Module BESTT MS4

Marine Steam Fuels

Aim

This unit introduces learners to the wide variety of fuels which may be encountered in steam launches and small steam ships. In each case, the properties of each fuel type are explored. Finally, important principles in clean and efficient combustion are explained in the context of current Health and Safety expectations.

INTRODUCTION

Coal and other solid fuels

Liquid and gaseous fuels

Heat transfer from the fire

Forced Draft options

Effective and efficient firing

Health and Safety

What do we need for burning? This is generally thought of as the Triangle of Fire:

Once started this 'triangle' is self-sustaining until one of the three elements is removed (or consumed). A fire can be put out by smothering it with a non-combustible (like sand) or it can be cooled by removing the heat faster than it is being generated (by 'drowning' it in water) or the fuel can be removed (turning off the fuel valve) or by starving of oxygen by CO_2 jet which will also remove heat.

This tells us that for successful combustion we need to maintain all three of these factors. In boilers we are looking to liberate the useful heat from the fuel and in order to do this it must be supplied with some form of heat to get it started (a match) and oxygen (from the air).

However, it should be noted that things burn in different ways: if a small open fire had a supply of wood that was cut to size, some coal that was in lumps of different sizes, some charcoal and a small amount of paraffin. Consider for a moment what would be chosen as fuel and how it might be arranged if the following were desired…

A slow burn?

A fast burn?

An intense hot burn?

A gentle smoulder?

A gentle flaming burn?

The right fuel in an age of change

Victorian explorers who used steamboats to find their way up the Amazon in South America and the Congo in Africa could only do so by burning the sort of hardwoods we'd want to actually build our boats with today! Hacked randomly from the rainforests in those days, these valuable timbers are now either banned imports for us or simply no longer available.

Boats in some parts of the world were fired successfully on what today we would regard as high-bulk biomass fuels – Bagasse – the dry fibrous material left over from sugar cane after the juice has been squeezed out of it or the husks of coconuts, for example. Even dried and compressed old grape vines are now being sold as fuel. In the UK bracken, which is a 'weed' as far as most farmers are concerned, is now being turned into highly compressed briquettes. This is, however, very much at an experimental level.

Coconut husks were tried out by a development worker in Congo about 30 years ago. The steam plant – to generate electricity in a rural settlement - consisted of a vertical cross-tube boiler driving a generator engine from a scrapped steam tug. The major problem he encountered was ash clearance. The husks burned well and generated lots of steam but left unexpectedly vast amounts of ash that proved very difficult to dispose of and were not even of much use on the land. The stuff blew around everywhere or turned into a thick and sticky mess in rain.

These new fuel sources – biofuels - are becoming more available all the time as people start to realise that fossil fuels won't last forever and can be seriously toxic when burned - to humans and to the atmosphere where long term damage can be a contributor to climate change.

Following recent Government legislation, due to come fully into force by 2023, banning the sale of 'house coal' the type of coal used by most 'Heritage' markets may not be available at all even though the 'Heritage' market will still be 'allowed' to burn it. Assuming it is available, will it be at anything like an affordable price?

If firebox and grate dimensions are correctly designed, not forgetting to give thought to the ash pan and the removal of ash and other by-products of burning, biomass products could form a fuel perspective that at least keeps costs to a reasonable level.

Dried animal dung has always been an acceptable fuel in desert and other arid parts of the World, and it burns like Irish peat – very completely and leaving very little ash. A new twist on this theme is that human sewage is currently a very real contender as the raw material for a new 'coal'. Not an attractive thought but it may prove to be quite effective!

A Spanish company (Ingelia) is working on this and their resulting product, we're told, 'burns like coal' but is carbon neutral - and it has a considerably lower production of harmful waste such as nitrogen, sulphur and chlorine. But as we'll see later, when people use the term 'burns like coal', traditional coals come in many types and they all burn in different ways.

'Biocoal' is now becoming available: it consists of compressed biomass material that has been 'torriefied', a process which forms it into something a bit like coal. It is (unfortunately) lower in calorific value, but it is compact, produces reduced harmful emissions and is, importantly, 'hydrophobic' i.e. like real coal it doesn't absorb water and turn into unusable sludge. This is a field of development to watch carefully.

It has been argued that 'biofuels' are theoretically carbon neutral because all crops that grow move (sequester) carbon dioxide (CO_2) from *above*-ground circulation to *below*-ground storage in the roots and the surrounding soil. However, the simple and convenient idea that biofuels are carbon neutral has been blown apart largely by recognition that for a particular biofuel project to be carbon neutral, the total carbon sequestered by the energy crop's root system must compensate for all the above-ground emissions when it is eventually burned. Thus many 'first generation' biofuel projects were found not to be carbon neutral at all, although they represent steps in the right direction.

If someone builds a steam launch and simply wishes to get on the water and steam happily for miles at virtually no cost, not overly bothered about high efficiency or the cleanliness of the air it might seem attractive, if the boiler firebox has the space, to burn old broken pallets or old fencing and any other rough timber including waste wood fished out of the river. However, rough timber used in gardens has since the 1930s, has been treated with some pretty toxic chemicals and what is generally called 'tanalised' wood (i.e. that used in fencing, garden decking etc.) has been treated with preservatives that may contain copper, chromium, arsenic, phosphorous, boron and various other toxic biocides.

Having said that, many a steam engine fire is lit up initially with old pallet wood of this kind, however it should not be used routinely for running.

There are many factors which need to be borne in mind when selecting the right fuel for a particular marine application. Some are listed below.

i.	Availability	Is it obtainable in quantity where it's needed?
ii.	Suitability	Does it suit the type of boiler/firebox?
iii.	Calorific Value	Quite simply, does it generate enough heat?
iv.	Cost	Is it economically realistic?
v.	Practicability	Is it easy to handle? /bulk? What about carriage to where it's needed - and what about ash & clinker removal?
vi.	Cleanliness	Is it clean for the operator / for others / products of combustion?
vii.	Ethical Issues	legality / environmental / sustainability?

As mentioned above, the obvious requirements for a fire of fuel and air; the fuel may be applied via a shovel or through a pipe, the air will rise though the grate to give the oxygen to the flames.

Anyone would think that things just 'burn' but it is well worth understanding how the many different fuels available tackle the business of steam generation.

Although lighting some sort of fire in a boiler to heat the water that it contains appears to be a very simple concept, it is helpful to start with a clear understanding of exactly what is happening when we apply a match.

When fuels burn there are two different processes.

1 Vapour / Gas combustion

2 Solids combustion

The vapour / gas combustion is the familiar one from cookers, school Bunsen burners or candles. Simply the fuel and oxygen combining in a flame to release heat (and light). Gas burns in this way but interestingly liquid fuels need to become a vapour (by misting or by evaporation) in order to burn. In the initial phase of burning, coal needs to be heated sufficiently to make the volatile hydrocarbons evaporate and they then burn as a gas.

Coal then passes on to a second phase: the solid fuel bed starts to glow red – or white if very hot – and it gives off **radiant heat** as it changes into ash.

There have been many attempts to maximise the heat transfer from this 'incandescent' phase and the Argentinian railway engineer L.D. Porta developed firebox and smokebox draughting systems that worked spectacularly well and transformed the performance of a handful of the last generation of steam locomotives.

Sadly, Porta's work came too late to stem the demise of steam on the railways of the world although elements of his systems found their way on to the last steam colliery shunters in the UK and even into some preserved locos in use in the UK today. Some exhaust steam was passed through the incandescent coal firebed to make 'producer gas' which then burned off on top of the fire. The engines ran very economically and almost smoke-free as a result. Other systems have used sand beds instead of the more familiar grate in which the sand is kept afloat (fluid) by jets of steam or compressed air and the solid fuel is burned on top, ash and clinker being taken away by a moving steel chain-type belt immediately under the combustion area. This is known as a fluidised bed boiler and is still used today in large power generating plants, especially those than burn household refuse.

It was realised in the mid19th century that coal dust burns explosively, and indeed the very earliest internal combustion engine thinking focused (unsuccessfully) on this idea prior to the arrival of hydrocarbon liquid fuels (oil /naptha/ petrol).

LO 1:

Solid Fuels

1. Types of solid fuel and their properties
2. Products of combustion
3. Environmental Issues
4. Comparing Energy Output

The white-gloved masters of pristine, the Thames and Windermere launches with their perfect varnish, paintwork and fresh flowers on the bow, were always seeking clean fuel or to certainly find the cleanest way of burning a dirty fuel, like coal.

Some classy steam boaters have been known to put their coal in paper bags, which is wonderfully clean and absolutely what should be done to maintain a boat's impeccable grooming at Henley! Some wealthy Victorians were also not above saying to their launch engineer: *'I say, my good man, make sure the coal for the launch has been whitewashed… there's a good chap…'*

Back in 1923 and again in 1948 Britain's railways saw 'locomotive exchanges' designed to see how the different companies' carefully designed passenger and goods engines would fare in different parts of the country. A lot of time and research had gone into designing fireboxes for the locomotives these railway companies ran to suit the coals most readily to hand in the region where they would be used and it was immediately obvious to observers that this was very definitely the case.

That principle was in the mind of those designing boats for inland waterway or local harbour/port use. Ocean going ships used 'dry steam coal' (more about that to come) available in all major ports in the days of coal fired steam ships. Massive tonnages of 'Deep Vein' steam coal from South Wales was shipped all around the world for the use of the coal-fired ships to ensure that fuel of the right grade was available on all continents.

Coal varieties all have their own specific usage. Soft European coals burn like fury but smokes everything up and fouls boiler tubes with soot, hence the quest for real 'dry steam coal' which was once produced in abundance at great human cost from very deep Welsh mines.

Having said that, many hard anthracites (sold as 'stove nuts') can be almost smokeless and slow burning. They 'cake' (clinker) more readily than the mythical Welsh dry steam coals but, burned on robust (ideally) stainless-steel firebars, will suit many small boilers very well.

Sadly some of the coal marketed specifically to enthusiasts 'for steam engines' might be fine for large-tubed loco-type boilers but is often quite unsuitable for small marine boilers: while high in 'volatiles' (i.e: burns rapidly and well) and therefore great for steam raising initially, the cost is usually rapid sooting of smaller tubes.

Coals were produced by the action of pressure and heat over æons of time on rotting vegetation that had accumulated in swamps buried under the earth millions of years ago. The different underground intensities of pressure and heat, along with the different lengths of time since the burial of the various timber and other deposits which were crushed into coal can account for the different basic types of coal.

Coal very definitely isn't 'just coal'. When there were hundreds of pits all around the UK the choice was enormous. All coals have different combustion characteristics and released different amounts of:

(i) heat

(ii) moisture

(iii) corrosive compounds

(iv) smoke

(v) clinker & ash

Some varieties suited a particular boiler design much better than others.

Excluding ash and moisture, the main chemical constituents of all coals are carbon, hydrogen and oxygen; their proportions vary and it is found that a very useful ranking of coals can be made on the basis of the percentages of carbon and hydrogen the coal substances themselves contain.

The youngest coals are the *Lignites*. Not normally available in Britain, these are ranked the lowest; they have the lowest calorific value and contain the least carbon. They have a high content of volatile matter, are very reactive, may ignite spontaneously and should certainly be avoided.

Bituminous coals come next in rank; they include various coals sold under the name of 'house coal'. Compared with the lignites they all contain more carbon but their content of volatile matter is not as high. When suitably free from ash they have high to very high calorific values. Although they will not ignite spontaneously when kept in small heaps they can be ignited fairly easily. On a traditional grate they burn with a flame that remains long and bright but rather smoky until most of the volatile matter has been driven off. Some of these coals tend to form a cake on the grate. Because of their tendency to make smoke it is illegal to burn bituminous coals (i.e. house coals) on a traditional grate in an officially designated Smoke Control Area so steam launches on inland waterways shoudn't use them.

Once much favoured for use in railway locos were Yorkshire *hards* or East Midlands *hards*, mainly because of their relative freedom from clinkering.

Higher in rank than bituminous coals come the *sub-bituminous* coals including a group of naturally 'smokeless' fuels - the *Welsh 'Dry' Steam Coals*. The 'dry' refers to the fact that they did not 'weep' any corrosive products of decomposition when heated. This was very good news for tubes and fireboxes and nothing to do with the quality of the steam.

Welsh dry steam coals had yet more carbon but less hydrogen and other volatile matter than bituminous coals, hence their flame was short and relatively smokeless, albeit bright. Their calorific value was high and they only cake lightly.

Moving up the ranks (more carbon, less hydrogen) we come to two more groups (these are of authorised smokeless fuels); firstly the *Semi-Anthracites* and finally the highest rank of all, the *Anthracites*. Both groups have high calorific values. Anthracites, having the lowest content of volatile matter, can be fairly difficult to light; they are rather dense and slow-burning and may not be easy to get burning vigorously again after a fire has been 'slumbering'.

It is probable that the old Welsh dry steam coal was the best solid fuel for steam launches, followed by semi-anthracite and then anthracite. The manufactured, as opposed to the naturally smokeless, fuels however deserve to be listed and some may still be available into the future. They included *Phurnacite, Homefire, Sunbrite, Coalite* and *Rexco*. (Coke was often used historically in steamboats on inland waterways but coke from gasworks is no longer available since the coming of natural gas).

Clinker

When coal burns it doesn't just disappear, it leaves ash, which must be cleaned out and disposed of, but it also leaves hard deposits that we know as clinker, which can choke up firebars and create localised areas of overheating. Clinker can be a problem and is particularly likely to form when a coal fire has been forced and brought to high heat using a steam blower or engine exhaust blast up the funnel.

Clinker forms into lumps and plates and is composed of the non-burnable (the better term is non-volatile) often metal-bearing, mineral particles found in the coal that have melted out and solidified together. There can be other inert stony material in the composition of the coal that is also left behind when burning takes place.

When steaming any coal-fired boiler, the fire needs regularly checking and 'cleaning' – and clinker removal -pricking it out with a hooked fire-iron and getting it out of the firebed with a suitable long flat shovel is an important element in ensuring the boiler steams efficiently.

Coal, of course, is quite literally a 'fossil fuel' composed of highly compressed and carbonised prehistoric living timbers and plant life so chemicals of all kinds are present in the various types available and these react to form solid deposits when the coal is burned.

Lump charcoal burns hot and dry, leaves only the merest amount of powdery ash and tubes stay perfectly clean. However, producing charcoal is neither energy efficient nor environmentally friendly and to burn charcoal can sometimes mean that the funnel produces showers of dangerous sparks. Some boiler operators use charcoal as a starter fuel for lighting fires as it provides enough heat to raise the temperature of conventional coal to its ignition point.

Burning wood has wide appeal – readily available and sustainable – unlike money it really does grow on trees! Wood is easy to ignite but releases much less energy per kg than coal. In addition, wood is much less dense than coal, so up to 8 times more volume of material is needed if wood is burnt rather than coal. More dense woods such as oak or beech reduce this ratio, but still need more than twice as much material than their coal equivalent.

Similarly, biomass fuels in pellet form, as used in some formerly coal-fired power stations such as Drax, would necessitate towing a fairly substantial Thames Lighter behind the average 20' launch to keep up with firing the boiler all the time!

Compressed 'logs' of one kind and another, coal pellets and so on have been tried by enterprising individuals but these are usually not 'hydrophobic': this tendency to absorb water plus their huge bulk makes them problematic in a wet climate. The 'logs' turn to 'Weetabix' and are unusable.

Irish steam boat owners have found peat, known locally as 'Turf', to be a great fuel, both cheap and fragrant. It is, of course, another form of fossil fuel and therefore only available in finite quantities – i.e. it's not 'sustainable'. 'Turf' burns away completely leaving a virtually clean grate with hardly any soot and only tiny ash deposits.

[No wonder loco engineer Oliver Bullied, newly returned to Ireland after his time on the Southern Railway wanted to use the stuff in locomotives back in the early 1950s. Had he succeeded it might have made some economic sense and the Irish railways could have become (a) the most attractively fragrant, and (b) the dustiest, in the world!]

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO1 1	Types of coal	Describe how coals may have different burning properties	Classroom	
LO1 2	Combustion products	Explain why a smoky fuel may present problems on longer voyages	Classroom / on a voyage	
LO1 3	Clinker	Identify clinker in a coal grate and explain the formation	Workshop	
LO1 4	Environmental issues	Suggest how the choice of solid fuel might impact the environment	Classroom	
LO1 5	Energy content	Explain why seagoing ships avoid using wood for a fuel	Classroom	

LO 2:

Liquids (Oils) as Fuels

1. Benefits of liquid fuels over solids
2. Suitable types of oils for marine applications
3. Hazards associated with oils
4. Burner technologies to produce vapour or gas
5. LPG gas: Butane and Propane
6. Routine maintenance of vapourising burners

One could argue that liquid hydrogen could be included here, but that is far too new a technology for inclusion. All the liquid fuels for boilers are hydrocarbons, i.e. Oils. However, there is no reason that they could not include liquid biofuels with the right treatment in order to improve the environmental credentials.

Liquid fuels have the distinct advantage over coals for the fireman: there is no need to use a shovel every few minutes. They are also much cleaner to supply to the firebox, can be regulated by the simple twist of a valve (and also instantly switched off) and their supply is pretty much automatic – either through gravity feed or some type of pump or pressure system.

The Royal Navy found huge advantages in using oil and dropped their global network of coaling stations as quickly as possible. British Rail also adopted oil as the fuel of choice with alarming and disappointing haste as quickly as they could once oil became widely available after WW2.

Traditional steamboats can burn oil and have been doing so since the 1880s with great success. Liquid fuels were used for some of the earliest road vehicles with reasonable safety by Serpollet, White, Stanley, Lifu and a host of others. Liquid fuel technology moved on very rapidly as internal combustion engines started to make an impact and steam engineers wanted to ensure that what they saw as the benefits of steam power were developed to best advantage.

> It is interesting to reflect that as late as 1906 there were more steam cars in America than petrol engined ones, and in the UK we were still building ships with oil fired steam machinery into the 1970s. A small number of specialised ships were built in Japan in the early 2000s to carry LPG (Propane) and they were designed to burn the 'boil-off' from the huge cargo gas tanks which meant that they had boilers and steam turbines.

Burning any oil can be fairly clean and efficient, and while they will generate soot in the flues, they will leave no ash to blow about and get into engine bearings. Burners can operate nearly silently or be very noisy indeed, roaring thunderously in the bowels of a boat, threatening the integrity of the engineer's eyebrows every time the boiler is lit ('flashed') up and sometimes demanding the presence of electrical systems for ignition and forced draught.

It is probably fair to say that those who choose liquid fuels live with a different order of vigilance from those who burn coal, and all users of oil-burning steamboats are aware of the risk of igniting excess oil which may have dribbled into the firebox 'ash' pan. There should always be an oil-appropriate fire extinguisher close at hand.

The privately-owned 25’ kerosene-fired steam launch ‘Saumerez V’ was crossing the Solent when her engineer/owner suddenly realised that there was a lot of smoky flame beneath the boiler: oil had been dripping unbeknown to him into the pan beneath the burner and been ignited by the heat from the pressure burner above.

He immediately knew what to do: he turned off the burner fuel valve and pilot light before reaching for the ‘steam lance’ on a length of pressure tubing. The lance might take the form of a simple thick-walled steel tube with an insulated handhold and control valve to squirt a jet of high-pressure steam which, as in this case, will quickly blanket the flames and extinguish them.

If no steam lance had been available, the option would have been a foam or a CO_2 extinguisher – use of a water extinguisher would run the risk that burning kerosene would swill even more dangerously outside the tray which was containing it because kerosene floats on water.

This incident happened on the Solent – an extremely busy area of water full of ferries, cruise ships, Naval vessels and fast-moving passenger catamarans. The owner needed to ‘flash up’ and get under way again as soon as possible.

The Right Oil?

Any oil available in bulk can be suitable. Paraffin (kerosene), diesel, old sump oil, used frying oils or heavy marine ‘bunker’ oils are all used depending on the size and type of burner and whether an electric forced-draught fan is used. This needn’t be a problem since many small steamboats carry deep-cycle 12v batteries and a number of boats have engine driven alternators or photovoltaic panels to keep their batteries charged. This adds slightly more complication to the UK’s Boat Safety Certification scheme for boats used on inland waters.

More than for any other fuel, steamboaters who use oil are not merely keeping alive a tradition, they are also involved in active development. Fuels used in the last 130 years include petrol (naphthalene as it was called when first marketed) and paraffin. The light (non-Diesel) fuel most readily available today is 28 Sec Heating Oil (also known as kerosene or Paraffin), the purest form of which is Jet A1 – aviation fuel.

A Health & Safety risk!

The 1880s saw the brief rise and rapid fall of what might have been a significant Health & Safety Executive challenge, had the HSE existed then. The 'naptha launch' was something of which it might be wise to say even today: 'don't try this at home'.

'Naptha' is what today we would call a low grade of petrol.

Naptha launches looked unbelievably serene and beautiful. But they were potential bombs-on-the-water. They flourished for about 20 years in the USA and, to a lesser extent, in the UK. Always elegantly turned out, naptha launches sported a very small wide-funnelled 'boiler', usually near the stern, in which naptha, contained in a closed circuit, was boiled in thick tubes over a pressure burner (like a camping Primus stove burner) fed with the same fuel.

Since petrol boils at a very low temperature, the vapour quickly developed a working pressure sufficient to drive a high speed three-cylinder, single-acting engine before being condensed in a long tube under the keel and returned to the tank in the bow ready to go round the cycle again or be burned off in the firebox.

It is to be hoped that owners repaired any vapour leaks in their piping or engine glands rather quickly and carefully and politely suggested that their guests didn't smoke.

Some of the 19th Century burner designs still perform impressively, those developed by Lifu on the Isle of Wight at the end of the 19th Century, for example, are well documented and modern versions are in use today burning kerosene.

Relatively easily made by the home mechanic was, and is, the Lune Valley inverted conical type. The principle is exactly the same as for the 'Primus' stove (mentioned above) once used extensively by campers before butane became available.

To start such a burner it is necessary to first heat its vapourising tubes with a burning tray of methylated spirit, pressurise the supply system or fuel tank with a few strokes of a hand pump and then, after a specific period (maybe 1-2 minutes), turn on the fuel. The fuel will immediately turn to vapour in the hot burner and, when released through jets ignite, if the gas/air ratio is right, with a powerful blue flame and a satisfying roar. The flame is then self-sustaining as it also pre-heats the vapourising tube.

This is a picture of the side view of a Lune Valley type burner – the vapourising tube is formed into a conical coil and the gas it releases when very hot fuel burns underneath it, thus keeping the tube hot and pressurised. There is just one jet in this type of burner and this bears on to the inverted hemispherical flame spreader seen below the vapouriser coil.

Vaporising burners, when they are set up correctly and clean, can work very well indeed but it is quite usual to find efficiency dropping off after a few hours of use. They are notoriously sensitive to the fuel being used and may perform well with one manufacturer's paraffin or kerosene and very poorly with that of another. Kerosene comes in different grades from '28 second heating oil' (central heating oil fuel) to Jet A1 (aviation fuel), the latter being very pure.

If the burner cokes up and becomes smoky and spluttery it should be shut down. The burner tube will be arranged for quick removal and it should be lifted out of the firebox and on to the bench where the flame holes can be pricked out with a primus picker (or a steel 'B' or 'G' string for a guitar!). In ring and long horizontal burner types you may find the tube is packed with wire wool. It is there to fill up space and to help ensure that vapour from the vaporising ring or coil finds its way to the flame holes to be burned immediately before soot and particulates form themselves into a shell on the inside of the burner tube. It may be necessary to unpack the wire wool and tap the tube with a copper mallet to encourage any deposits out.

Atomising Burners

Some launches use the same system as larger ships: an atomising burner. In these systems a pump is used (often electric) to pressurise the oil and feed it though a fine nozzle. The combination of rapidly reducing pressure and high speed causes the oil to form micro-droplets and the oil will ignite without the need for pre-heating. For efficient burning air is also forced into the combustion chamber. This whole system is rather similar to the domestic oil burners. There needs to be an associated electrical system to power the burner which may not be desirable on a small launch, but would not be a barrier on a ship with all the associated electrical paraphernalia which a large vessel must carry.

One final point... if a steam plant is to use a liquid fuel, research is needed as to where to buy supplies of the chosen variety of oil and, just as important, where and how to store it safely and in compliance with H&S stipulations.

For convenience, as well as cleanliness, the fuel to consider is Liquid Petroleum Gas (LPG) in the form of Propane. Propane is a very versatile fuel. It offers instant lighting, no soot, no ash, reasonably clean hands and no need for electrics. Butane is also available but does not release so much heat per kg and so is not as popular. For those that like to steamboat in the colder months one advantage of Butane is that it freezes at a lower temperature than Propane.

Propane is usually supplied in heavy cylinders. A 16' boat might get up to 12 hours steaming, for example, from two 13kg Propane cylinders.

There is no reason why a large fixed tank should not be installed in a steamboat, which, en-route to the river, could be filled up exactly like a car, but the spread of 'dual fuel' (Propane/petrol) cars has not taken off as expected since electric vehicles gained ascendancy so it is important to know where is the nearest propane depot.

Initial costs for a marine gas installation remain relatively high. The UK Boat Safety Inspection handbook will specify in detail the requirements for built-in tanks and the specs are being updated. Suffice to say, steel gas lockers (boxes) are required for the cylinders to contain leakage of this heavier-than-air gas. Pipes coming out of the lockers need to be welded – to obviate flying nuts and bolts perchance there is an explosive problem. Tubing, where it is likely to be trodden on or is at risk of other disturbance, needs to be enclosed in larger diameter tubes and joints in the piping cannot be sealed with PTFE tape. In use a fail-safe 'flame out' system needs to be fitted to ensure that the gas supply is shut off in the event of the flame going out. It is advisable to clear any residual gas out of the bilges by means of a scavenging pump driven by a brushless electric motor before starting the lighting up sequence.

Many years of practical experience using a gas fired steamboat has shown that since the gas is burned rapidly under the boiler and up into a long funnel, it very effectively scavenges (sucks out) the bowels of the boat and there never is a build-up or even smell of gas in the bilges. Even so, all joints should be very carefully examined and maintained and any sign of green mildew-like deposits on any piping or joints regarded as an early warning that a joint needs to be remade and the seal corrected.

Is that all? What about other fuels?

There is always the nuclear option! Small steam launches don't use it but the last steamboats in the Royal Navy are its few remaining nuclear submarines, in which nuclear reactors heat boilers to drive steam turbines. Probably another instance of 'don't try this at home'.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO2 1	Using oil as a fuel	List the reasons why oil may be the best choice of fuel on a steam launch or ship	Classroom	
LO2 2	Hazards	Describe why oils may be considered more hazardous than solid fuels	Classroom	
LO2 3	Vapourising Burners	Sketch the general arrangement for a vapourising burner and explain why methylated spirits (or similar) are initially needed	Classroom	
LO2 4	Atomising jet burners	Describe the additional equipment needed if atomising jet burners are used on a boat	Classroom	
LO2 5	LPG fuels	Explain the benefits and the potential drawbacks of using gas as a fuel in a marine environment	Classroom	
LO2 6	Maintenance	Decarbonise a burner and clear jets	Workshop	

LO 3:

Heat Exchange Surfaces

1. What are the 3 ways heat may be transferred from a fire?
2. Characteristics of coal fireboxes
3. Characteristics of oil and gas fireboxes
4. Movement of fire and flue gases through the boiler
5. Retaining heat in the firebox
6. Formation of steam in the pressure vessel

Heat Transfer

Three forms of heat transfer must be borne in mind:

1. Radiation in which heat travels in straight lines. The intensity decreases with distance from the source, and solid objects will block radiation and cause a shadow-region

2. Conduction in which heat travels by contact. Metals are the best conductors. Copper is particularly good, and stainless steel is surprisingly poor.

3. Convection in which heat is conveyed by moving liquids or gases as a result of reducing density as their temperature increases. Hot gases or liquids will rise. This will cause a 'convection current' which can draw cool fluids in at the bottom whist the warm fluid rises.

A boiler designed for burning solids will have a firebox designed to take advantage of the **radiant** and **conducted** heat from its bed. The vapours released will be burnt in a combustion chamber mainly designed to take advantage of the conducted heat from the flames and hot gases. It may even have 'water walls' or 'thermic siphons' to take further advantage of that extremely hot radiant firebed.

It is therefore the case in watertube boilers designed for 'vapour burning', that a firebox in the true sense of the word will be of little value. All that is needed is a surround for the flame that will direct and reflect the heat generated up around the tubes where the work of steam generating is done.

Heating Surface

In seeing if a given boiler will produce enough steam to run a particular engine we must ask 'how much water will the boiler evaporate in a given time period?' The size of the 'heating surface' is therefore very important indeed.

When water bears against a heated surface, small bubbles of steam form which then break away and rise to the surface, so for any boiler design, the question has to be asked 'can the bubbles of steam forming on heating surfaces (e.g. in tubes) be easily released into the steam space where steam is taken off for drive purposes?'

In some large boilers the firebox crown, the area directly above the fire, was corrugated. This provided a larger steel surface area for the fire to act on the steel, and similarly a larger surface area for the hot steel to be in contact with the water.

The size of the grate in a coal fired boiler is so critical; partly because a larger grate means a larger fire can be accommodated, but also because large grate will yield a greater horizontal and vertical heating surface area and offer greater thermal transfer. On the other hand, we need to be a bit wary of horizontal heating surfaces such as the top of a firebox. If it's ever left uncovered because of low water level the steel may rapidly become much softer than expected and distort so that the top plate rips itself away from its stays as it is forced downwards by the pressure of steam above it. This kind of catastrophic collapse was once surprisingly common and was the cause of many a historic boiler explosion on the railways. It was often a consequence of a misread water gauge. One solution to this appalling situation was the installation of a 'fusible plug' which is a bronze fitting with a narrow orifice which is sealed with lead solder. When fitted in the crown of the firebox it is covered with water and so the lead always stays below the melting point. However if the water level falls so low that the firebox crown is in the steam void, the localised temperature rises sufficiently to melt the lead plug and the fire is extinguished by the escaping steam. There is an inherent danger though: if the Firehole door is open when the plug melts, or the firehole door is not mechanically closed then the fireman may get severely burned by the rapid escape of steam. However many consider this hazard the lesser when compared to a complete boiler rupture.

Tubes in a boiler

If we were to submerge a steel cube, with a heat source inside it, in water we would find that the upper surface generates heat more than twice as fast as the vertical sides whilst the lower face seems to generate none.

The reason for this is simple: steam forms in bubbles which can fly off a flat top surface easily. It's a little harder for them to detach themselves from the vertical surface, and the bottom surface traps the bubbles completely and on this surface there forms a thin film of steam which will be going nowhere. That thin film of steam is a very good insulator to stop further water gaining energy and evaporating.

Without going too deeply into the physics of the way water boils, it is worth noting that steam bubbles form differently when surrounded by water under pressure (hydrostatic pressure). At the same time, in any kind of steam engine boiler we will find a mix of flat, curved and tubular heated surfaces which, simply because of their shape, will promote evaporation at different rates.

This isn't a problem in steam pressure vessels as other factors are at work, notably **convection**, the tendency of the hottest (and therefore the lightest) water to find its way to the surface and thus create a constant circulation. The water in an active boiler is therefore never static.

One of the intriguing features of early steamships – and also steam tugs and pinnaces up to the end of the 19th Century - was that their boilers were frequently built in fairly random 'box' shapes, tailor made to fit into the hull spaces available. This meant that they were often a complex mass of joints and stays. While they delivered the steam needed, they were often very hard to clean internally, and poor or salty feedwater could pose a grave threat to their safety. Boilers did not last very long and new ones were a regular expense for ship owners.

Fire tubes

The tubes should not be too long as they drop off in efficiency in the course of their length. Forced draught – i.e. a blast at the funnel end or a blast beneath the grate will enliven and oxygenate the fire as well as improve heat distribution by drawing flue gases rapidly through the tubes and encouraging heat transfer.

Stanley steam cars were designed with compact petrol-fired fire tube boilers designed to produce as much as 600psi of steam pressure. These little boilers are packed tightly with very small-bore, very short fire tubes. People used to handling larger boilers, where it is normal to keep the water level at around ¾ of a glass or comfortably above, are surprised to find that Stanley boilers only operate efficiently if the glass is practically full and almost the full length and surface area of those little firetubes is being deployed. These boilers only need a small 'steam space' to provide a bit of 'reserve' to help the vehicle up a hill or accelerate out of trouble.

What would be the best sort of design for burning vapours or gas?

The 'water in a box' explanation above suggests that the way to get the best heat transfer out of burning vapour is to employ water tubes as near to the horizontal as practical.

However, we also want to use a phenomenon always found in liquids when heated: the liquid (in our case, water) starts to move around because of the **convection** - which makes the hottest water rise to the top where it can easily flash into steam, while cooler water comes in beneath it.

Firebox temperature

Coal-fired steam railway locomotives had a bad reputation for making smoke, but a good deal of this was avoidable. Early British locomotives were often coke fired, and it was the invention of the brick arch which enabled coal to be burned in larger locomotives. The arch, built out over the long fire in a loco boiler, got extremely hot and helped to 'burn up' solids in the smoke on its way to the tubes. Volatile matter needs an extremely high temperature for proper combustion. The brick arch forms a high temperature area above the fire and when 'top air' is introduced via the fire hole; this can mix with unburned gases before passing into the tubes. The fire hole will have deflector plates which direct the air under the brick arch and prevent air going straight through the tubes.

Marine boiler designs such as those by Babcock & Wilcox which feature baffles made of ceramic refractory materials (firebricks which remain stable at high temperatures, retain heat and re-emit it) use the same principle, but on the whole, the pressure was not on marine boiler designers in the coal-burning era to cut smoke down. However, that pressure is with us today and the heritage industry is wise to expend time and effort on burning the right fuels in the right way to keep harmful products of combustion – be they particulates (i.e. smoke) or in the form of toxic gases – to an absolute minimum. In addition, in a coal firing firebox the use of refractory bricks to retain a proportion of the fire's heat is often associated with improved thermal output from the same sized grate. Some claim that the reduced grate size caused by accommodating firebricks is more than compensated for by the increased efficiency of burning

Thinking about the future

As launch boilers wear out and need replacing it would be interesting – and perfectly possible - to try Porta's gas producer combustion system in a steam launch. It is a simple development from a normal locomotive type fire-box. It could be applied to a vertical boiler too. The main differences from normal are that extra air is provided between the fire box and the brick arch – in the VFT steamboat boiler that's the bottom tube plate - reducing the draught across the fire bed. Exhaust steam is led into the ashpan to be drawn up into the fire bed. The extra air comes in through carefully placed holes around the firebox just above the fire bed. The main consequence is that the fire bed acts more as a 'gasifier' than as a 'combustor'; the gases and smoke arising from the bed are then burnt up very efficiently in the high turbulence created by the extra air coming in all round the box above the fire bed.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO3 1	Heat transfer	Describe the characteristics of the 3 means of heat transfer	Classroom	
LO3 2	Boiler heating surfaces	Explain why a large heating surface is important in boilers	Classroom	
LO3 3	Flames and smoke	Describe the movement of the flames and hot flue gases through a boiler	Classroom	
LO3 4	Firebed Temperature	Suggest how the inclusion of refractory material in a firebox may aid efficiency	Classroom	
LO3 5	Pressure vessel shape	Explain why flat surfaces directly above the firebox are undesirable in boilers.	Classroom	

LO 4:

Firing Technique

1. Conditions for efficient combustion of coal
2. Conditions for efficient combustion of vapours and gas
3. Signs of trouble

The firing of a boiler whether it be in a locomotive, a traction engine or a marine setting, depends on the amount of volatile matter released from the coal. There is a wide variety of types from different collieries.

Once coal has been brought up to red heat in the lighting up process it begins to emit vapours which will burn. If the supply of oxygen is sufficient then the carbon element of the fuel begins to burn too producing more heat.

The aim is to burn all of the fuel and to achieve this the firebed depth must be controlled.

- A firebed which is too thin will result in excess air passing through the fuel and reducing the overall temperature of the flue gas above the fire.
- A firebed which is too thick results in incomplete combustion and this will lead to reduced energy release from the fuel and is also usually associated with smoke production, especially if the coal is of the bituminous type. If the coal is of the 'smokeless' type, then unburned fuel is released as carbon monoxide into the atmosphere.

Little and often is the advice given for firing: there is a lot to be said for the old maxim *'A little to the left, a little to the right, and keep the centre burning bright'*!

The following is an extract from the From the 'Handbook for Railway Steam Locomotive Enginemen' published by the British Transport Commission

> ***Combustion Temperature***
>
> *Broadly speaking, coal must be heated to 450°C to ignite but much higher temperatures are required for it to burn efficiently. At temperatures in the range of 1350 °C the hydrocarbons in volatile matter split to facilitate combustion of carbon and hydrogen. If there is enough oxygen, complete combustion results in the production of carbon dioxide and water. If insufficient oxygen is present, incomplete combustion occurs resulting in carbon monoxide and unburned carbon (smoke/soot). The energy released is consequently reduced depending on the severity of oxygen deficit. This will be observed as black smoke.*
>
> ***Volatile matter***
>
> *Coal as a fuel contains two parts. Volatile matter which is released as gas when the coal is heated and fixed (solid) carbon in the form of coke which remains after the volatile matter has been given off. The combustion of volatile matter may be observed as yellowish smoke when firing from cold, or when too much coal has been loaded onto the fire at one go. If the fire bed has been raised to a high enough temperature, the volatile matter from newly added coal begins to be released immediately. These gases are quickly drawn out of the firebox and will pass out of the funnel unless enough air is present. Volatiles contain a*

large proportion of the heat value of the coal and failure to allow complete combustion will represent a considerable loss of energy and, hence, efficiency.

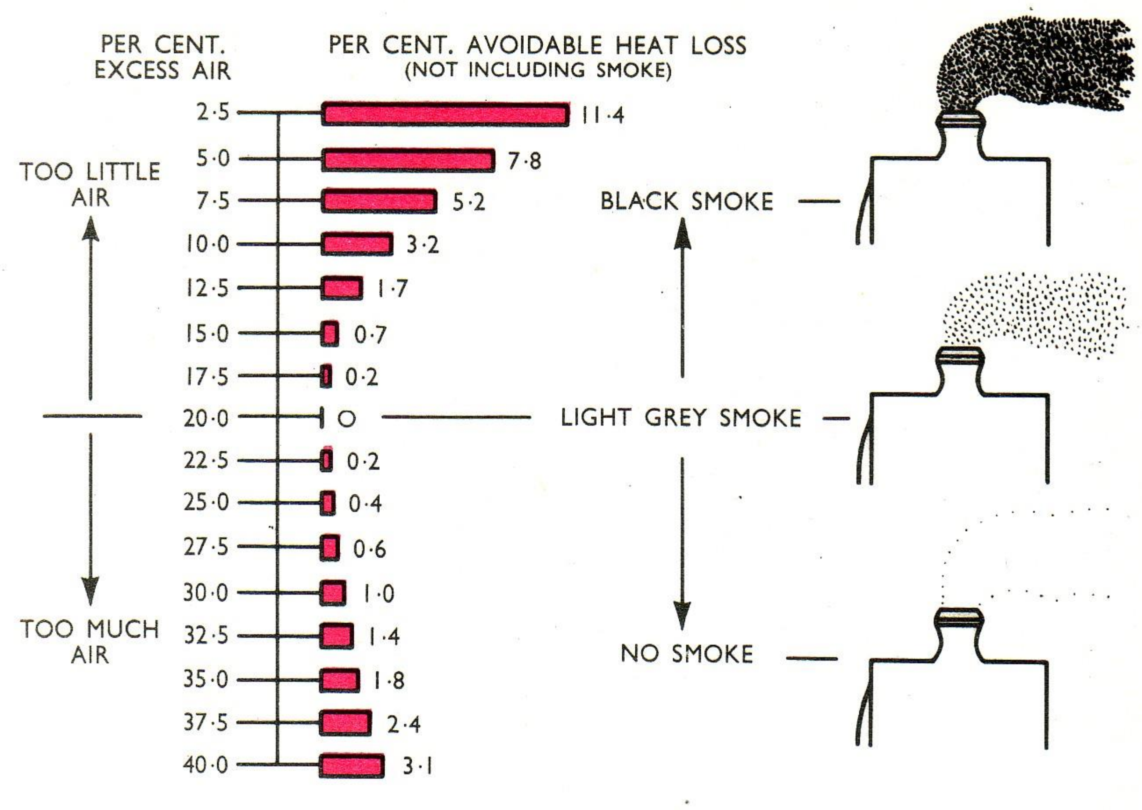
Adding Air

Air may be supplied in two ways:

1. *Primary air, through the fire grate*
2. *Secondary air through the firehole door*

The primary air is likely to be insufficient to allow combustion of the volatiles and therefore it is essential to permit secondary air to enter at the same time. Once the volatiles have been driven off, the coke that remains will stay on the fire bed until sufficient primary air is supplied to allow combustion, and again sufficient secondary air must be supplied to ensure complete combustion of carbon to carbon dioxide rather than carbon monoxide.

There will of course be heat loss from the introduction of more air than is required for combustion. The excess air will be heated to about 400°C as it passes through the boiler to the funnel, and losses in this way are thought to rise to as much as 10% and are probably less significant than the contra-losses through too little air (Figure 1).



Burning vapours and gas are also complicated to get 'just right'.

The critical factors in vapour burning are **complete combustion** and **length of flame** and it is interesting to consider how we can control them. The appearance of the flame is the best guide and there are easily recognised indications of what's happening in the case of paraffin (kerosene):

1. Fuel temperature

(a) Too hot - it will flash instead of burning.

(b) Correct - it will burn steadily when mixed with air.

(c) Too cool - it will dribble out of the jet with a dull, yellow, spluttery, smoky flame – and leave an inflammable residue in the floor pan – ready to burst into flame when the operator is least prepared.

2. Fuel pressure

(a) Too high - will give a noisy, fierce, blue lean flame, often too short to reach the tubes.

(b) Correct - will give a long white flame rimmed with blue at its base (the blue is not always so apparent with the slightly heavier kerosene). Noise will be a low roar.

(c) Too low - will give a silent smoky yellow flame.

3. Air mixture

(a) Lean mixtures - burns with a very noisy fierce blue unstable flame.

(b) Correct mixtures - burns with a long white flame with a narrow blue base and a low roar.

(c) Rich mixtures - burn with a smoky yellow near-silent flame.

In large ships using heavy 'bunker oil' the oil is pre-warmed and injected into the furnace with a steam jet, burning instantly. In a small steam launch the right temperature for burning will be dictated by the size and design of the fuel heating element of the burner. Although complicated cast iron types have been used, by far the most common takes the form of a coil mounted above a flame spreader – along the general principle of the Lune Valley type.

The pressure within the burner and the tank feeding it with fuel are critical. An increase in pressure will increase noise and reduce smoke, and a decrease will reduce noise but will promote smoke. An indication that all is well will be a white flame with a tinge of blue at its base.

More on Mixture

Getting these pressure oil burners to work well is something of a fine art, demanding as they do on fuel fed at the right pressure, the right length and size of tube for the vapouriser and the right size jet for burning. In addition to those factors, air take-up is influenced by the distance between the jet and the 'flame spreader', the role of which is to fan the flame out to play on the tubes in the most efficient pattern to use the hottest part of the flame when everything is correctly set up. The greater distance the fuel travels as a gas the more air it can absorb and the better the flame is likely to be.

Whatever the fuel being burned, if there is a yellow sooty flame, and black smoke coming from the funnel things are not correct: the fuel is not burning fully and the black is unburned carbon. This seemingly harmless soot will cause havoc to boiler performance: whether fire tube or water tube the soot can quickly form spider webs of blockages to the flue gas pathways which can eventually clog and starve the through flow of air. The build-up of soot must be removed as quickly as possible, and the reason for incomplete combustion rectified before the vessel has to limp home, unable to raise enough pressure.

The 'pot burner': a modern development

A very simple modern kind of burner often encountered in small contemporary steam launches is called the 'pot burner.'

Oil or whatever liquid we desire to burn is simply dripped into a circular or rectangular tray, all around which is a double-walled chamber into which air is blown at a pressure of up to about 3psi. This air escapes through small horizontally angled holes into the tray area to provide a vortex. The tray area is filled with burning fuel which mixes with the vortex creating a dramatic yellow flame with a powerful vertical 'swirl' effect. These very simple burners are controlled by the amount of fuel being burned and, more importantly, by the output of the air blower, the speed of which is variable. Not enough air at the right pressure will give a smoky, dirty flame. Too much air and not enough fuel will cause flame-out, so, once again, balancing air and fuel is critical.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO4 1	Firing with coal	Explain why 'little and often' is best when coal firing	On the water / workshop	
LO4 2	Controlling the air with a coal fire	Show methods to reduce the smoke emissions from a fire	On the water / workshop	
LO4 3	Burning gas efficiently	Demonstrate the effects of changing the flow rate of a gas or oil burner	On the water / workshop	
LO4 4	Smoke Production	Describe the long term consequences of a sooty flame	Workshop	

LO 5:

Natural vs Forced Draft

Why is draft important in coal fired steam boilers?

How can draft be reduced?

What did the VIC puffers do?

Understanding water demands

Blowers

The fire requires oxygen to burn and for burning coal in a domestic fireplace, simple convection currents of cold air being drawn through the grate and coals will provide enough oxygen for a warm and comfortable glow. However, to provide motive power a fire needs to be encouraged to burn much more intensely. The oxygen demand is much higher and natural air draw though the grate will not always provide sufficient oxygen. This problem is made worse when there is clinker in the bottom of the grate: not only is there additional material blocking flow of air to the fire, but the extreme heat of the fire is not being effectively carried upwards with the rising air towards the heat exchange surfaces (tubes). Instead, the intense heat remains close to the grate and cause warping of the cast iron firebars. Riddling is the physical agitation of the coal base close to the firebars to break up clinker and encourage it to fall into the ashpan. Cold air can then be drawn up though the firebars more easily, keeping the bars cooler and supplying oxygen to the fire.

This problem is not an issue in vapour/gas burning as there is no grate or unburned fuel blocking the air's path.

Industrial factories solved this problem by building impressive chimneys – hundreds of feet of warm rising gases produces a considerable low pressure to draw fresh air into the fire through the grate. Although some steamers exploit this principle to a limited extent, in order to be effective hundreds rather than tens of feet of flue are required.

On a steam locomotive the exhaust steam from the cylinders is blasted up the funnel creating a forced draft in the firebox leading to a good draught.

The same principle can be used on a steam engine and boiler system in a boat – the term 'puffer' is used for boats which use this principle.

Any steam system which uses exhaust steam in this way needs to have a large supply of clean fresh water – the tender or side tanks on a locomotive, or a river or lake for a boat. When the boat works in a salty environment (even a brackish estuary) then feedwater for the boiler cannot be drawn from the surroundings. In these circumstances the exhaust steam needs to be retained, condensed, and reused. This is called a condensing plant.

Sea going steam vessels will always have condensing boiler plant because of the potential damage presented by salt in sea water to their boilers. The primitive iron boilers in extremely early sea going vessels, prior to development of good condensing systems, didn't last long and at the end of every voyage the salt deposits had to be, quite literally, shovelled out. The speed of dangerous corrosion was alarming and very early ships' boilers built of iron were often of a 'box' configuration shaped irregularly to fit the hull for which they were built. They had many stays, joints and corners and, although only very low pressure, they presented issues a boiler inspector today would find hair raising in the extreme. Boilers in freshwater vessels survived longer and many quite large lake steamers (e.g. on Ullswater) were puffers, ‘drinking the lake’ and exhausting to atmosphere.

A vessel that condenses its exhaust does not have a steam blast up a funnel to enliven a fire – which affects the way its heat source behaves.

To counter this in a small steam launch with a condensing plant there will be a ‘blower’, exactly like that on a railway loco: a controllable steam blast to be used as needed – to encourage the fire if it’s a bit slow or has been allowed to get dormant for any reason.

A boiler burning solid fuel in a confined firebox will always need a ‘blower’ – a steam blast up the funnel to create a partial vacuum and ‘suck’ the fire through the tubes to get the fire burning at a high enough temperature for complete (and efficient) combustion. The blower is either a simple pipe blowing up the funnel or it can be a more sophisticated ring with vertical holes mounted in the smokebox. Railway locos have blowers to compensate for lack of exhaust blast when the engine is stationary.

Some marine boilers use mechanical blowers to force air pressure under the firebed to ensure that enough oxygen gets to the fire to ensure good, complete combustion. This is known as Forced Draught. If this system is encountered, there should be a mechanism so that the blower is disabled before the fire hole door can be opened to avoid hot gases or flames being blown towards the fireman.

Designs and operation of blowers will be considered in more detail in MS03.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO5 1	Why do coal boilers need to be able to force the draft?	Explain why a forced draft is important for boilers driving an engine	Classroom	
LO5 2	Riddling	Explain why it is important to remove clinker from the fire bed?	On the water	
LO5 3	'Puffing' ships	Describe how a 'puffer' forces the firebox draft	Classroom	
LO5 4	Understanding water demands	Why is it undesirable for estuarine or coastal boats to 'puff'	Classroom	
LO5 5	Forcing the draft on demand	Service a blower with multiple nozzles	Workshop	
LO5 6	Blowers before the firebox	Explain the risks associated with a blower below the grate	Classroom	

BESTT Marine Steam Fuels Module MS4

Assessment Record for: Training Centre: Year:

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