Module BESTT MS1

Marine Steam Boiler Types, Construction and Maintenance.

Aim

This unit introduces learners to the wide variety of fuels which may be encountered in steam launches and small steam ships operating on inland waterways or sheltered coastal waters. The range of types of boilers is explained. In each case, the benefits of each fuel type or boiler type are explored. The reasons for caution when conducting external work on old boilers are explained.

INTRODUCTION

Boiler types considered
- Horizontal Fire Tube boilers (including locomotive type)
- Vertical Fire Tube boilers
- Horizontal Drum Water Tube boilers
- Vertical Drum Water Tube boilers
- Single coil (or Flash) boilers

Construction, design and general arrangements
- Heat transfer
- Cleaning
- Considerations for boiler choice and design
- Options for materials and insulations
- Boiler cladding materials

The sheer variety of boiler types used in marine applications is wider than anything we will encounter for railway locomotives or in road steam applications.
Although fire tube boilers from earliest days have been the norm for railway locomotives, water tube boilers could also very occasionally be found in locomotives. The well-known Sentinel shunters had water tube boilers a little bigger but otherwise similar to the company's steam wagon boilers, and Sir Nigel Gresley on the LNER experimented with a 'Yarrow' type boiler but dropped the idea and fitted Britain's only 4-6-4 express engine with a traditional loco boiler.

For shipping, various forms of the classic marine multi-furnace fire tube 'Scotch' boiler was a norm to the last, and vertical fire tube types were a standard for small steam launches, but alongside these a huge range of highly efficient water tube types was under constant development resulting in many different configurations. Development culminated in the Royal Navy: highly efficient water tube boilers in the destroyer fleet and then the nuclear submarine fleet.

What follows is not – and never can be – an exhaustive list, but it is useful at the outset to look at some basic boiler designs used in steam launches. The diagrams below provide a rough cross section of the inside of each type.

This may seem pretty obvious but it is important to state that in sourcing a boiler to provide steam for an engine it is essential that the boiler size is tailored to the steam requirement of the engine both in terms of the steam volume and the steam pressure needed. If the boiler is too big and therefore provides too much steam for the engine, energy will be wasted through the pressure relief valve. If the boiler is too small and provides insufficient steam for the engine, then the boiler will fail to maintain working pressure.

Do not be seduced into thinking that a smaller boiler will be cheaper to run and that you don't want the vessel to go that fast anyway. A boiler which provides insufficient steam, or steam at a lower pressure than that which the engine requires, will mean that the engine has insufficient power to manoeuvre the vessel. For example, the paddle steamer *Kingswear Castle* with a full boiler pressure of 120psi will stop very quickly indeed if put from ahead into full astern. If the boiler pressure is less than 80psi, then the engine loses most of its power and the ship stops much less quickly.

Learning Outcomes

- LO1 Horizontal fire tube boiler construction, design and general arrangement
- LO2 Vertical fire tube boiler construction, design and general arrangement
- LO3 Water tube boiler construction, design and general arrangement
- LO4 Comparing boiler types and materials

Learning Outcomes

LO1:

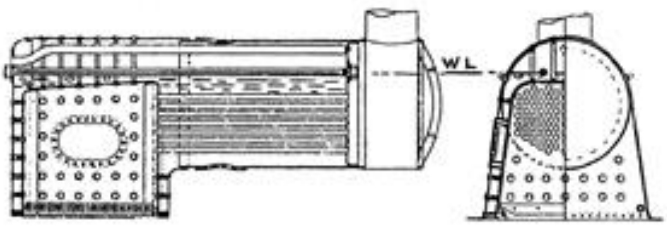
Horizontal fire tube boiler construction, design and general arrangement

1. The construction of the pressure vessel
2. Where transfer of heat occurs
3. The purpose of 'stays' or tie-rods
4. The general arrangements of common HFT boiler types
5. Cleaning

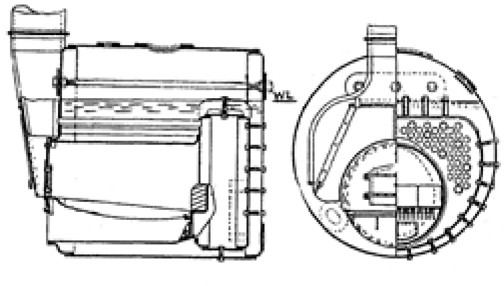
Horizontal fire tube boilers follow very well-known design patterns and are probably the most common of steam boilers still in operation. Locomotives and traction engines will have boilers supplying between 8 and 12,000 Horsepower. The scope of this training will not go that high, but the principles of boiler construction remain.

The pressure vessel will be a composite of several curved or flat steel plates which will be riveted or welded together. The pressure vessel surrounds the inner firebox and extends through a large cylindrical chamber which has horizontal tubes penetrating through. These horizontal tubes carry the exhaust gases from the fire, and hence assist in transfer of heat to the water. The tubes may be termed fire tubes or smoke tubes. They need to be kept clean so that soot does not block the transfer of heat, but also because this is the route of all smoke from the fire to vent to the atmosphere. Blocked tubes will cause the fire to lose vigour and also force smoke, and even flames, through the firehole. However the majority of heat transfer takes place through the walls of the firebox via radiant heat transfer. This principle will be explored in detail later.

Because there are large flat surfaces under pressure, a horizontal fire tube boiler will usually be designed with 'stays' in the boiler: steel rods which pass right through the pressure vessel and prevent the surfaces from distorting under pressure. These stays will be in the firebox region.



Horizontal Firetube (Locomotive type) boiler Some steam launches use this kind of boiler: it will be similar in shape to those found on locos but may be a little more squat and might also be fired from one side (side firing) rather than from the backhead like a railway loco.



'Scotch' type boiler These classic marine boilers may have just one or a number of large furnace tubes – often corrugated for extra strength and heat transfer surface area - in which coal or oil is burned. The heat from these furnaces travels to an internal combustion chamber and then back over the furnace tubes in small fire tubes to a smokebox over the top of the furnace doors and thence to the funnel.

The exposed fire/smoke tube ends in *Lydia Eva's* Scotch Return Tube boiler built in 1961. *Lydia Eva* is a preserved steam drifter, launched in 1930 and now based in East Anglia in the ownership of the Lydia Eva and Mincarlo Trust.

Cleaning

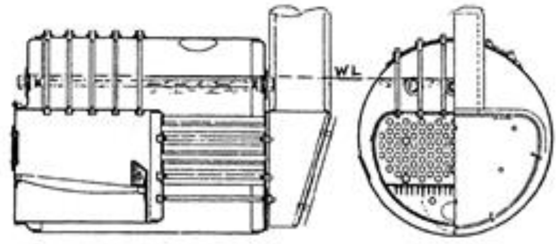
Firetubes will progressively build up soot and detritus from unburned fuels in the narrow tubes linking the firebox with the smokebox.

Some very large Scotch boilers were, in coal burning days, double-ended, their multiple furnaces being fired from both ends. The furnace flues in this kind of boiler were big enough for men to climb into for maintenance and cleaning and the fire tubes in these big oil-burning 'Scotches' could be cleaned from the firing end although frequently the Chief Engineer would ask permission from the Captain for 'permission to blow soot' – using internal steam jets. The ship would, if convenient, be turned so that this could happen and as little soot as possible would land on the decks – or the passengers!

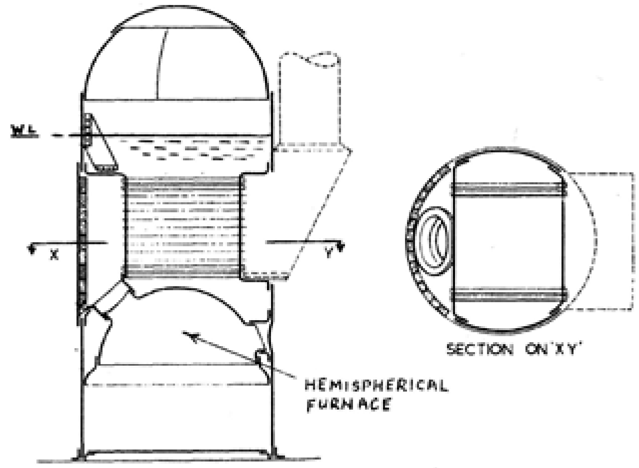
Whilst blowing steam into the smokebox using a steam lance or fixed jets is an effective way of dislodging soot, the mess produced may be undesirable. In a similar manner to traction engines and locomotives, long stiff brushes must be thrust and drawn through the tubes regularly to keep the passages clear and also to maximise heat transfer. Although most of the heat transfer is via radiation in the firebox, the contribution from the hot gases is also significant in efficient running.

Additionally, the sulphurous compounds in soot will be highly corrosive when combined with moisture from the air, and so if the soot is not removed before the boiler is stored cold between uses there will be additional corrosion of the fire tube surfaces.

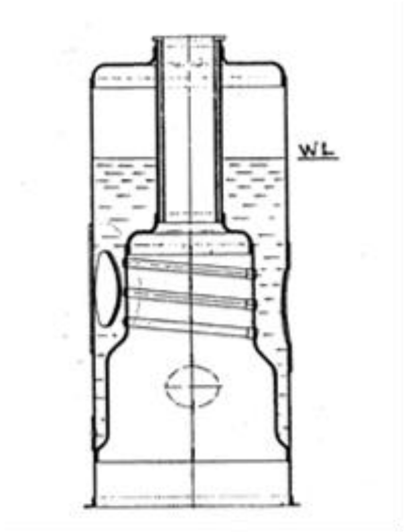
On horizontal fire tube and larger vertical fire tube boilers there will usually be a removable panel or door to access the tube ends. On small vertical boilers it is often necessary to remove the funnel and smoke hood to access the tube ends.



'Gunboat' type boiler Similar in many ways to small Scotch type boilers, they often feature a single furnace and there is no internal combustion chamber. Often found in Victorian steam launches.



Cochran type vertical boiler – a variation on the VFT in which a vertical boiler contains a partially domed firebox combined with an internal combustion chamber linked by horizontal fire tubes across the water space to an external smokebox and funnel. They were efficient and it was easy to clean the tubes since the top of the boiler did not need to be removed to do so as with a VFT. Again, these boilers might be found in small slow-moving 'short sea' or inland waterway cargo vessels.



Vertical cross tube boiler Most usually found on dry land and used for steam cranes or in factories, these are often referred to as 'tank' boilers – because they are indeed big tanks of water - with large fireboxes inside a vertical drum. The most basic type has a single wide flue across which runs a small number of large-diameter cross-tubes. They are not efficient but could be found, for example, in steam dock lighters and in some of the famous Clyde 'Puffers'.

Cracking:
Even very recent boilers and fittings can experience fatigue issues and cracking. Furthermore, two boilers of identical design, materials and workmanship may have very different lifespans brought about by different regularities of steaming, the quality of feed water available or the result of burning different kinds of coal or other fuel.
The two large Thermax boilers in the paddle steamer 'Waverley' had to be replaced in 2020 at a cost of £2.3m following the discovery of cracks after 19 years of use when predicted life was up to about 25 years. Cochrans, the builders, have practically unparalleled experience with boiler making. Whilst nobody knows why these fine boilers came to the end of their lives a little earlier than expected, it is worth commenting that in an industrial setting large boilers holding several tonnes of water can remain in steam for very long periods and are thus spared the kind of heating and cooling stresses suffered by similar boilers in a preserved excursion steamer.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO1 1	Boiler design	Sketch the general arrangement for a named fire tube boiler type	Classroom	
LO1 2	Heat transfer	Describe how the fire tubes assist in the efficiency of a boiler	Classroom	
LO1 3	Boiler construction	Identify the locations of stay rod ends and explain their purpose	Workshop	
LO1 4	Cleaning	Demonstrate the methods of smokebox side cleaning for a fire tube boiler	Workshop	
LO1 5	Cleaning	Identify the locations of the blowdown(s) and explain their purpose	Workshop	
LO1 6	Cleaning	Identify the locations of the washout plugs and explain their purpose	Workshop	

Learning Outcomes

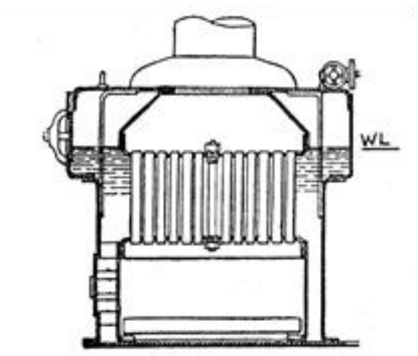
LO2:

Vertical fire tube boiler construction, design and general arrangement

1. Common VFT boiler designs
2. Heat transfer
3. Methods of boiler construction
4. External (smoke side) Cleaning
5. Internal (water / steam chest) cleaning
6. Safety considerations

It is interesting to note that the fire tubes on these boilers are often much shorter than the fire tubes on the horizontal designs. Calculations have shown that the majority of heat transfer in the tubes takes place in the first few inches and so the loss off efficiency in these boilers is minimal, and many would argue this is offset by the compact size and generally lighter weight.

Firetubes or indeed water tubes can be fixed to the main pressure vessel in several ways. In very small boilers it may be possible to heat the entire body sufficiently to allow a silver solder joint between the mating surfaces. Welding steel tubes into steel drums may be encountered in larger boilers. However, the most common method of fixing is by expanding the tubes. Holes are accurately drilled and reamed in the tube plates and the tube inserted with a small protrusion at both ends. A tube expander is used to swell the bore of the tube and force a tight fit with the hole in the tube plate. This is easy with annealed copper tube but requires more force with steel tubes.



Vertical fire tube boiler (VFT) VFT boilers take many forms, but all consist of a vertical drum inside which is a firebox from which fire tubes extend to an upper tubeplate and from thence to the funnel. These boilers were very often found in steam launches. They are efficient and stable steam raisers. They hold a lot of water and in steam launches will not usually be run at pressures of more than 250psi.

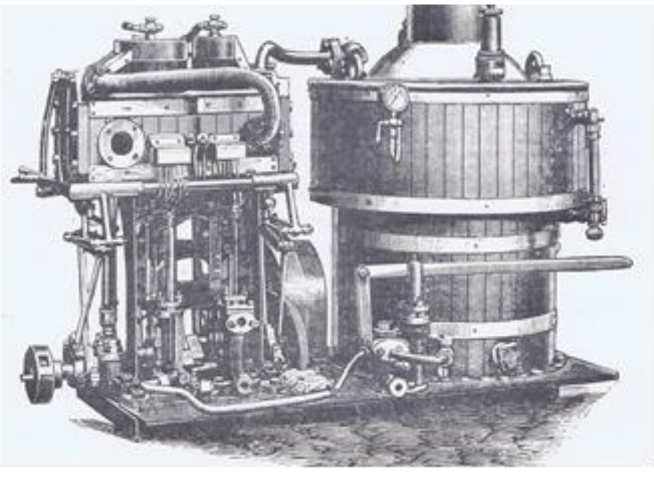
Boilers will often have a layer of external insulation material held in place with eye-pleasing timber cladding and brass banding. There may be occasions when the cladding might char, especially in regions around the Firehole door and small panels may need replacement during periodic maintenance. Mahogany was commonly used in the past, and consideration should be given to suitable timbers for replacement now that the importance of rainforests is better understood. In older boilers great care should be taken with any operation which involves the insulation materials – whether on the boiler or lagged pipes. Asbestos was commonly used and if it is suspected that asbestos may be present stop work immediately and seek professional advice.

Part of the daily routine maintenance of a boiler is to clean the grate and in doing so the condition of the firebars can be assessed. If a fire has not been regularly riddled and / or hard anthracite coals have been used, very hot spots can develop in the grate leading to softening and distortion of the fire bars. If there is excessive damage then the individual bars or a section of the grate will need to be replaced.

The clean cast iron fire bars of *Lydia Eva*

When the boiler is off-line and cooled down the steam pressure vessel should be flushed through in order to remove any accumulated debris. This is in addition to the regular blowdowns performed whilst the boiler is 'in-steam'. How often this needs to take place is dependent on the frequency of steaming and the source of the boiler make up feedwater.

Some vertical fire tube boilers have an access plate on the side which may be removed to facilitate maintenance. When the interior has been flushed/cleaned, the gasket on the access panel should be inspected for damage. If undamaged it can be replaced and refitted, otherwise it must be replaced. Soft rubber gaskets rated for the temperature and pressure of the boiler are becoming increasingly popular because, whilst more expensive to buy than conventional gasket material, they are easy to open without causing damage to either the gasket or the gasket seat faces. Great care should be taken with this operation as a failure of an access panel can be catastrophic.



LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO2 1	Boiler design	Sketch the general arrangement for a vertical fire tube boiler type identifying the main components	Classroom	
LO2 2	Heat transfer	Describe how the fire tube length may affect heat transfer	Classroom	
LO2 3	Boiler construction	Remove the smokebox hood and identify the method of tube fixing	Workshop	
LO2 4	Tube fixing	Drill & ream steel plate and expand a sample copper tube	Workshop	
LO2 5	Smokeside cleaning	Clear grate, and assess condition of firebars	Workshop	
LO2 6	Pressure vessel cleaning	Flush through boiler and conduct internal inspection	Workshop	
LO2 7	Safety	Explain why extreme caution should be taken when examining a boiler and list the precautions that must be checked before opening the pressure vessel	Classroom	
LO2 8	Safety	Open an inspection port and check the gasket and gasket seat faces	Workshop	

Learning Outcomes

LO3:

Water tube boiler construction, design and general arrangement

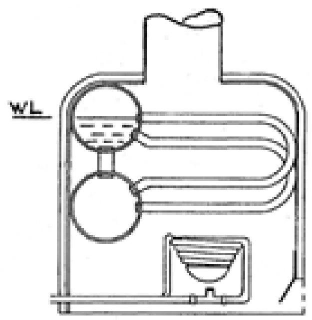
1. Common boiler designs
2. Heat transfer in water tubes
3. Methods of boiler construction
4. Casing arrangements
5. External cleaning – the smoke side
6. Internal cleaning – the water / steam chest
7. Routine maintenance requirements

The use of these boilers is particularly common in the smaller, recreational scale of boats. Having said that, large ones were designed and fitted into destroyers, and even in tandem up to 3 were fitted in larger capital ships. There are still a few mid-sized water tube boilers in operation, such as in Steam Pinnace 199 which is based at Gosport at the time of writing.

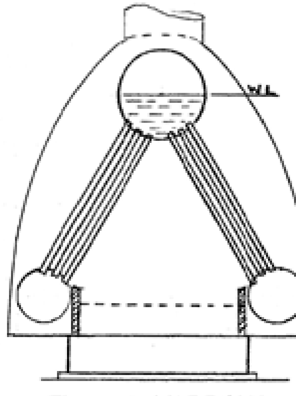
The pressure drums are generally smaller than fire tube boiler's of similar output which may be desirable if minimising weight is a priority. It may be desirable to be able to transport recreational steam launches by road on occasion and so reducing weight is valuable: less effort to lift the boat from the water, and a lighter boiler will impose less stress on the hull during the rigours of road transport.

The relatively small size of these boilers, and the fact that many are recently manufactured means that welding is frequently used in their fabrication. Manufacturing techniques and materials for boilers are investigated in much more depth elsewhere, but it is useful to be aware that there are very high standards required in the quality of materials in steam pressure vessels and in the quality of fabrication and jointing. All materials used in the construction of boilers of any type must come with a Certificate of Conformity which must stay with the boiler throughout its working life.

Any welding which has been performed in the fabrication of a boiler will have been carried out by a highly skilled 'coded' welder. The high standard of welding is essential as any fault could cause potentially catastrophic and fatal results.

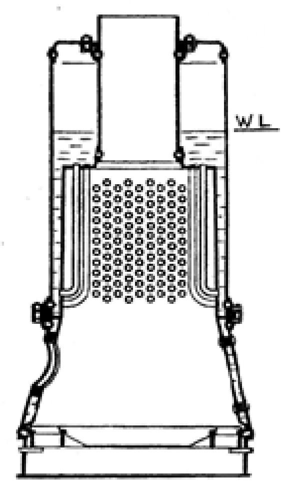


Two Drum Horizontal water tube boiler
The drums are at the end of the firebox and the tubes extend over the fire. This kind of boiler is very commonly found in small launches. The fire is easy to access and there is a large grate area and combustion chamber. The one shown in the illustration if fitted with an oil burner.

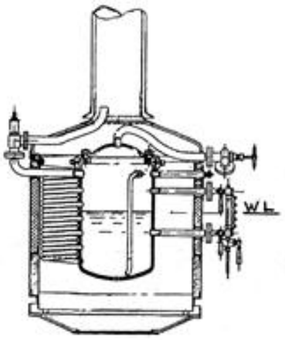


<u>Three drum horizontal water tube boiler</u> There were many variations on the three drum boiler. This illustration is the 'Yarrow' type. The two lower ('mud' drums) were on either side of the firebox and linked to the upper 'steam drum' either by straight tubes angled over the fire (as shown in this illustration) or by many other configurations of bent tubes designed to get the most out of the fire. There are obvious restrictions on the grate area. They were developed initially for fast torpedo boats.

Steam Pinnace 199 Yarrow Boiler (NationalHistoricShips.co.uk)

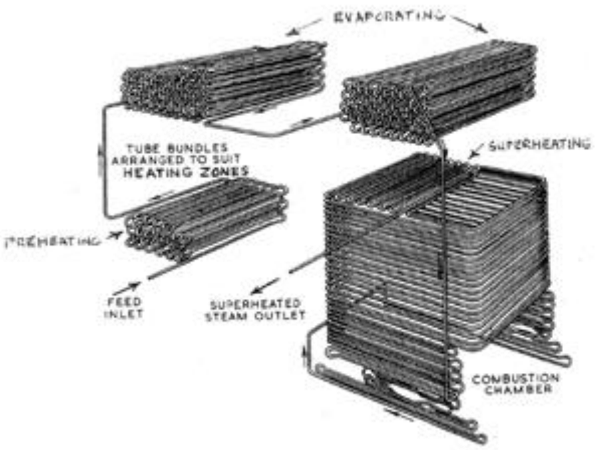


<u>Vertical water tube boiler</u> (Merryweather / Sentinel) Quite complex and very fast steamers. These boilers are often fired from the top because the 'sucking' effect (or draw) of the funnel continued to pull the smoke and fumes from the fire even when the fire door was open. These boilers are developments of the 'cross tube' type however they contain a nest of small cross tubes to make a great deal of steam quickly. 'Merryweathers' were used by the London Fire Brigade as recently as WW2 to power the steam engines for their water pumps.



Ofeldt type water tube boiler Developed primarily for steam cars they are often found in steam launches. They consist of a vertical pressure vessel or 'standpipe' out of which come pigtail coils which return to the drum at a slightly higher level all around it. They present a large tube surface area and were designed for very quick steaming. Similar in concept are Illingworth (vertical 'W' tubes from the central standpipe) – and other boilers including 'porcupine' boilers, in which horizontal tubes with sealed ends poke out all around the central drum.

'Flash' Boilers (also known as monotube or coil boilers)



'Flash' boiler   Flash steam technology is a study in itself, but flash boilers (e.g. as in the White and Doble steam cars) hold no water except that which is injected into them by a pump when steam is needed. They are started with a hand pump. Steam is generated immediately, starting the engine which drives another pump. The boiler tube-coils are kept extremely hot and the water 'flashes' instantly into steam for use as required by the engine. These boilers require to be fed with very pure water.

These boilers are inherently safer than the boilers with a drum full of hot water and steam and also have the advantage that steam and motive power can be produced almost instantaneously. They are also the lightest of all of the boiler options. They are suited to use fuels which can be accurately controlled (eg gas or oil).

Cleaning
As with the fire tube boilers, there will be a progressive build-up of carbon-based residues contaminated with corrosive elements as a result of the fire. (Watertube boilers may use oil or gas as a fuel which tends to burn more cleanly than coal or wood and so cleaning may not be required as frequently if these fuels are used) The tubes need to be brushed clean on all surfaces which can be challenging if they are in an intricate nest of tubes.

If the tubes are made of copper, or modern copper/nickel/iron alloys such as Cunifer, then corrosion in the tube nest areas will be slow. However the steam drums and mud drums will be just as susceptible to the sulphuric acid accelerated corrosion on the outer surfaces of the pressure vessel as on water tube boilers.

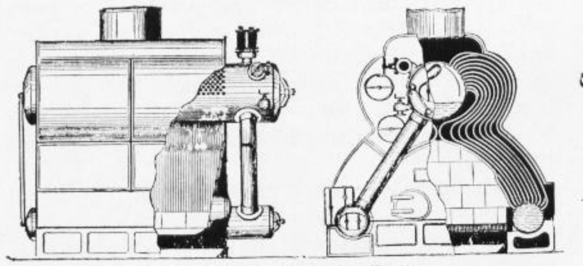
There will often be a large panel in the boiler outer casing which can be removed to allow the dirty job of sweeping the tubes and associated areas clean.

Steam and mud drums each have end plates, normally heavy steel discs held in with either tie rods or multiple bolts at the periphery. Some smaller boilers have just one large diameter tie rod per drum and the gaskets between the smoothly machined drum ends and these gaskets must be replaced at each inspection. These will probably be a thick (ca 1/8" /3mm) ring of graphited gasket material (Vulcanite or similar) although modern boilers are using silicone or Fluorocarbon (Viton) 'O' rings.

Why 'mud drums'? Well 'mud' is the right word because all the sediment and particulates carried in the feedwater drops down into these lower drums and that means it's important to 'blow down' very regularly. If the boiler has more than one mud drum, each should be blown down regularly, indeed a small water tube boiler should be blown down after every steaming, and even while actually steaming it can be useful to open up the blowdown valve for a few seconds from time to time to ensure that potentially damaging sediment is blown out.

The blowdown cock exhausts through the hull skin of the boat and when opened it can empty a boiler quickly, so be respectful of it, and never blow down completely – that is, empty the boiler – unless the fire or burner is definitely out and pressure is down to about 1/3 of working pressure. The cock itself is usually a simple ¼-turn plug cock, generally only having a square drive and no handle [for obvious reasons]. It can be opened with a spanner or a loose lever in the keeping of the engineer.

Even with regular blowing down, removal of the end-plates or inspection ports will allow the drums to be fully cleaned out which is enormously beneficial: the collection of detritus will reduce water flow near the surface and prevent anti-corrosion boiler water treatment reaching the area. It can also produce localised overheating in the steam drum.



"SPEEDY" TYPE (Fig. 1).

The sad old water tube boiler at left is a Thornycroft 'Speedy' (similar to the three drum 'Yarrow' type) removed from a Congo steamer in 1906. The maker's advertising cutaway drawing above shows what it looked like in its prime with its casing fitted. The wide fire grate enabled good firing with coal, wood or oil fuels. Notice the complex arrangement of water tubes to try to make the greatest possible surface area to extract maximum heat from the hot smoke as it rises through the smokebox chamber.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO3 1	Boiler design	Sketch the general arrangement for a named water tube boiler type	Classroom	
LO3 2	Heat transfer	Describe the role of the water tubes in heat transfer	Classroom	
LO3 3	Boiler construction	Explain why any welding on boilers must be carried out by suitably qualified engineers	Classroom	
LO3 4	Casing arrangements	Identify access panels for cleaning smokeside areas of a water tube boiler	Workshop	
LO3 5	External cleaning	Clean the smokeside of a fire tube boiler	Workshop	
LO3 6	Internal cleaning	Clean and inspect the steam and mud drums and replace the inspection covers under supervision	Workshop	
LO3 7	Routine Maintenance	Explain why cleaning on the smoke side of the boiler is important even if the water tubes are of a corrosion resistant material	Classroom	

Learning Outcomes

LO4:

Comparing boiler types and materials

1. Why is there such diversity in designs of marine steam boilers?
2. How have the choices of materials in construction changed over time?
3. Simple comparisons between boiler types
4. Are there always compromises when constructing a boiler?
5. Materials suitable for pressure vessels
6. Materials suitable for insulation

At all times and with all steam boilers, the principal demand made of designers is to achieve the highest possible steam output from the least fuel.

These various boiler types all release the energy from a chemical store to generate heat. There was, and still is, a great deal of investigation, experimentation, development and debate about relative merits of different designs.

In addition to this principal demand, there are numerous other desirable characteristics (not listed in any particular priority)

- Efficient burning
- Rapid steam raising
- Stability of steam production
- Ease of fire maintenance
- Ease of internal inspection (of stays, tubes and plating)
- Ease of cleaning of fire areas
- Ease of cleaning internal water spaces
- (As far as possible) minimum weight without sacrificing strength/durability
- Ease of tube replacement and other maintenance
- Simplicity of construction (= least initial production costs)
- Materials and techniques available at the time of manufacture*

Inevitably, every boiler design has compromises, but one of the attractive aspects of steamboats and steam ships is that virtually every plant is unique. The initial designs will have been tailored to the customers' requirements, and in many cases, subsequently modified to suit new owners. This is part of the attraction of Marine Steam to the many followers of this rather specialised field.

What should boilers be made of? Boiler inspectors, and the insurers behind them, want to know where every bit of metal in a pressure vessel has come from. Thus, any boiler today should have with it a sheaf of documentation detailing the provenance of the materials used in the drums and end plates, and something similar to vouch for the metallurgical integrity of the tubes as well.

Boilers can be made from steel or copper and tubes from steel, copper or cupro-nickel alloy (Cunifer) and these metals are alloyed to many different specifications and can also vary widely in quality. Copper has been used traditionally in small steamboat boilers, but it does 'age' (fatigues) and constant heating and cooling puts all metals under stress to some degree to the point that distortion can occur and cracks appear. The Steamboat Association of Great Britain runs its own boiler testing service (SBA Services Ltd) and will not allow copper boiler pressure vessels to have a maximum working pressure of more than 100psi. Most Model Engineering Societies globally have adopted the same limit.

As boiler metals have to be meticulously specified, the same is true of the metals used for boiler fittings and pipework because they also carry potentially highly dangerous levels of hot steam and can fail with disastrous results. All pipework joints need to be made with great care and tested carefully once installed in the boat. Similarly, boiler access hole gaskets need to be positioned extremely carefully and they need to be of the correct profile and material specification. It must be remembered that boiler door joints and gaskets generally soften when heated so although they may stand a hydraulic cold test they may fail at steam temperature and pressure.

In 1992, the failure of a lower mudhole door joint in a Scotch boiler caused the sad loss of two lives aboard the preserved steam yacht 'Carola' during boiler testing. The door was not correctly centralised before tightening, causing the jointing to be displaced with catastrophic release of steam and superheated water into the confined boiler room space.

Lagging: In order to keep heat from escaping from a boiler and its pipework, it is important that they are covered with insulation – 'lagged'. On a steam launch, drum type boilers, whether vertical or horizontal, can be lagged with polished wooden slats. Usually there will be a layer of ceramic or similar blanket type insulation beneath and there may even be a thin painted sheet-steel plating on top (like a traction engine). Pipes will be lagged with some form of string.

The material for all lagging in the past was asbestos, however the dangers of this material have been recognised for many years and if asbestos is found in the course of restoring any boat, most likely on older boats, work must stop, the area sealed off and removal and disposal of the contaminated parts put into the hands of professionals.

There are several good non-toxic modern substitute lagging materials. Pipes can be wound with string of suitable thickness made from materials as diverse as hemp, fibreglass, ceramic fibres or silicone. All are good insulators that will keep the heat in and help the engineer to avoid burns. On some steam launches pipes can be found wound with medical bandages steeped in Plaster of Paris: smoothed carefully by hand when applied, once dry it can be gently sanded flat and painted.

The boiler tubes may be steel, copper or, nowadays, cupro-nickel (Cunifer) - a highly durable alloy that rose to prominence with the maritime oil industry. Tubes are expanded in to ensure that they can be replaced reasonably easily. Some might advocate that if one tube ever develops a pinhole and starts to leak it can, in extreme 'get you home' circumstances, be temporarily plugged from inside the drums – the pressure in the drums keeping the plugs forced into place. However, this practice is not advocated by BESTT.

Drums and tube nests are covered with a steel casing lined on the inside with a 1" thick (or more) 'refractory lining'. This can be made of thin fire brick or cast fire cement or other more contemporary insulation materials and the idea is to reflect the fire heat inwards and keep the casing reasonably cool. In general firebrick is used to protect the proper insulation from the rigours of the fire as the fire brick is not a good insulator.

The table below summarises some of the key differences between the generic boiler designs. However, in nearly every case there are likely to be exceptions.

	Fire Tube	**Water Tube**	**Monotube**
Water volume	These tend to have the largest volume of water. In many designs the firebox also has a water jacket (known as a wet firebox)	Less water volume than a fire tube boiler with as much as 50% being in the water tubes adjacent to the fire	Very small volume of water
Mass of metal	Due to the outer and inner pressure vessel components fire tube boilers have the greatest weight	The total weight of these boilers may be comparable to fire tube boilers, but a proportion of that weight is outer casing	By far the lightest of the boiler types: the pressure vessel is a single pipe
Raising steam	The large thermal mass* means that raising steam is the slowest in this type	The lower thermal mass means steam may be raised in much less time than fire tube boilers	Almost instant steam raising ability
Stability of steam supply	The large thermal mass means that steam supply is very stable	Changes in the firebox or to the feedwater are quickly translated into altered steam output	Inherently unstable but extremely responsive to feedwater or fire differences
Cleaning	Simple design = easy to clean	Cleaning dense tube banks, especially in small boilers can be difficult	Simple design, usually gas or oil fired, so relatively easy to clean
Cost of manufacture	Relatively simple design with low tolerances on most components leads to lower production cost	More complicated design with tight tolerances on holes for expanding tubes means more time and skill needed, hence more cost	Simple design but needs high spec materials and sophisticated control system
Running costs	Least efficient of these boiler types in steam vessels hence most costly to run	Better efficiency means lower running cost	Very efficient but generally uses higher cost fuels

***Thermal mass is the amount of material which has to be heated.**
Steel requires 50,000 Joules to raise the temperature of 1kg by 100°C
Water requires 400,000 Joules to raise the temperature of 1 litre by 100°C

*Quality of metals available and development of production methods

Engineering has only ever been able to move forward realistically if it ran in parallel with Materials Technology. The metallurgical knowledge of the Victorians had to develop fast and the arrival of Bessemer steel, for example, radically changed the shipbuilding industry which hitherto had only had cast and wrought iron with steel available only in limited quantities.

New metallurgies and the arrival of reliable hammered, then gas, then electric welding techniques allowed the slow transition from riveted hull and boiler construction. The development of precision casting techniques and the ability to build very large accurate machine tools with effective metal cutting blades all made an impact.

One of the problems faced by Isambard Kingdom Brunel was that his huge ideas – e.g. the 'Great Eastern', the biggest iron ship of her day, were way in advance of the metallurgies and technologies needed to make them economically realistic! The cast cylinders that formed part of the hydraulic system designed to launch such a large ship were so poorly cast that the water (not oil in those days) came out through the cast metal before they could generate enough pressure to push the ship down the slipway. However, lessons were learned and this was another step towards further progress.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO4 1	Diversity in designs of boilers	Describe the factors which might influences choices made by designers	Classroom	
LO4 2	Materials in construction	Explain why welded steel construction is not found on early steam boilers	Classroom	
LO4 3	Choices in designs	Explain the advantages and disadvantages of large thermal mass	Classroom	
LO4 4	Compromises in designs	Suggest under what circumstances a water tube boiler might be a good choice for a canal user	Classroom	
LO4 5	Refractory materials	Inspect and repair firebox refractory material	Workshop	
LO4 6	Insulation	Inspect and repair the lagging of a boiler and lag a demonstration length of pipe.	Workshop	
LO4 7	Valves	Repack a valve gland	Workshop	

BESTT Marine steam maintenance and repair Module MS1

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	6	7	8
Supervisor Initials and date when completed								
LO3	1	2	3	4	5	6	7	
Supervisor Initials and date when completed								
LO4	1	2	3	4	5	6	7	
Supervisor Initials and date when completed								