam launches there are also low-level alarms fitted (compulsory on large vessels) which may operate using a magnetic float switch or by using conductivity rods.

When the water level is at the top of the glass, there is still sufficient steam volume so that water carry-over in the steam is unlikely. Hence, the spacing of the top and bottom fittings, and the height of the glass can vary substantially between boilers.

The reflex types of water level gauge has glass which is over 10mm thick and does not require tube protectors. The disadvantage is that the level can only be seen from one viewpoint rather than over 270^0

Many operators use boiler water treatment in order to reduce corrosion and an additional benefit is that it allows the water level to be seen more clearly in the gauge glass due to the colour of the boiler water treatment when dissolved in the water. If clean water is used it can be useful to exploit the refractive index of water to make the level more visible as shown in the diagrams below.

Tube type gauge glasses. Note the heavy gauge glass protector.

https://www.model-engineer.co.uk/forums/postings.asp?th=99984

The glass tube in these gauges requires periodic replacement and specific pressure rated glass is essential. At the time of replacing the glass, the packing sleeves and/or rubber cones or rubber square sections may also require replacement. Overtightening of the top or bottom rubbers can cause the glass to crack or break so care must be taken. (See BESTT Newsletter November 2019). Hand tightening is often sufficient.

Reflex-type gauges have much thicker glass with the associated extended longevity. However, it is not unknown for these glasses to chip or crack if they are inserted without a suitable compressible gasket. They will then need replacement.

One of the differences between launches and locomotives is that a locomotive will always remain approximately horizontal and so the level on the water gauge will be accurate. In a launch the boat may be carrying passengers or loads which mean that the vessel may be out of trim. This is important to be borne in mind when reading the apparent boiler water level from the glass.

In the unlikely event of a water gauge glass fracturing whilst under steam load the chances of injury are extremely high. To reduce the likelihood and severity of injury, the gauge glass should have a thick toughened glass gauge glass protector around it. This assembly is designed to deflect the breaking glass and fast flowing high pressure steam away from a potential casualty.

Some gauge glass fittings have the additional feature of a caged ball bearing which, in the event of a sudden escape of steam, will be thrown into a seating and thus stem the high-pressure flow. Special care should be taken when testing these fittings that the ball has not blocked the steam or water passage.

Fault Finding

The water gauge should be tested frequently to ensure that the bottom and top ports to the boiler are free of blockages. The standard procedure is as follows

1. Shut the top (steam) and bottom (water) cock by rotating the handles to horizontal
2. Open the drain cock and **water should promptly disappear**
3. Blow through top cock and close again
4. Blow through bottom cock and close again
5. Close drain cock
6. Open top and bottom cocks and **water should promptly appear** and rise to equal the boiler water level

If there is any sluggishness in the movement of the water, then consideration should be given whether it is safe to continue steaming and the assembly should be dismantled and all passages thoroughly cleaned when cold to identify the cause of the fault.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO3 1	Water gauge design	Sketch the arrangement of cocks and gauge glass	Classroom	
LO3 2	Water gauge operation	Describe the circumstances which could cause an incorrect reading	Classroom	
LO3 3	Reading of gauge glass	Explain the effects of trim on water level misrepresentation.	classroom	
LO3 4	Water gauge fault finding	Demonstrate the 6 steps in blowing through a gauge glass	In situ under steam	
LO3 5	Servicing of gauge glass protector	Remove, clean, and securely replace the gauge glass protector assembly	workshop	
LO3 6	Servicing of gauge glass	Remove, assess, and replace the gauge glass in tube and reflex water gauges. Replace glands and gaskets as required	workshop	

Learning Outcome

LO 4:

Pressure Relief Valves and Pressure Gauges

1. The purposes of the pressure relief valve
2. Location of a relief valve
3. How does a relief valve work?
4. Relief valve adjustments and testing
5. Uses of the pressure gauges
6. How the Bourdon gauge works
7. Fitting the pressure gauge
8. Pressure Gauge calibration and gauge range

The terms 'Pressure Relief Valve' and 'Safety Valve' are often used interchangeably which is understandable. A Pressure Relief Valve's purpose is to control a boiler's pressure at a desired level whereas a Safety Valve is to prevent the steam pressure in the boiler exceeding the safe working pressure.

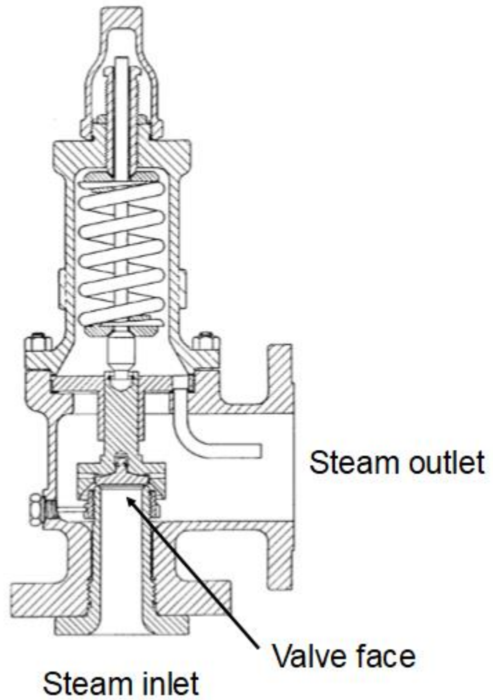
The Pressure Relief Valve may be readily adjustable and not always immediately mounted on the boiler. The Safety Valve, on the other hand, should not be adjusted once set. It is common for the set pressure adjustor to be locked. In addition, the Safety Valve should be mounted directly on the top of the steam drum.

Unlike every other steam ancillary there must NOT be an isolation valve between the boiler and the safety valve

Many small boilers use the same valve for both of the above purposes, but larger systems may well have two pressure operated valves. Some may even carry two safety valves in addition to any pressure relief valves. The carrying of a duplicate safety valve (redundancy) may be advisable when one considers the appalling consequences of a safety valve failing to operate.

The Safety Valve must be capable of venting 1.5x the maximum theoretical output of the boiler. As in locomotives this is checked during the annual Boiler Test when the inspector will expect to see the Safety Valve operating to prevent the boiler pressure exceeding the boiler's design maximum working pressure, even when the fire is roaring and the blower is operating (see MS02 Forced Draft Options). The outlet from the Safety Valve must vent directly to atmosphere, discharge well away from passengers and crew, and also have a small drain at the lowest point in the pipework to prevent the pipe from accumulating water which will 'fountain' as and when the valve operates.

The valves operate in the following way: Steam is applied to a valve face which is kept closed either by a weight arm or by a spring. The former is likely to be seen only in museums and old photographs. The force of the spring sets the pressure for operation, and the spring may compressed by a small amount to give adjustment. As the steam pressure overcomes the force from the spring the valve opens and steam is released. An elaboration of this simple system is the Full Lift or ‘pop’ valve: the shape of the valve face is such that as the steam starts to escape the steam can act on a larger surface of the valve face and so it is immediately lifted higher. Steam can rapidly escape and will continue to do so until the pressure has dropped by perhaps 10PSI when the valve will then instantly close. This valve is very effective but can be alarming for any passengers close by!

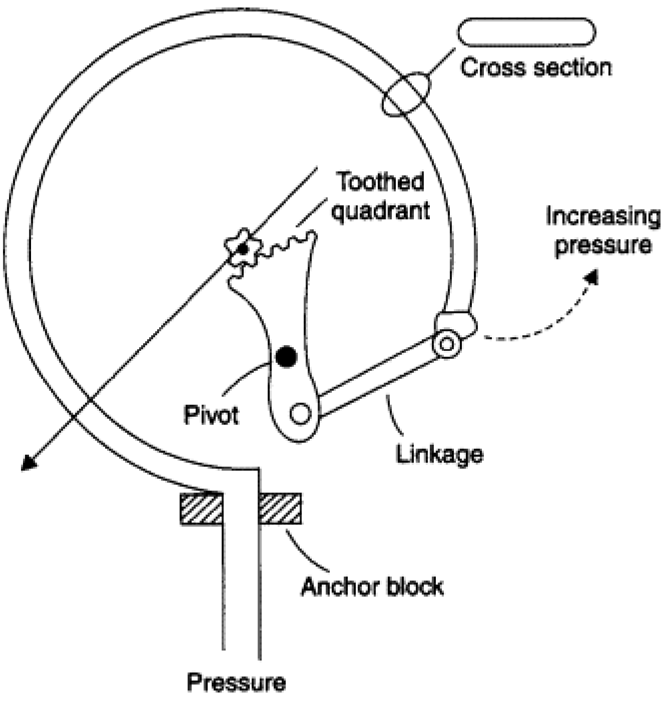


Pressure Gauges

A steam system may have a number of pressure gauges. The most important will be the one which shows the pressure within the boiler. It should have a line marked for the maximum boiler pressure which will assist in balancing fire management with steam demand and reduce the likelihood of the Safety Valve lifting and wasting steam.

Other pressure gauges which may be present could be used to indicate the feedwater pressure, the vacuum (connected to the condenser) or even oil pressure for a liquid fuelled vessel. If the engine is a compound or a triple expansion engine, gauges showing pressure on the High-Pressure and Low-Pressure cylinders may be valuable. These could assist in valve setting to maximise efficiency.

Whilst modern electronic pressure transducers are available, traditional boilers will be using a Bourdon gauge. The Bourdon gauge consists of an oval shaped bronze tube which is curved into a semi-circle. The tube is connected to the steam supply and increasing pressure forces the tube to straighten slightly. Pulling a vacuum will cause the tube to do the opposite. These small changes in curvature are transferred to a needle pointer via a geared link which amplifies the movement.



https://www.sciencedirect.com/topics/engineering/bourdon-tube

Any pressure gauge should be mounted vertically. The tube should not be exposed to steam and so a trap should be placed between the boiler and the gauge. This could consist of an uninsulated loop or U-bend (termed wet bend or syphon) in which steam will condense before reaching the sensitive gauge. There is usually an isolating cock adjacent to the gauge, but this should be left in the open position routinely.

Any new gauge should be checked against a known and trusted gauge for accuracy. Not just at the maximum, but at intervals across the range. The calibration of the gauge will be checked annually by the Boiler Inspector. In selecting the range of reading it is desirable that the gauge has the capacity to read 150% working pressure for the periodic cold hydraulic test (although some prefer to conduct this test with an external independent gauge). If the range is more than twice the working pressure, then the needle will not move with sufficient resolution to measure small pressure changes in the operating range.

One final type of gauge to be aware of is a combination gauge. This one can show pressures above and below atmospheric pressure (i.e. working pressure or vacuum). These are particularly useful between compound engine cylinders.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO4 1	Pressure relief valves	Describe the purpose of pressure relief valves	Classroom	
LO4 2	The Safety valve	Explain the importance of the location of the safety valve	Classroom	
LO4 3	Servicing	Strip, inspect, reassemble and test under hydraulic and steam	Workshop	
LO4 4	Adjustments and testing	Adjust a pressure relief valve to operate 5% over, 10% under and exactly on the manufacturers level	Workshop	
LO4 5	Pressure gauges	Describe which pressures might be monitored	Classroom	
LO4 6	The Bourdon Gauge	Explain how a Bourdon gauge works	Classroom	
LO4 7	Pressure Gauge Fitting	Explain why a siphon or U-bend is essential	Classroom	
LO4 8	Pressure gauge calibration	Compare 3 pressure gauges in pairs or as a triple on a manifold across the entire range	Workshop	

Learning Outcomes

LO 5:

Efficiency: feed water heaters, economisers, super heaters

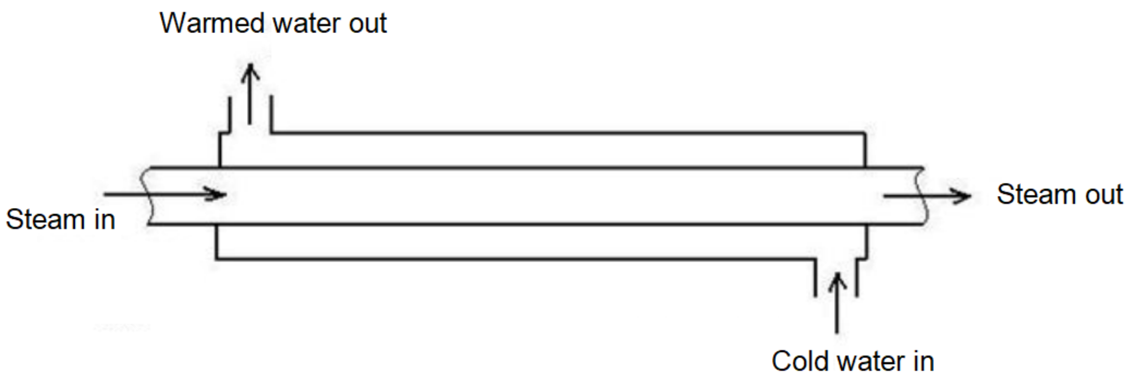
1. Feedwater heaters using exhaust steam
2. Feedwater heaters using flue gases (economiser)
3. Additional steam energy from the fire (superheater)

The boiler must make as much steam and provide it for the engine at the highest temperature possible. There are some ancillaries which can either reduce the energy required to raise the cold water to boiling point or add thermal energy to the steam produced. Both of these features will improve the efficiency of the plant: produce more steam for less energy.

Feedwater heater

The feedwater heater uses waste steam, which has already done work passing through the engine, to raise the temperature of the cold water being fed into the boiler. This has two benefits. Firstly, it takes less energy to boil warm water than cold water. Secondly, if cold water is introduced into the steam space it will cause steam to condense locally and reduce pressure slightly.

A feedwater heater is a heat exchanger fitted in the exhaust steam line to reuse some of the heat which would otherwise go up the chimney or simply heat the surrounding seawater if it is destined for a condenser. Ideally the heat exchanger wants to be close to the engine where the steam is still the hottest.



By running in counter-flow the temperature of the water is elevated to closer to the temperature of the steam entering the exchanger. Efficiency of these exchangers depends upon many factors, but particularly internal surface area.

Reciprocating pumps prefer cold water as they are less likely to cavitate on the draw stroke if the water is cold. It has already been shown that injectors work better with cold water too, so the position of the heat exchanger / heater in the feedwater system is important.

Because this type of apparatus is operating with the exhaust steam, perhaps at 30PSI (2 BAR) and 130°C it is possible for the feedwater to exceed 100°C which is of great thermal advantage. It is worth insulating the output both for safety and for efficiency.

Economiser

An Economiser also takes advantage of thermal energy which would otherwise be wasted but this time by scavenging heat from the flue gases. These gases may be considerably hotter than the exhaust steam and so further advantage may be gained. The economiser is simply a coil or nest of tubes in the smokebox of the boiler or at the base of the flue. When water is continually passing through the tube the flow is sufficient to keep the tube cool but if the water is not flowing then the tube can rise to the extreme temperature of the smokebox and the residual water can become superheated. It is important that the water control valves are arranged such that the economiser can vent to the boiler or to atmosphere so that the tube is not forced to withstand excessive pressure and temperature. A pressure relief valve may be required here.

Steam collecting in the top space of a boiler, from where it is taken off to be used, is in contact with water at the same temperature. This means that it is a mixture of *dry saturated steam* (water as a gas) and *saturated water* (water droplets, or vapour). The proportion of steam to water, by mass, is called the *dryness fraction*. A dryness fraction of 1 is dry steam, while a value of 0 is pure water.

Generally, from the point of view of efficiency, the drier the steam the better. A well-designed boiler and take-offs (the *steam dome*) can produce a dryness of around 0.97, but it may be helpful to improve this further. To evaporate the remaining water droplets, the steam must be taken away from the bulk water and further thermal energy added.

Steam dryer

A steam dryer is a coil of tubing in the flue above the boiler, in much the same region as the economiser, through which the wet steam passes. Its intention is to produce dry saturated steam (dryness fraction 1) without increasing the temperature above the saturation temperature.

Superheater

A superheater is a similar device, but closer to the firebox. It will go further than a drier and produce steam at a higher temperature than the saturation temperature for the particular pressure – i.e. *superheated steam.*

The distinction between a drier and a superheater is small but significant – at low steam demand, a drier may superheat the steam, and at high demand a superheater may only just dry it. So both of them need to be designed to accept the maximum superheat temperature and the maximum boiler pressure. This will also apply to the temperature rating of any fittings downstream of the superheater.

Because it is good practice to have an isolator cock on all boiler outlets as close to the pressure vessel as possible, and it is likely that an engine will have further ‘throttle’ valve, it is possible that the superheater may be closed at both ends. Therefore it is essential that the superheater also has a pressure relief valve (safety valve) of its own.

Monotube (or flash) boilers tend to produce highly superheated steam without additional complications – the water is all evaporated early in the process, and there is no bulk liquid water in the system.

The disadvantage of dry or superheated steam is that you must introduce cylinder lubrication. The water in wet steam is an excellent lubricant for cast iron cylinders and piston rings, and many steamboats rely on it completely. Indeed, some full scale, large marine triple and quadruple expansion engines used no cylinder lubrication. This means that the complication of separating oil from the condensate in a condensing plant is negated.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO5 1	Feedwater pre-heating	Explain why it is beneficial to heat the feedwater	Classroom	
LO5 2	Feedwater heater	Sketch the general arrangement for a heat exchanger	Classroom	
LO5 3	Superheaters	Explain why the superheater will have a safety valve	Classroom	

Learning Outcomes

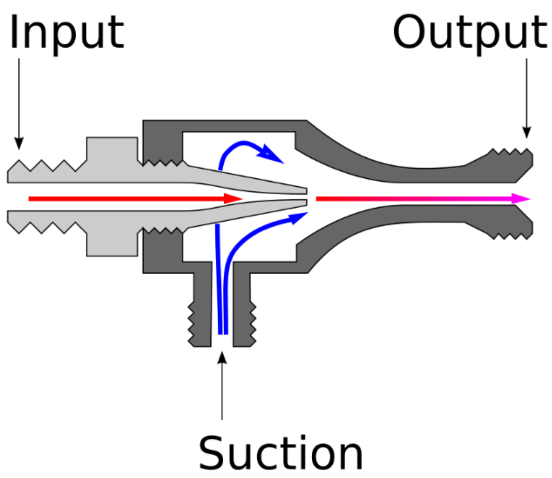
LO 6:

Ancillaries: kettle, bilge ejector, steam separator, whistle.

1. How does a Windermere Kettle work?
2. How does a Steam Ejector work?
3. Steam traps and their advantages
4. Whistle design and mounting

Ejectors

An ejector is a pump similar to an injector, but less complex. The *closed jet* ejector has a shaped passageway which leads to a useful drop in pressure, which can be used to lift the fluid being pumped. The most common application on a steamboat is bilge pumping.



https://commons.wikimedia.org/wiki/File:Eductor_pump.svg

Steam from the boiler is fed to an orifice, like that for a blower (around 1 mm diameter and 5 mm long). The resulting jet passes through the mixing chamber and into a convergent-divergent passage, and thence to outlet. The high jet velocity and the convergence cause a low pressure which draws up the secondary fluid. A lift of 150 mm is typical. (Large ejectors used by traction engines to lift water from a roadside stream can manage to lift up to 10 feet).

An ejector depends on smooth passages in the same was as an injector so routine cleaning and removal of tarnish is important. In addition, if the ejector is being used for bilge draining there should be an effective sieve or filter before the intake.

The Windermere Kettle

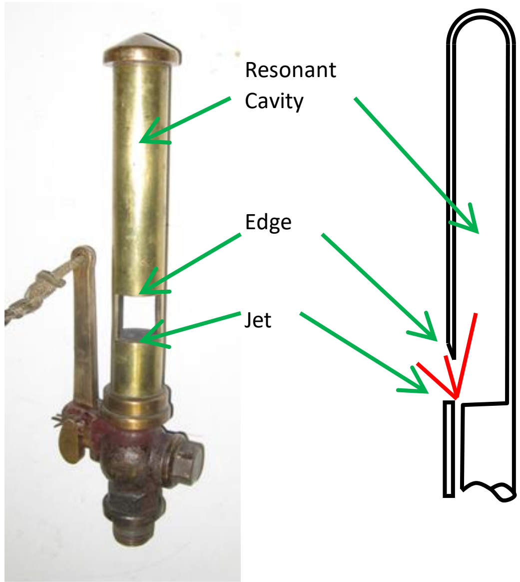
The Windermere Kettle is found on many recreational steam launches. The name suggests where the device was invented. In principal it is a metal 'kettle' with a tap near the bottom and a heating coil inside. Copper or brass are the most common metals used.

Steam is taken from the boiler through a stop valve. If full flow is used, much of the steam will go straight through without giving up its heat, so a constriction is usually put in the pipe downstream of the kettle. The reason for putting it downstream rather than upstream, or using the stop valve, is that one effect of a constriction is to dry the steam: the pressure is lowered without significant temperature change, so the steam, which was at saturation temperature at the higher pressure, is superheated at the lower pressure. Wet steam has a higher heat transfer coefficient than superheated, and so is preferable in the heating coil. Either a fixed constriction – a small orifice – or a needle valve may be used. The latter is more flexible for changes in pressure: it can be adjusted until steam gently comes out of the outlet, which will give the best heating rate.

Most kettles are sized between 1 and 2 litres (1½ to 3 pints) and will boil in a couple of minutes when provided with steam at around 7 bar (100 psi). This implies an equivalent power of around 3 kW (4 horsepower) - much the same as the boat's engine. However the kettle is near 100% efficient, while the engine is more likely to be 5 to 10% efficient, so in fact the engine will use much more steam. Even so, the pressure usually drops significantly when the kettle is put on to boil.

Whistles and Sirens

A whistle or siren is essential for communicating intentions of movements to other boats, or to signal alarm. It must be loud and reliable. In many cases it is often highly polished and decorative.



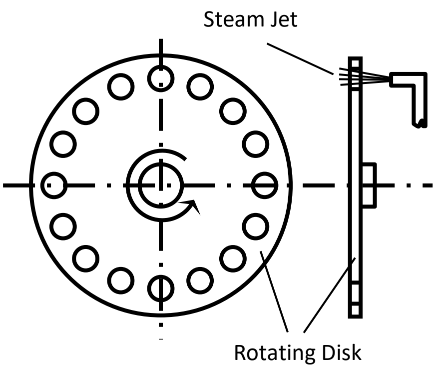
When a high-speed jet of fluid strikes a sharp edge, it tends to oscillate from one side to another in an unstable and unpredictable manner, containing motion over a wide range of frequencies. If there is a resonant cavity nearby (like an organ pipe), the frequencies of the fluid oscillation which are close to the resonant frequency of the cavity will be reinforced. This is the principle of many musical instruments as well as organs and the steam whistle.

The resonant frequency depends mainly on the length of the tube but the note can jump an octave if higher pressure steam is used. Some whistles have the facility for adjustment of the distance between the jet and the edge which will allow for refinement of the note and volume for the steam plant's normal working pressure.

Some people like to have several whistles which sound together – bi-tone or tri-tone. Real enthusiasts have a whole scale, with independent controls, so they can play tunes (a *calliope*).

The siren works by a rather different method. A jet of steam is directed to a spinning plate with holes in it. The jet is alternately let through the holes and obstructed. Now you hear it; now you don't. If the disc spins fast enough, the interruption is at a sufficiently high frequency to produce an audible note. The frequency only depends on the number of holes and the rotational speed. The disc is usually powered by some form of steam turbine. The spinning up and down of the turbine are what give the siren its characteristic wail.

The whistle, and to a lesser extent, the siren like the steam to be dry; droplets of water spoil the effect. This means that it is preferable to keep them hot,



otherwise they will not sound clearly and immediately. This is easily done by mounting it directly on top of the boiler – but this leads to complaints from passengers with nearby ears. Another way is to run the whistle pipe inside the funnel. A third is to keep it well lagged and allow a continuous slow leak of steam through it (which often is the case more by accident than design).

Steam Separators and Traps

Instead of adding heat to evaporate the water droplets, they can be removed mechanically by a *steam separator* and *steam trap*.

Separators work by forcing the steam to rapidly change direction. The much denser water particles are separated from the steam due to their inertia, and they gravitate to the bottom of the separator body, where they collect and drain away via a steam trap.

The Steam Trap is a sump where the separated water collects, and from where it can be drained from time to time either manually or with some kind of automatic system such as a float valve.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO6 1	Ejectors	Strip, service and reassemble an ejector	Workshop	
LO6 2	Windermere kettle	Describe why it is better to have a restrictor on the outlet of the heater coil	Workshop	
LO6 3	Steam traps	Internally inspect a steam trap and service as necessary	Workshop	
LO6 4	Whistles & Sirens	Service a whistle / siren spring-loaded valve	Workshop	

BESTT Marine steam maintenance and repair Module MS 5

Assessment Record for: Training Centre: Year:

LO1	1	2	3	4	5			
Supervisor Initials and date when completed								
LO2	1	2	3	4				
Supervisor Initials and date when completed								
LO3	1	2	3	4	5	6		
Supervisor Initials and date when completed								
LO4	1	2	3	4	5	6	7	8
Supervisor Initials and date when completed								
LO5	1	2	3					
Supervisor Initials and date when completed								
Continued Over								

LO6	1	2	3	4				
Supervisor Initials and date when completed								