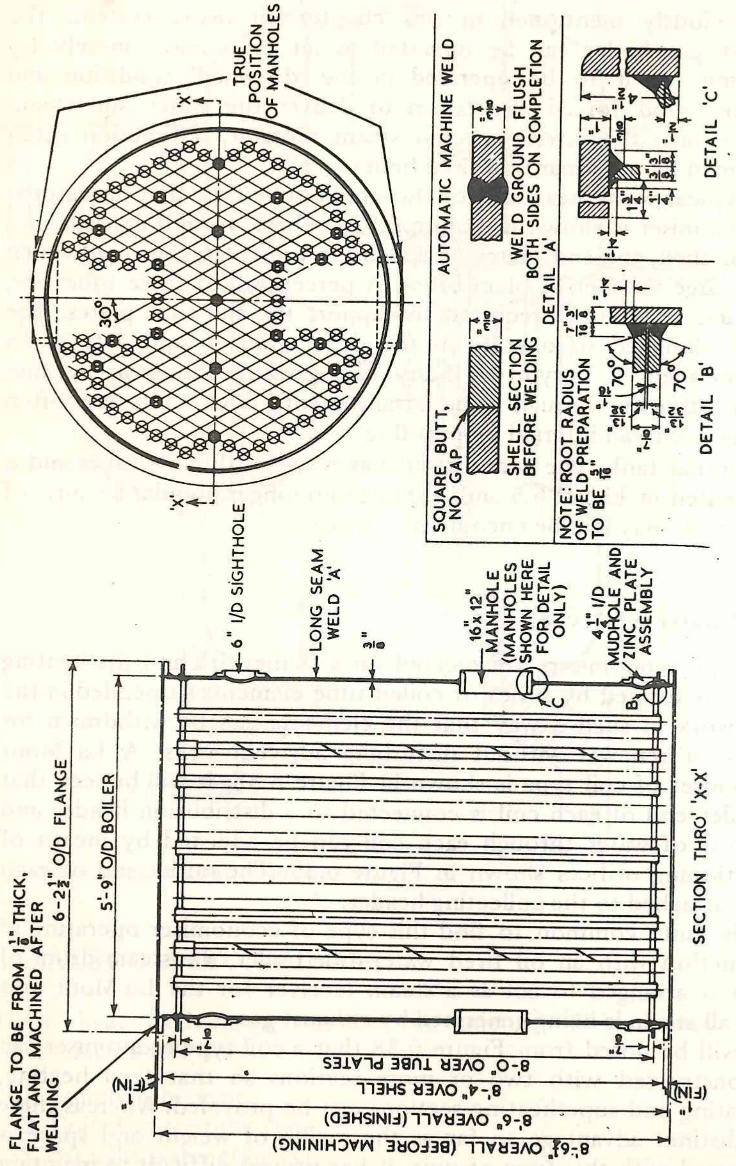


Figure 6.37 Spanner Swirlyflo exhaust gas heat exchanger

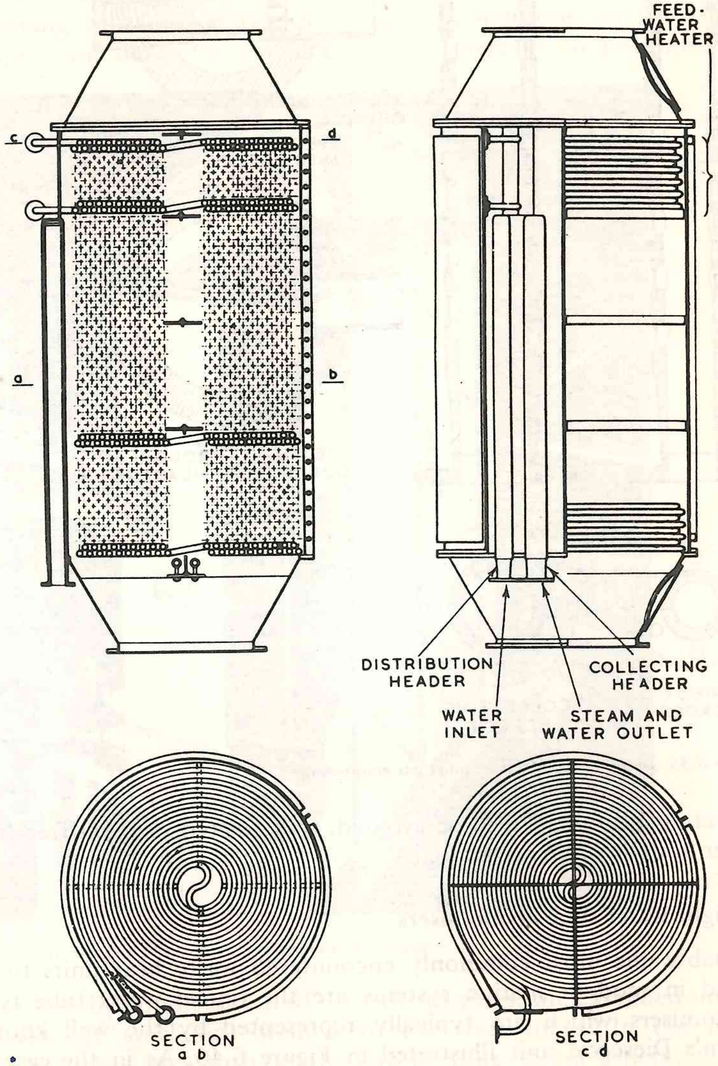


Figure 6.38 La Mont exhaust gas economiser

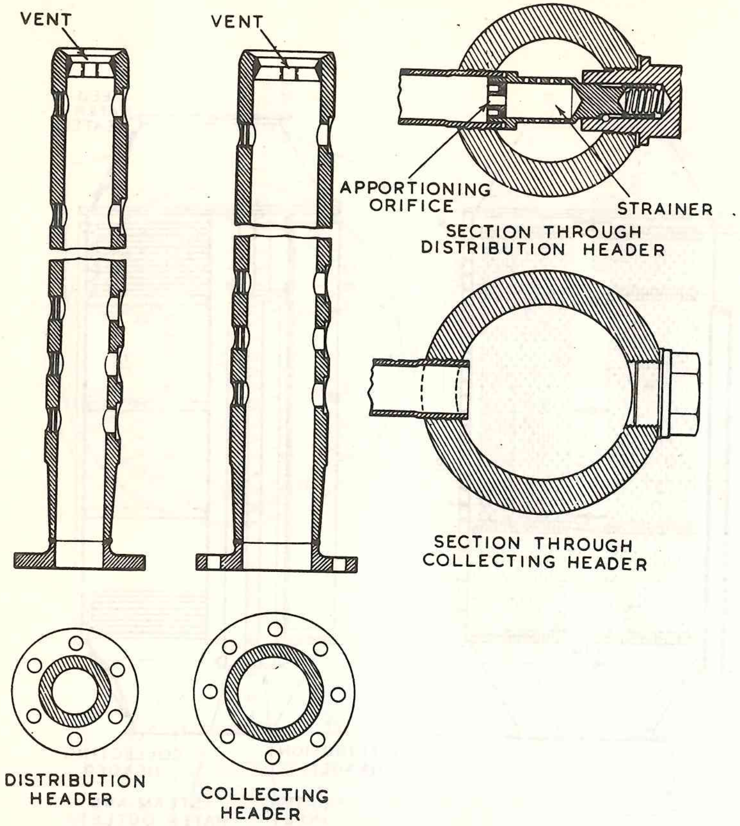


Figure 6.39 Detail of La Mont exhaust gas economiser

operating troubles are to be avoided, well treated, oxygen free feed water in the system is essential.

Straight water tube economisers

Probably the most commonly encountered waste heat units to be found in modern marine systems are the finned water tube type economisers which are typically represented by the well known Green's Diesecon unit illustrated in Figure 6.40. As in the case of the coil type, these units are constructed on a steel framework and may consist of a number of sections. Each section consists of a horizontal inlet and outlet header to which the tube elements are connected. Each element comprises a series of equal length straight

tubes connected to each other by 180° bends to form a sinuous element, see Figure 6.40.

To provide compact waste-heat units of low weight, extended surface tubes are used, this surface normally being steel or cast iron according to the operating temperature conditions. In the higher temperature zones of the unit, where there is no possibility of

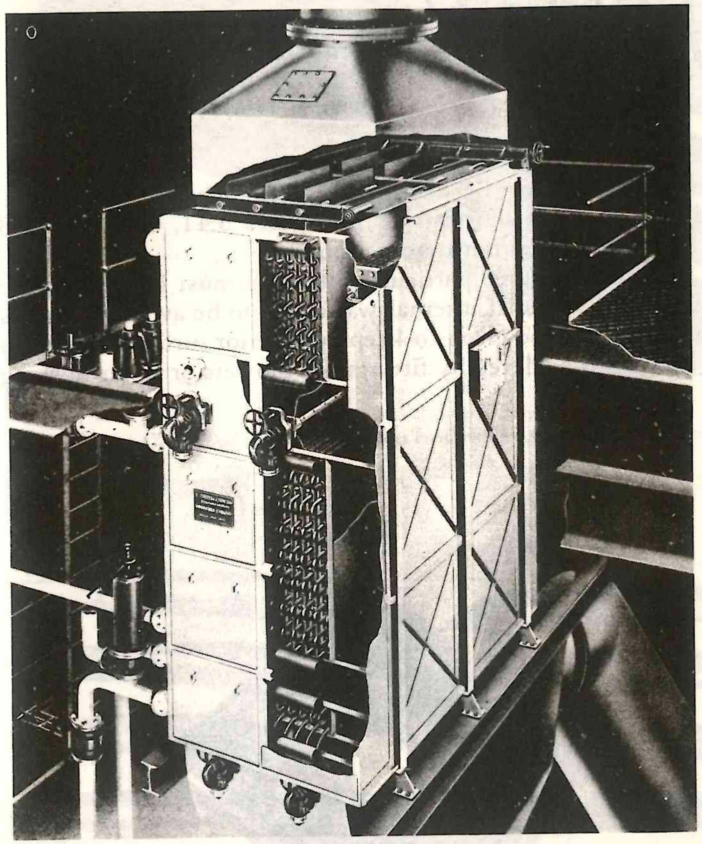


Figure 6.40 Green's Diesecon water tubes economiser

corrosion by condensation of the exhaust gases, the extended surface consists of steel fins welded to the steel tubes. In the lower temperature zones such as the low-pressure steam generating and feed-heating sections, the external surfaces may consist of cast-iron fins shrunk on to the tubes. The superheater section is normally constructed from plain steel tubes.

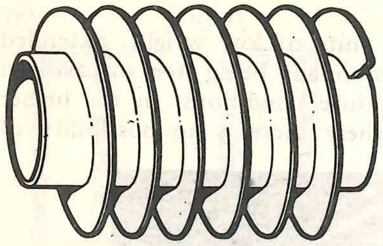


Figure 6.41 Showing helically wound fins welded to mild steel tube

Various means have been employed to achieve satisfactory extended surfaces. The illustrations in Figures 6.41, 6.42 and 6.43 showing arrangements currently to be found.

As in the coil-type unit particular attention must be paid to the purity of the feed water if internal wastage is to be avoided. No less attention should also be given to keeping exterior surfaces free from deposits and this is achieved by fitting soot blowers or water washing devices.

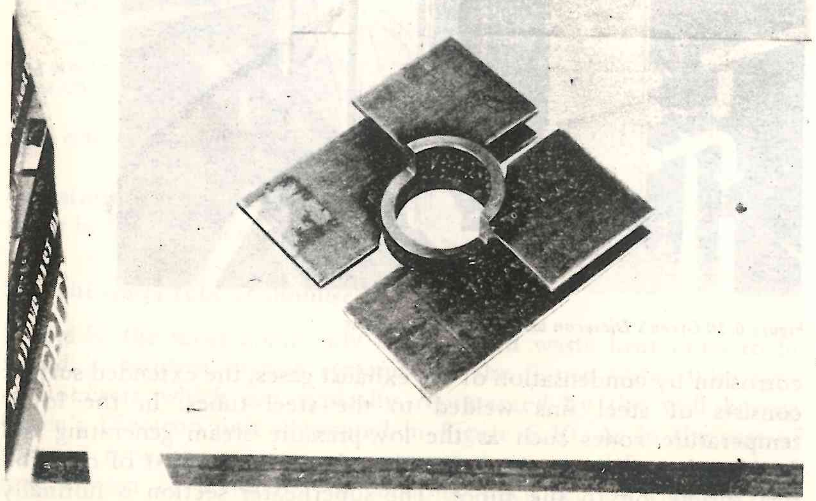


Figure 6.42(a) Section cut from 'finned' or 'gilled' economiser tube (Green's)

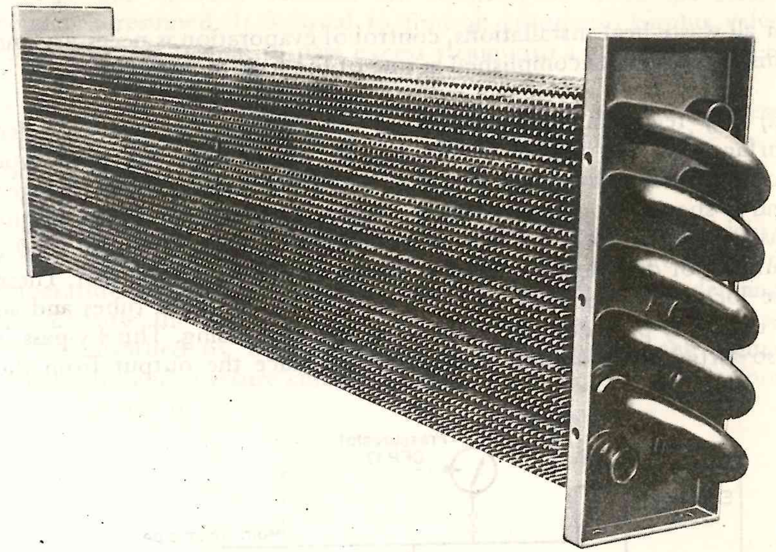


Figure 6.42(b) Element of Sunrod exhaust gas economiser (AB Svenska Maskinverken)

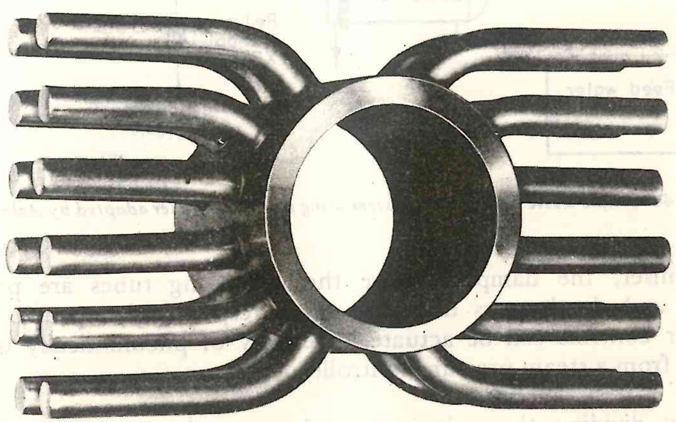


Figure 6.43 Section through tube of Sunrod economiser showing patent finned form (AB Svenska Maskinverken)

CONTROL OF EVAPORATION

In all waste-heat installations, control of evaporation is necessary and this is generally accomplished in one of the following ways:

(a) By regulating the amount of gas flowing over the extended surface, i.e. by damper regulation. In the case of the tank type composite or exhaust gas boiler or economiser this is easily arranged and is shown diagrammatically in Figure 6.29, 6.30 and 6.31. In the case of the water-tube type of economiser shown in Figure 6.40 a number of dampers are fitted at the gas outlet end of the unit. These are located on spindles disposed parallel to the gilled tubes and an external by-pass duct is included in the unit casing. This by-pass is also fitted with suitable dampers. To reduce the output from the

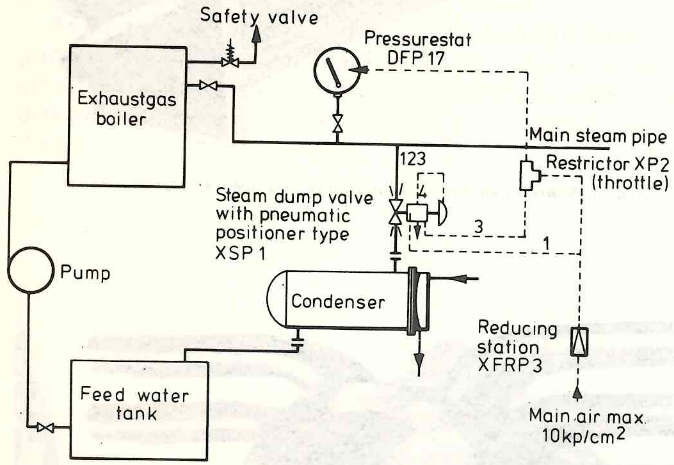


Figure 6.44 Simple waste heat control system using dump condenser adopted by Aalborg Vaerft

economiser, the dampers above the generating tubes are partly closed and the by-pass dampers are correspondingly opened. The damper controls can be actuated manually or pneumatically upon signals from a steam pressure controller.

(b) By dividing the unit into sections so that each section is controlled by an inlet valve which is penumatically operated and controlled automatically by means of signals from a step controller linked to a pressure controller. Thus, a constant steam pressure in the

steam receiver is achieved. When the steam demand falls, sections are cut out and similarly sections are reconnected when the steam demand is resumed. It is usual to find an automatic surplus valve included in this system to pass excess steam into a dump condenser.

(c) By far the most simple control method is that of passing excess steam through an automatic pressure controlled surplus valve to a dump condenser. This is shown diagrammatically in Figure 6.44.

(d) Less commonly encountered is a system designed for a higher pressure than that at which it is to operate. Here the pressure and temperature is allowed to rise in operation when the steam demand falls. Because the temperature of the exhaust gases is constant, less heat is absorbed by the steam and water mixture at the higher temperature and pressure conditions and the evaporation is therefore simply controlled.

7 Forced circulation boilers

The boilers mentioned so far rely on natural circulation for their successful operation; the speed of this circulation varying with the design and prevailing working conditions. A logical development of the natural-circulation boiler is one in which the circulation is made positive by means of a pump. These so-called forced-circulation boilers (more commonly used in land than marine installations) are generally acknowledged to have the following advantages over the natural-circulation type:

(a) saving in space and weight;
(b) shape can be varied to suit environment;
(c) suitable for high pressures and temperatures;
(d) circulation is positive and independent of firing conditions;
(e) not so sensitive to sudden changes in pressure and temperature.

There are three main classes of forced-circulation boiler:
1. Forced-water circulation;
2. Forced steam circulation;
3. 'Once-through' tubular boilers in which all the feed-water entering the boiler at the inlet end of the continuous tubes leaves the other end of these tubes in the form of superheated steam.

FORCED WATER CIRCULATION BOILERS

Typical of this class is the La Mont boiler. This has a normal steam drum, the water from which is forced by a circulating pump into various headers, and from these the flow is proportioned by orifices into the generating tubes. The sizes of the orifices are graded so that each tube receives the correct amount of water for its steam-generating capacity. The dimensioning of the orifices is so adjusted that at normal boiler load each tube receives eight times as much

water as steam generated in the tube. By this ratio, high velocities of the steam water mixture in the boiler tubes are ensured at all loads, so that overheating of the tubes is made impossible, even under the most severe conditions.

The La Mont boiler is not unorthodox but is simply a straightforward water tube boiler designed so that the water circulation is directly controlled. The nozzles or orifices in the tubes meter the correct amount of water from the circulating pump to each tube, ensuring ample cooling of the various tube banks under all conditions of load. The introduction of nozzles which must be kept clear, and a circulating pump which must always be kept running while the boiler is steaming, are additional possible sources of trouble, to set against the advantages obtained by having a positive high-velocity circulation through the boiler tubes.

With forced circulation it is claimed that, in addition to preventing overheated tubes, the formation of scale is lessened, the starting-up time from cold is shorter, expansion stresses throughout the boiler are less, due to the levelling out of the metal temperatures, and also as tube inclination does not affect the circulation, the design can be adjusted to suit varying environments.

La Mont boiler data

A typical diagrammatic arrangement of a La Mont boiler circulation is shown in Figure 7.1.

Evaporation normal full power	27 000 kg/hr
Working pressure superheater outlet	34.5 bar
Design pressure	38.6 bar
Steam temperature at stop valve	426.7°C
Feed-water temperature to economiser	154.4°C
Quantity of water circulated	163.000 kg/hr
Differential pressure	1.6 bar
Safety valve settings: Boiler drum	38.3 and 38.6 bar
Superheater	37.6 and 37.9 bar

Heating surfaces

Boiler	288 m^2
Superheater	144 m^2
Economiser	161.6 m^2
Air-heaters	623.8 m^2
Oil burners	5

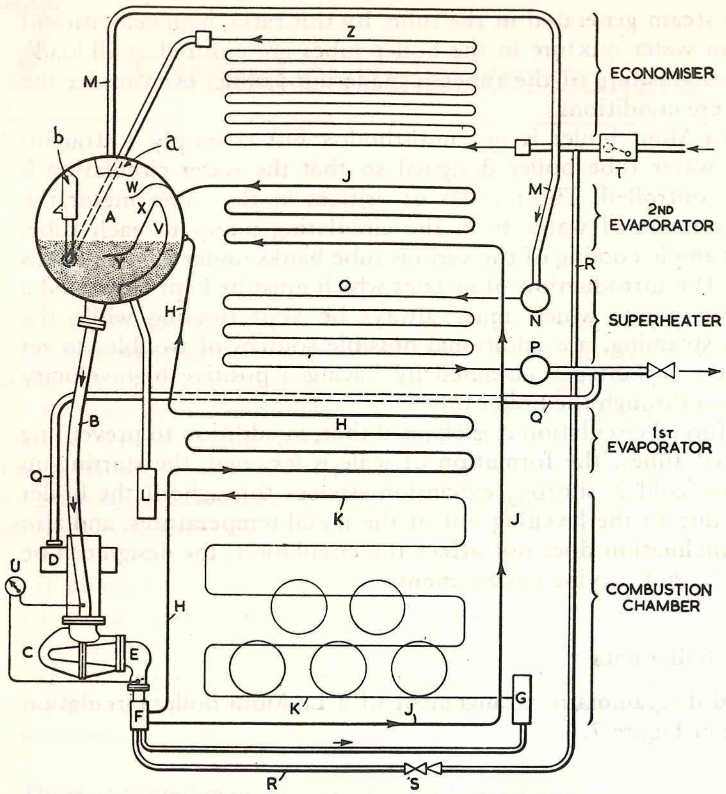


Figure 7.1 Diagrammatic arrangement of La Mont boiler circulation

- *A.* *Steam and water drum.*
- *B.* *Suction pipes.*
- *C.* *Circulating pump.*
- *D.* *Turbine.*
- *E.* *Breeches pipe.*
- *F.* *Main distribution header.*
- *G.* *Rear wall distributor header.*
- *H.* *1st evaporator tubes.*
- *J.* *2nd evaporator tubes.*
- *K.* *Rear wall tubes.*
- *L.* *Rear wall collector header.*
- *M.* *Saturated steam pipes.*
- *N.* *Superheater inlet header.*
- *O.* *Superheater tubes.*
- *P.* *Superheater outlet header.*
- *Q.* *Steam to circulating pump.*
- *R.* *Economiser recirculating pipe.*
- *S.* *Economiser recirculating valve.*
- *T.* *Feed regulator.*
- *U.* *Differential pressure gauge.*
- *V.* *Annulus baffle.*
- *W.* *Hood baffle*
- *X.* *Spill plate*
- *Y.* *Perforated baffle.*
- *Z.* *Economiser tubes.*
- *a.* *Steam take-off baffle.*
- *b.* *Feed boxes.*

In large oil-engined vessels, where a considerable quantity of low-pressure steam is required for ships' services, a double evaporation boiler system is sometimes employed. It is claimed that the units involved are less bulky than cylindrical or low-pressure water tube boilers. The arrangement is as shown in Figure 7.2. An oil-fired La

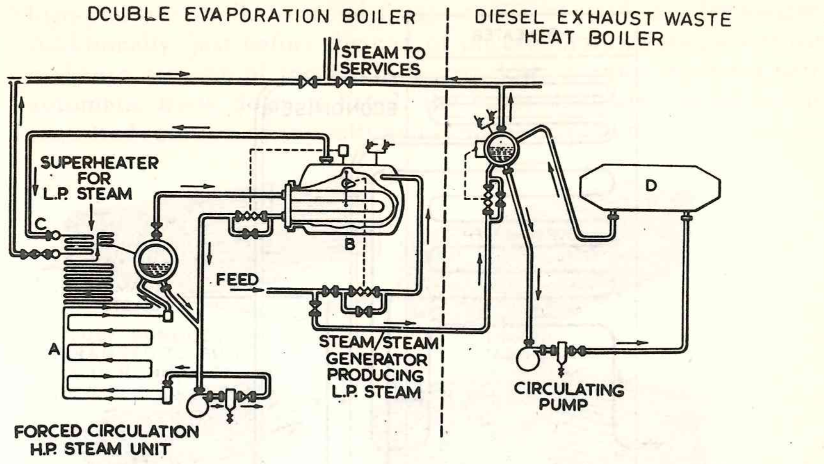


Figure 7.2 La Mont double evaporation generating system working in conjunction with an exhaust gas boiler

Mont forced-circulation boiler *A* operates in a closed circuit, the circuit passing through a steam/steam generator *B* in which low-pressure steam is produced. The low-pressure steam may be passed through a superheater *C* if required. As the high-pressure unit is operating in a closed circuit, internal deterioration of the tubes through feed-water contamination should not occur. Waste heat boilers *D* inserted in the oil engine exhaust trunkways (see Figures 6.38 and 6.40, Chapter 6) can be added, enabling the double evaporation unit to be shut down when the vessel is under way at sea.

FORCED-STEAM-CIRCULATION BOILER

In this class is the Loeffler boiler in which the circulating pump draws saturated steam from an evaporator drum, and forces it through radiant and convection superheaters, where it becomes highly superheated. A portion of this steam is led off into the steam mains for use, while the remainder takes one of two paths back into the evaporator drum. In the first path the steam is forced to pass through the water in the drum, giving up its superheat and producing further saturated steam for the circuit. The steam taking the second path passes into the drum above water-level, along with the feed-water from the economiser (see Figure 7.3).

In this unit the circulated steam in the tubes absorbs the heat of the furnace gases, not steam and water as in other types. On this

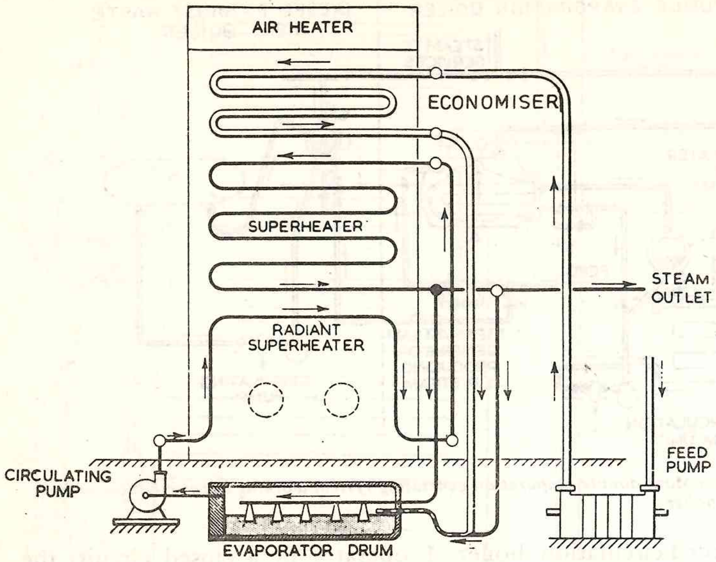


Figure 7.3 Diagrammatic arrangement of Loeffler boiler

account, and in view of the fact that the evaporator drum is outside the actual boiler, where it is not subjected to external heat, purity of feed-water is not of primary importance – any impurities in the feed are deposited in the evaporator. These boilers are designed for the production of steam at pressures of 127.5–131 bar and a temperature of 443–498°C, as in order to circulate steam at lower pressures and densities, in sufficient volume to keep the heat-transfer rate through the tube material at a safe figure, would require a circulating pump of unfavourable dimensions.

'ONCE THROUGH' BOILERS

The Sulzer 'Once through' boiler

The Sulzer 'Once through' boiler consists essentially of one long tube, or for high outputs several tubes in parallel (Figure 7.4). These tubes are coiled in distinct zones, and the working medium from the circulating pump is forced in succession through the preheating, evaporating and superheating zones. A deposit of scale in a boiler of this type would be most undesirable, both from the overheating and circulation-restriction points of view, and in common with other

high-pressure boilers, condensate only is used as feed-water. Additionally, just before the end of the evaporating zone, where the moisture content of the steam is very low, a water separator with automatic blow down is fitted, the water discharged being a concentrated solution of any salts which might be present.

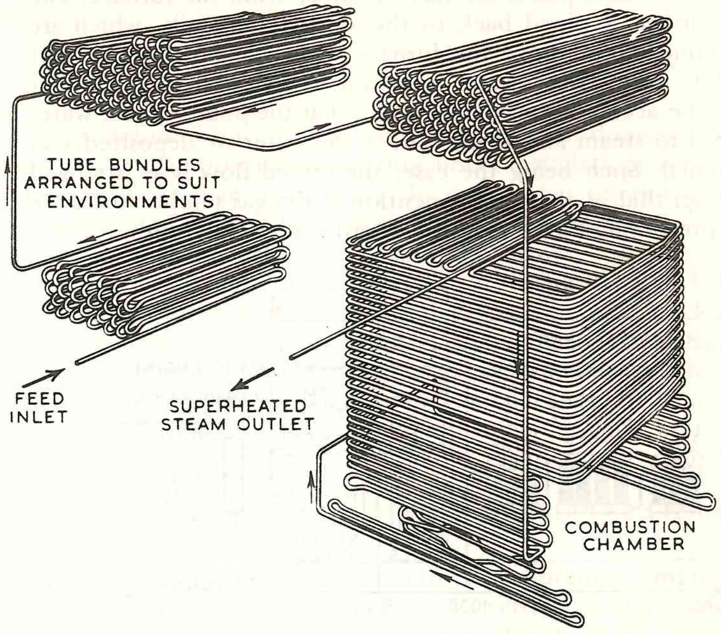


Figure 7.4 Tube system of Sulzer monotube boiler

The length of tubing per individual run, i.e., from water inlet to high superheated steam outlet, is in the region of 1 km, the boilers being constructed for all outputs from 22 700 to 249 500 kg of steam per hour at pressures ranging from 76-155 bar and temperatures of 448.9° to 521.1°C.

The Benson 'Once through' boiler

The Benson boiler, like the Sulzer, has no drum, but in this design the tubes are not in several individual long lengths from water inlet to superheated steam outlet. The different zones are made up of tubes and headers connected together in series by suitable piping.

The combustion chamber forming the first zone is surrounded on three sides, top and bottom, by units consisting of short headers and tubes, all connected in series, the outlet of one being connected to the inlet of the next. The tubes in the furnace zone are of molybdenum steel welded to the headers. Above the furnace are further headers and coils of tubing, over which the furnace gases pass, these being so placed that the coils, in which the transition stage from water to steam takes place, are farthest away from the furnace. The steam as formed is piped back to the superheater coils, which are situated immediately above the furnace. It is claimed that the heat transmission from gas to water or steam in any part of this boiler circuit can be accurately calculated, and that the points where water is converted to steam and where salts in the water are deposited, can be ascertained. Such being the case, the forced flow is so arranged in this design that at the points mentioned the gas temperatures are low, thus preventing the formation of hard scale in the tubes.

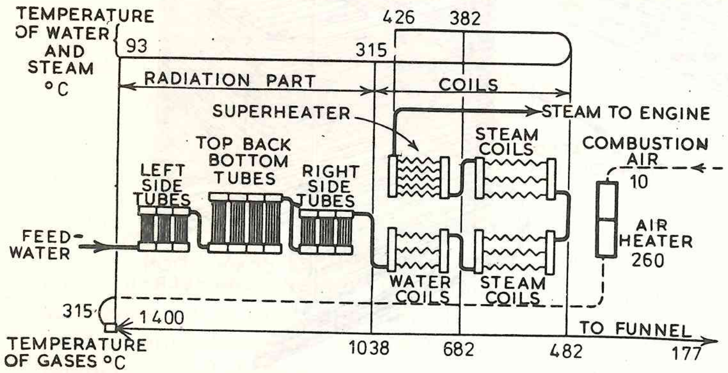


Figure 7.5 Benson boiler showing temperature and flow of feed water and steam, temperature and flow of air and combustion gases

The flow in this boiler is diagrammatically illustrated in Figure 7.5. It is possible to generate steam in this type at pressures up to 207 bar.

Obviously, in boilers of the 'once-through' type, where the working fluid content is so small, very accurate and sensitive control of the feed, combustion and steam temperatures is necessary for their successful operation. Also, this type is more suited to constant load than the rapidly fluctuating load conditions which can be experienced in marine installations.

The extra weight and expense of the drum boiler, whether natural or forced circulation, are justified, because its additional steam capacity results in superior performance of the machinery installation under manoeuvring conditions.

8 Low-pressure steam generators

The provision of low pressure saturated steam for domestic and other services in high-pressure water tube boiler installations and in motorships is effected in many ways. In motorships where it is an extra economy to extract heat from the exhaust gases at sea, a low-pressure boiler installation is usually the answer, the same boiler, or another working in conjunction with it, being used with oil-firing in port. In water tube boiler installations, where circumstances are somewhat different, desuperheaters and reducing valves have been commonly used. In modern high-pressure installations other means, such as low-pressure steam generators and packaged boilers, are being increasingly fitted.

LOW PRESSURE STEAM HEATED STEAM GENERATORS

These steam generators are in effect evaporators, and two basic designs are in general use, one having a vertical shell and the other a horizontal shell. Both designs are suitable for steam inlet pressures of up to 41 bar, and for a given surface the output is dependent on the saturated temperatures of the heating steam and the generated steam. Vertical generators are designed in general for shell pressures of up to 8.25 bar and outputs of up to 4500 kg/h, the heating surface comprising mild steel or copper coils arranged in layers. The coils are attached to the steam box by means of screwed couplings and each layer can be removed independently.

A typical arrangement is shown in Figure 8.1. This particular generator was designed to give an output of 2500 kg/h steam at a pressure of 7 bar., with a heating surface 14 m^2 when supplied with 380 kg/h saturated steam at a pressure of 16 bar.

Horizontal steam heated steam generators are made for shell pressures up to 12.5 bar with surfaces up to 150 m^2 and higher pressures and larger heating surfaces are sometimes used. The heating elements are U-tubes of copper, mild steel or cupro-nickel, depending on pressure conditions. The tubes are expanded into mild steel headers as shown in Figure 8.2, which shows a low-pressure steam generator having a surface of 74 m^2 and designed to give an output of 12 500 kg/h steam at a pressure of 10.5 bar when supplied with 15 500 kg/h of saturated steam at a pressure of 20.7 bar.

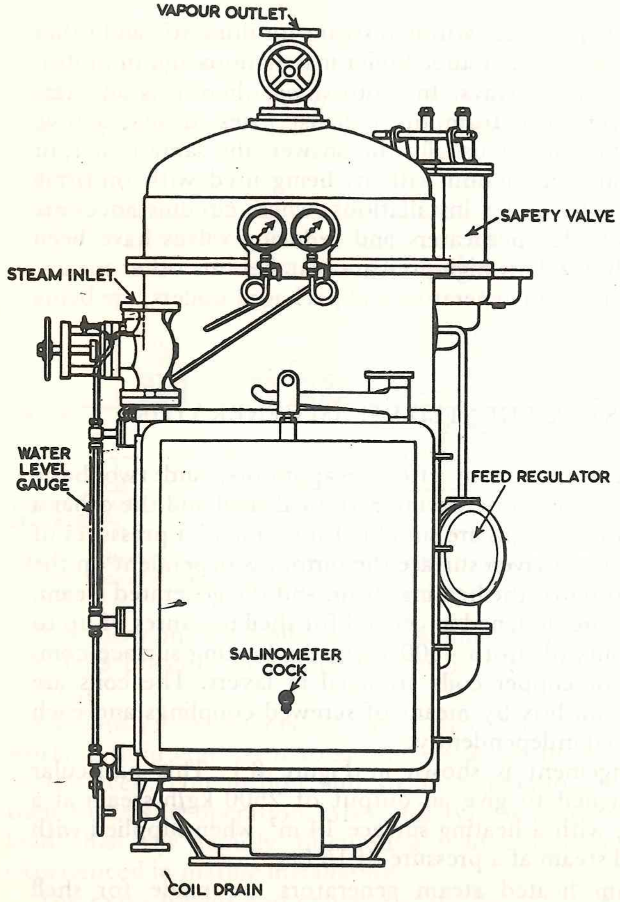


Figure 8.1(a) General view of typical vertical low pressure steam heated steam generator
Shell: 8 bar working pressure; 16 bar hydraulic test pressure
Steambox and coils: 16 bar working pressure; 32 bar hydraulic test pressure

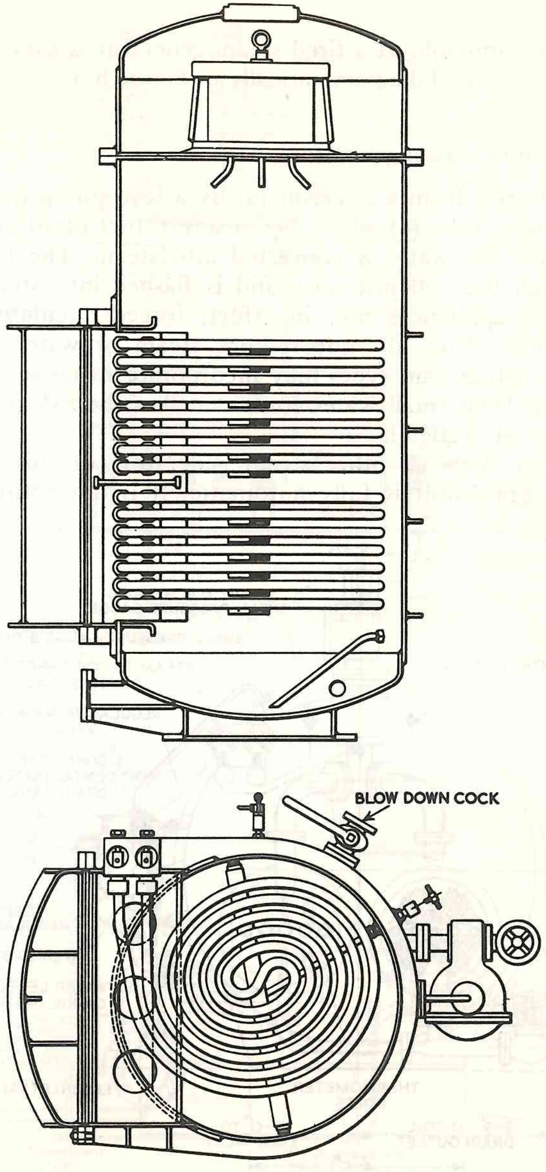


Figure 8.1(b) Vertical and longitudinal sections of typical vertical low pressure steam heated steam generator

FIRED STEAM GENERATORS

The operating principle of a fired steam generator is easy to understand and is illustrated diagrammatically in Figure 8.3.

Wanson 'Vaporax' steam generator

Water is delivered from a reservoir (a) by a feed pump (b) into the coiled generating tube (c) where, by means of fuel admitted through the burner (d) the water is converted into steam. The feed water passes through the coil just once and is flashed into steam in the process. Such appliances are, in effect, forced circulation, once-through boilers. They do not require steam or water drums or headers although certain types may incorporate steam separators or accumulators. Their small water content makes the risk of a serious explosion almost negligible.

In common with all other steam generators of this type, the Wanson 'Vaporax' unit is fully automatic. It is down fired and of

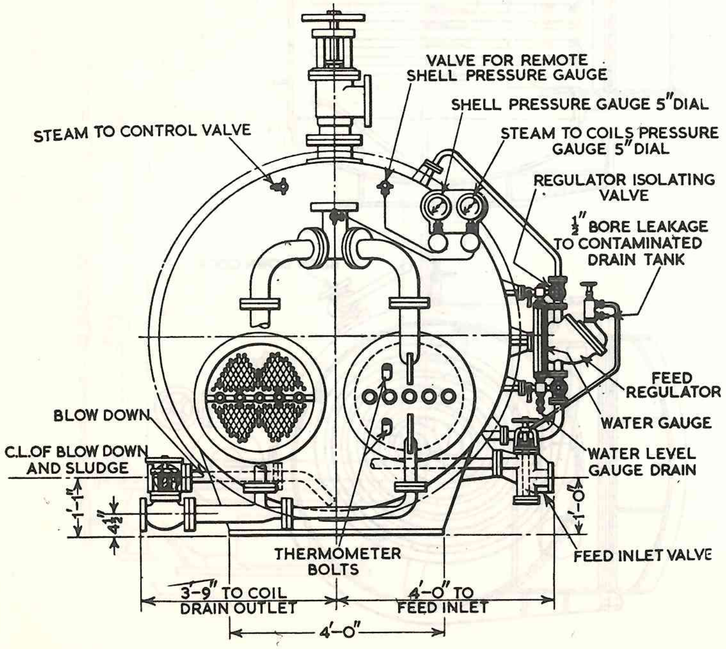


Figure 8.2(a) Arrangement of a typical horizontal low pressure steam/steam generator HP steam header and tubes: 20.7 bar working pressure; 41.5 bar hydraulic test pressure Shell: 10.35 bar working pressure; 20 bar hydraulic test pressure

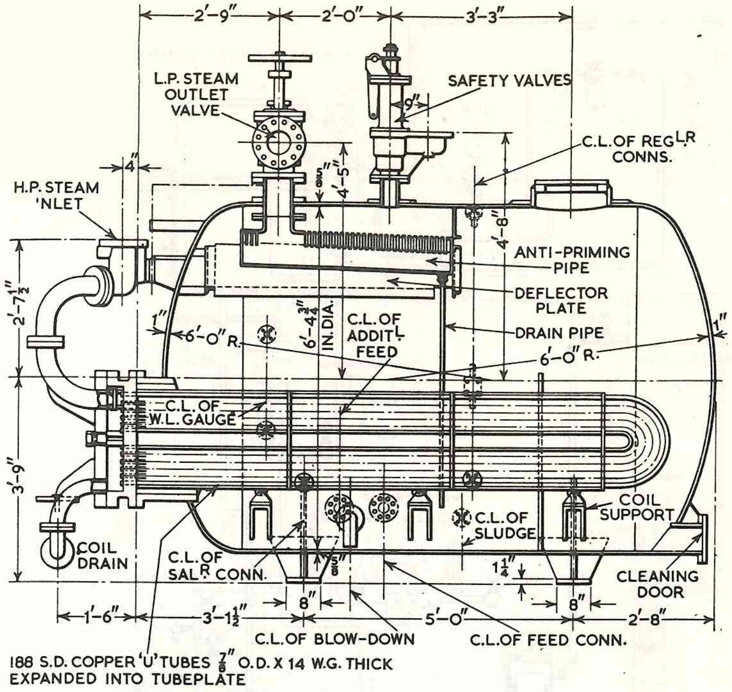


Figure 8.2(b) Longitudinal section of a horizontal low pressure steam/steam generator

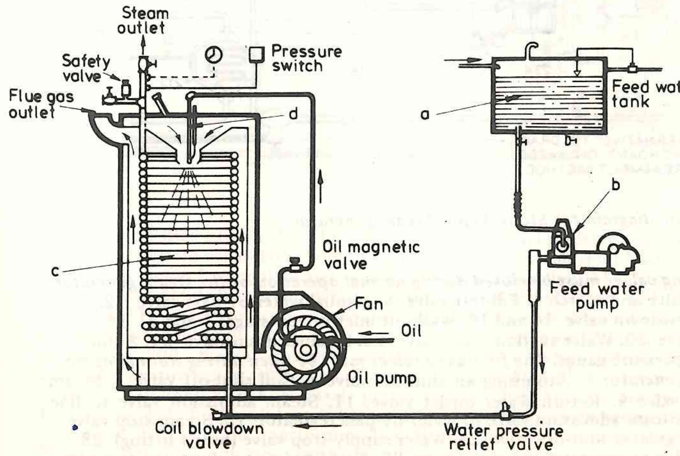


Figure 8.3 Wanson 'Vaporax' steam generator

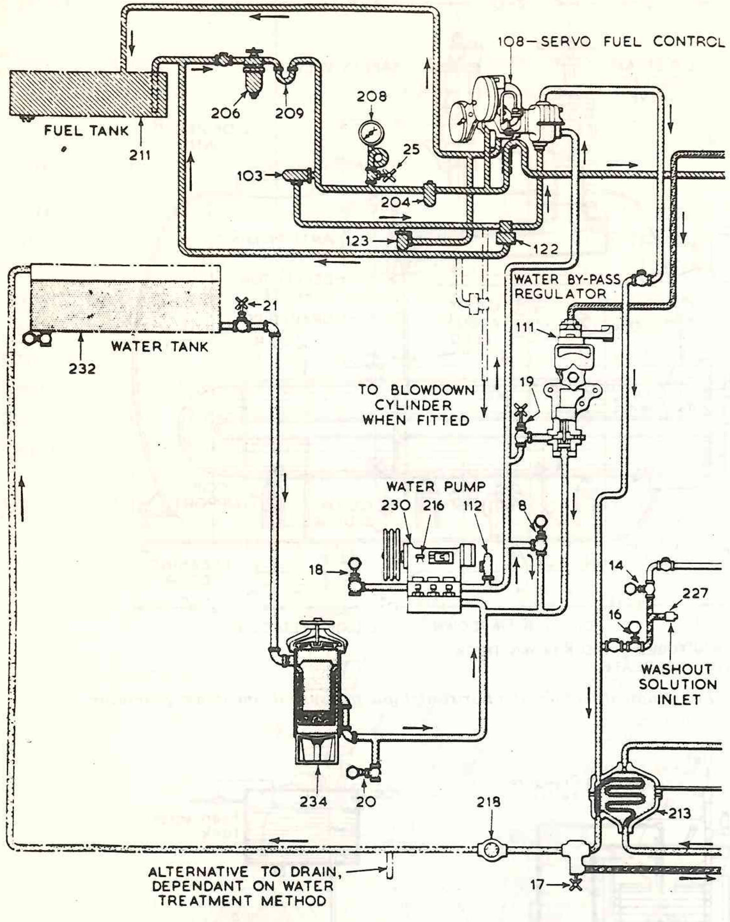
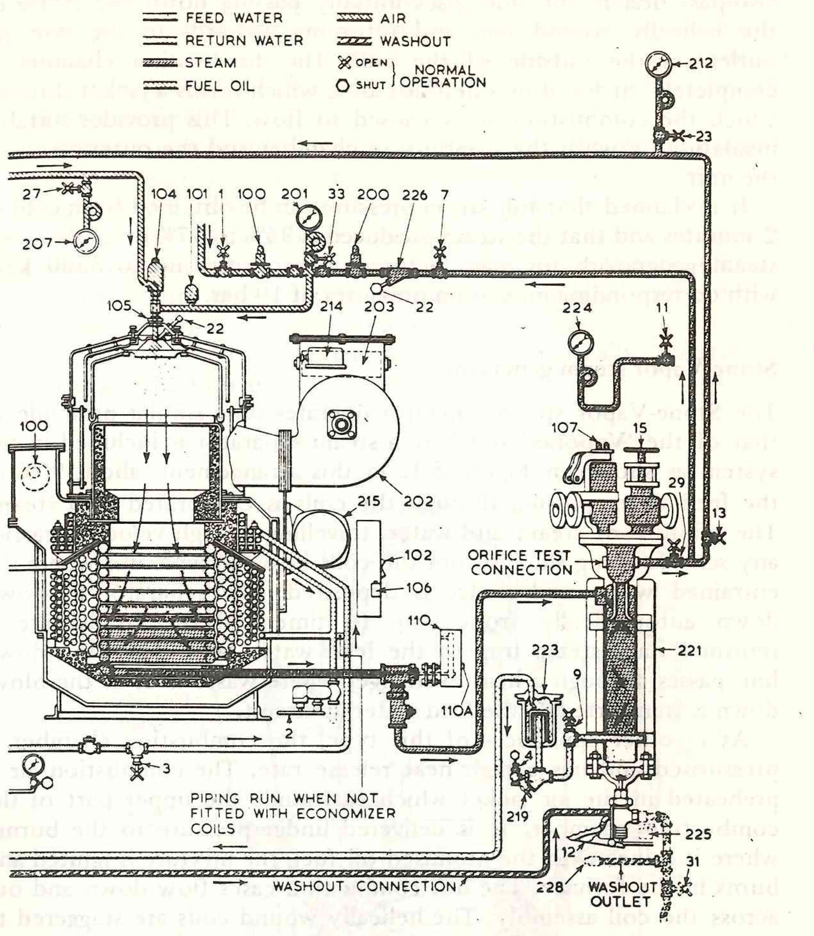


Figure 8.4 Schematic diagram for Stone-Vapor Steam generator

Key

Valves. *The following valves must be closed during normal operation of the steam generator* 2. Coil blowdown valve and switch 4. Fill-test valve 8. Manual water-by-pass valve 12. Steam separator blowdown valve 14 and 16. Washout inlet valves (stages 1 and 2) 18. Water pump test valve 20. Water suction drain valve 22. Strainer drain valve 24. Admission valve to water pressure gauge. *The following valves must be open during normal operation of the steam generator* 1. Atomising air shut-off valve 3. Coil shut-off valve 7. Steam atomising shut-off valve 9. Return water outlet valve. 11. Steam admission valve to line pressure gauge 13. Steam admission valve to water-by-pass regulator 15. Steam stop valve 19. Water by-pass regulator shut-off valve 21. Water supply stop valve (user's fitting) 23. Steam admission valve to generator pressure gauge 25. Fuel admission valve to system pressure gauge 27. Fuel admission valve to nozzle pressure gauge 29. Steam master valve to regulator and steam atomization 31. Blowdown shut-off valve (user's fitting) 33. Admission valve to atomizing pressure gauge. **Controls** 100. Atomising air pressure regulator 101.



Atomising pressure switch 102. Control switch 103. Fuel pressure regulator 150 lb/sq in. 104. Fuel solenoid valve 105. Fuel spray head 106. Overload reset button 107. Safety valves 108. Servo fuel control and switch 109. Stack switches 110. Steam temperature limit control 110A. Steam temperatures limit control reset button 111. Water by-pass regulator 112. Water pressure relief valve 122. Fuel by-pass solenoid valve (operated by steam temperature limit control) 123. Fuel pressure regulator 65 lb/sq in.

Accessories 200. Steam atomising pressure regulator (when fitted) 201. Atomising air or steam pressure gauge 202. Fan 203. Damper 204. Fuel filter (pressure line) 206. Fuel filter (suction line) 207. Fuel nozzle pressure gauge 208. Fuel system pressure gauge 209. Fuel pump 211. Fuel tank (user's fitting) 212. Generator steam pressure gauge 213. Heat exchanger 214. Ignition transformer 215. Motor 216. Oil filter tap (water pump) 218. Return water flow indicator transformer 219. Return water strainer 22. Electrode 221. Steam separator 223. Steam trap (return water line) 224. Line steam gauge 225. Operating cylinder for automatic blowdown (when fitted) 226. Steam atomizing strainer 227 and 228. Washout solution inlet and outlet 229. Water pressure gauge 230. Water pump 232. Water tank (user's fitting) 234 Water strainer.

two-pass design, the flue gases initially passing down the centre of the helically wound coil and returning upwards to the flue gas outlet on the outside of the coil. The combustion chamber is completely enclosed in a double casing which forms a jacket through which the combustion air is caused to flow. This provides suitable insulation between the combustion chamber and the outer casing of the unit.

It is claimed that full steam pressure can be obtained from cold in 2 minutes and that the steam produced is 95% to 97% dry. 'Vaporax' steam generators are manufactured in capacities up to 3500 kg/h with corresponding maximum pressures of 10 bar.

Stone-Vapor steam generator

The Stone-Vapor steam generator operates on a similar principle to that of the 'Vaporax' but here a steam separator is included in the system as shown in Figure 8.4. In this arrangement, about 90% of the feed water passing through the coils is evaporated into steam. The mixture of steam and water, travelling at high velocity, carries any scale-forming sludge from the coils into the separator where the entrained water and sludge is deposited. The separator is blown down automatically from time to time and the condensate is returned via a steam trap to the feed water tank. The blow-down line passes through a heat exchanger where waste heat in the blow-down is transferred to the feed water in circuit.

As in other appliances of this type, the combustion chamber is pressurised and has a high heat release rate. The combustion air is preheated in the air jacket which surrounds the upper part of the combustion chamber. It is delivered under pressure to the burner where it mixes with the atomised oil fuel, the mixture is ignited and burns in the furnace. The hot combustion gases flow down and out across the coil assembly. The helically wound coils are staggered to present maximum surface to the gas flow. A single electric motor drives the water pump, fuel pump and forced draught fan – full steam output being developed after 3 to 4 minutes operation.

Where compressed air is used to atomize the fuel, a separate electric motor is fitted to drive the hydrovane compressor.

Proportioning flow controls regulate the admission of water, fuel and combustion air in accordance with steam demands. A water by-pass regulator controls steam-output pressure by regulating admission of feed water into the coils. This device is actuated by steam pressure to by-pass varying amounts of feed water back to the pump suction, thereby causing a corresponding variation of feed

water flow to the coils. The volume of this feed-water flow, in its turn, governs the amount of fuel and air supplied to the burner – through the servo-fuel control, which automatically adjusts the admission rate of the fuel and air in direct proportion to the rate of feed water flow.

The servo-fuel control protects the boiler, in the event of failure of the water supply, by shutting down the unit if the water flow should drop below a pre-determined minimum. A temperature limit control protects the coils against abnormally high steam temperatures (operation with low water flow or maladjusted flame). Flame and ignition failure protection is provided by means of a photo electric cell which passes its signal to a programmer system. In conjunction with this the programmer system automatically controls each starting, operation and shut-down period.

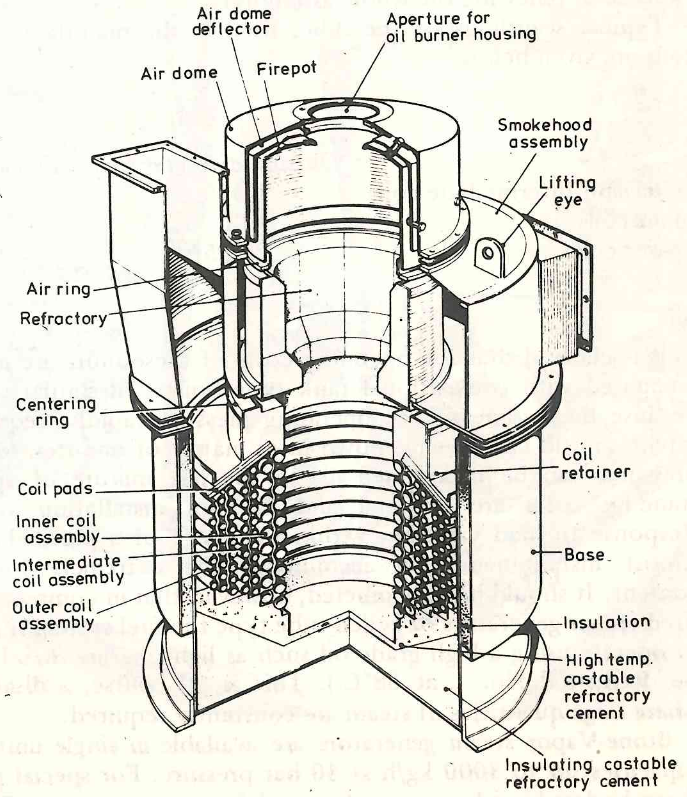


Figure 8.5 Cut-away view of Model 7217 Stone-Vapor steam generator showing coil assembly

The main pressure component of a Stone-Vapor steam generator is the coil assembly which is shown in Figure 8.5. This may consist of as many as four separate helically wound steel coils manufactured from 20 ft lengths of electric resistance welded tube. The lengths are butt welded together in an automatic welding machine until the desired length of each coil is obtained. Specially developed machines are used to cold form the long lengths of tube into the various sized coils. These coils are subsequently connected by means of conventional screwed or flanged couplings to produce the complete coil assembly. The couplings are located outside the casings of the units as any such connections could not be accommodated within the combustion chamber without causing serious problems due to local overheating. This construction makes it possible for sections of coil assemblies to be renewed easily and without incurring the expense of renewing the whole assembly.

Typical scantlings of the tubes used in the manufacture of the coils are given below:

	Outside diameter (in)	*Thickness (in)*
Outer and Intermediate coils	1.315	0.135
Inner coils	1.66	0.15
Lower coils	2.125	0.15

It is claimed that the operating costs of these units are low when compared with conventional tank type boilers of similar capacities because they come to full operating pressure rapidly, require little attention and can be shut down in a matter of minutes. Maximum pressures can be maintained up to the last minute of operation, stand-by costs are minimal and cost of installation very low. Response to load variation within the range of a particular unit is almost instantaneous on account of the extremely low water content. It should be remembered, however, that in common with all fired steam generators of coiled tube type the fuel system is designed to operate using a high grade oil such as light marine diesel (35–45 sec Redwood No. 1 at 38°C.). This is, of course, a disadvantage where large quantities of steam are constantly required.

Stone-Vapor steam generators are available in single units having capacities up to 3000 kg/h at 40 bar pressure. For special purposes these boilers have been manufactured for pressures up to 79 bar. A typical Stone-Vapor steam generator is shown in Figure 8.6.

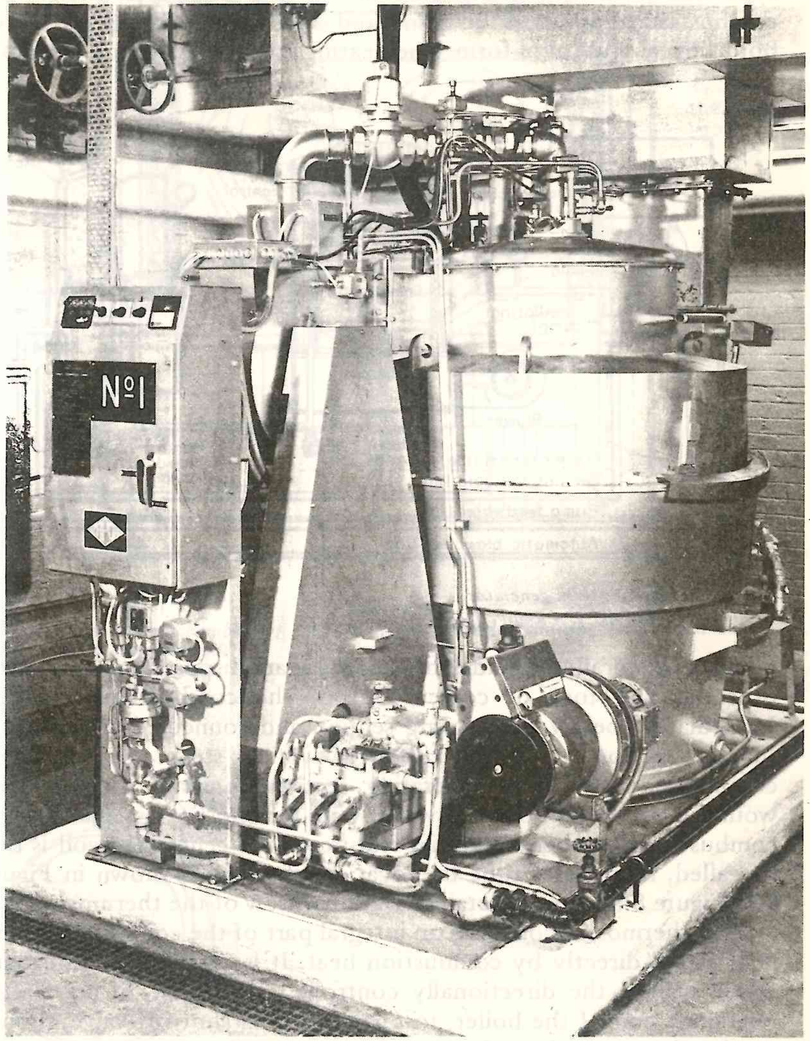


Figure 8.6 Model 7245 Stone-Vapor steam generator

Clayton steam generator

The Clayton steam generator is another well known appliance of this type and is illustrated in Figure 8.7. In this single pass design, the combustion chamber is bottom fired and the pressure coils are of both helical and spiral form. The heating section of the coil assembly

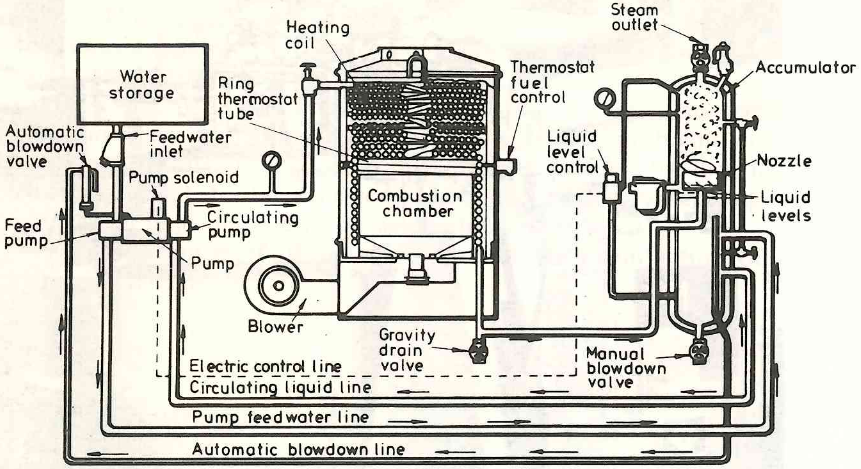


Figure 8.7 Clayton steam generator
This consists basically of a pump, a coil and a burner

consists of spirally wound tubes and they are disposed one above the other at the top, or cooler, end of the combustion chamber. Immediately below the heating section and connected in series is a further section of spiral tubes in which steam generation is commenced. The final generating section consists of a helically wound coil which forms a water wall for the hottest part of the combustion chamber. A special feature of the generating coil is the, so called, thermostat tube the location of which is shown in Figure 8.8. Figure 8.9 shows a detailed sectional view of the thermostat.

This thermostat control is an integral part of the coil assembly and is actuated directly by combustion heat. It is, in effect, a safeguard which utilises the directionally controlled expansion, of one partly restrained coil of the boiler, to operate a fuel shut off valve, should overheating occur through water shortage or other reason.

It should be noted that, unlike the Stone-Vapor generator, the Clayton makes use of two water pumps. The feed water pump, actuated by a liquid level control, maintains a constant water level in the steam receiver or accumulator where the steam is liberated,

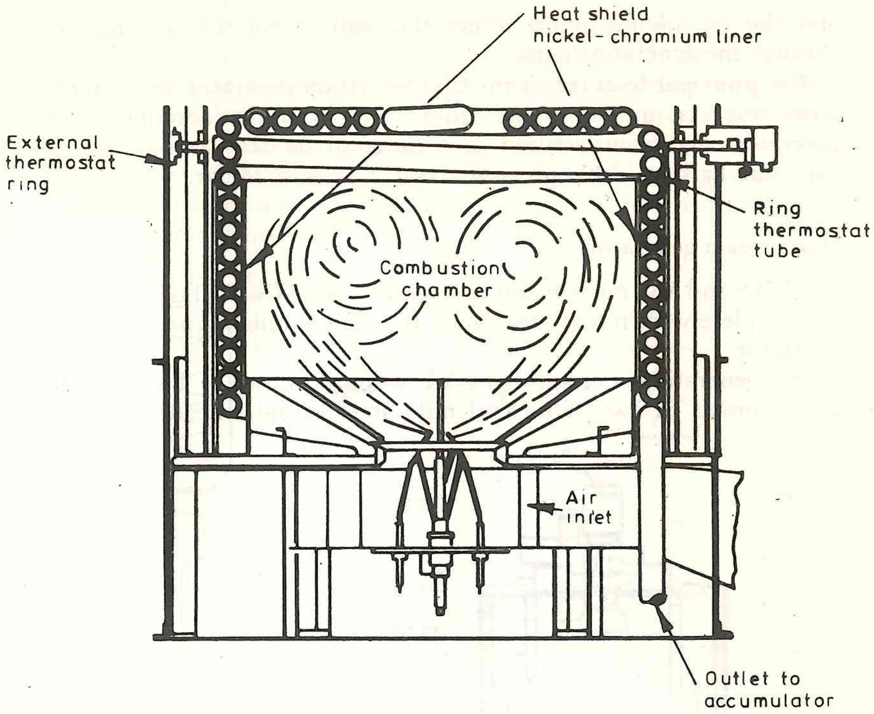


Figure 8.8 Combustion chamber of Clayton steam generator showing heat shield and location of ring thermostat tube

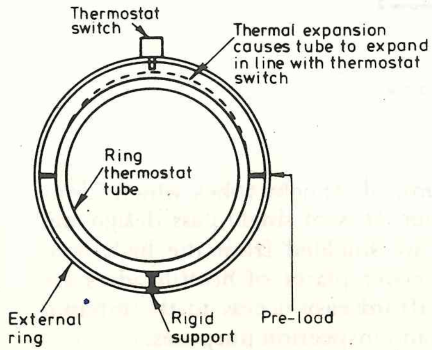


Figure 8.9 Clayton steam generator ring thermostat tube

and the circulating pump forces the water from the accumulator through the generating coils.

The principal features of the Clayton steam generator are, in most other respects, similar to the other units previously described. The generators are manufactured in a range of models having outputs from 259 kg/h at 11 bar pressure to 4675 kg/h at 28 bar.

Miura steam generators

The VWS and VW range manufactured by Miura Co. Ltd of Japan are of completely different design to the coiled tube type of steam generator.

The generating section of the VWS unit is shown in Figure 8.10. This consists of two fabricated mild steel toroidal headers of box

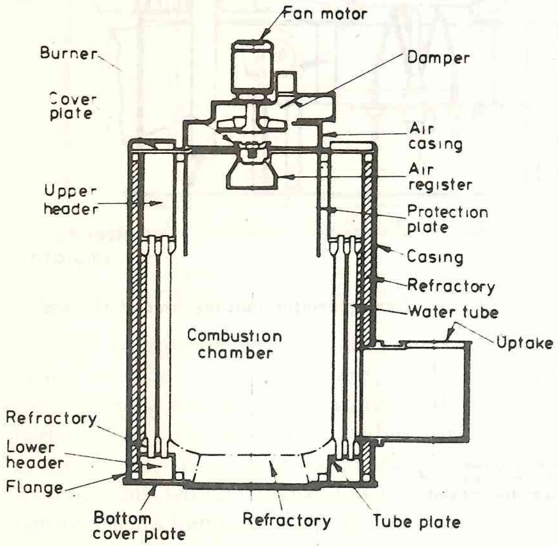


Figure 8.10 The Miura VWS generator

section connected together by a bank of straight tubes which forms the walls of the combustion chamber. It is of single pass design and the inner surfaces of the headers are shielded from the high temperatures within the furnace. The cover plates of both headers are secured by bolted connections to afford easy access to the internal surfaces of the headers for cleaning and inspection purposes.

A typical flow diagram for this type of steam generator is shown in Figure 8.11. The exhaust gas economiser shown in the diagram is

not an integral part of this unit but it illustrates the versatility of the appliance when fitted in a marine installation. It should also be made clear that neither the oil fuel settling tanks nor the hot well form part of the unit as supplied by the manufacturers. It is merely an indication that the manufacturers feel so strongly about the importance of feed water treatment that they have made the chemical dosage tank and the make-up feed water treatment plant integral with the unit.

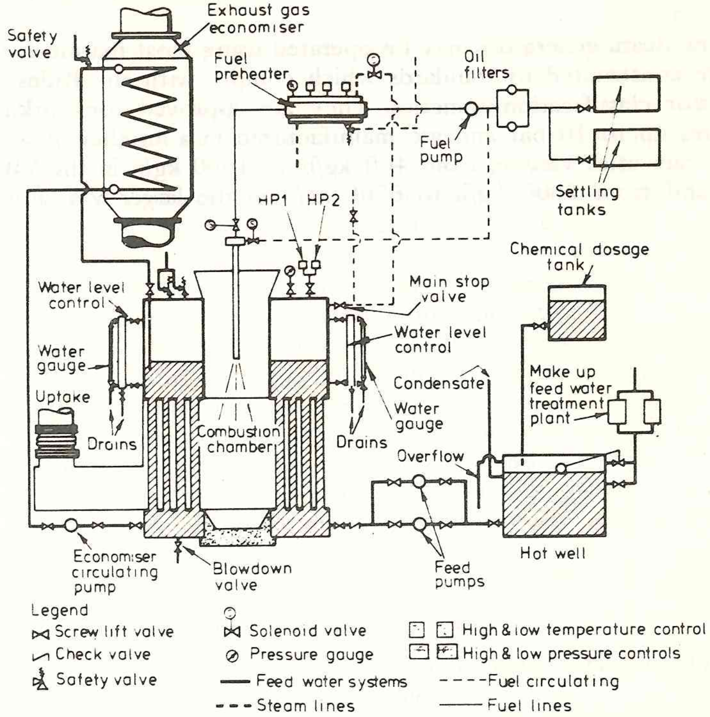


Figure 8.11 Miura VWS steam generator flow diagram

Duplicate automatic feed water controllers are provided situated adjacent to the usual mandatory water gauges. These controllers are electrically connected to the feed pumps and thus maintain a constant water level in the boiler. In the event of an excessively low water situation the fuel supply to the burner is cut off and audible and visual alarms activated.

High and low pressure controllers regulate the flow of oil to the burner by means of the solenoid valves on the burner manifold. The temperature of the oil is kept constant by means of temperature controls situated on the fuel preheaters which regulate the valve supplying steam to this appliance. The pressure in the fuel line is also controlled automatically. The unit is programmed for automatic purging of the combustion chamber by means of the forced draught fan and in common with all automatic or semi-automatic installations, a flame failure device is provided. Another important safety feature is the provision of a high flue gas temperature cut out which forms an additional safeguard in the event of a low water condition.

Miura steam generators may be operated using most marine fuels and are constructed to standards which comply with the Rules of the major classification societies. They are approved for working pressures up to 10 bar and are manufactured in a number of sizes having capacities varying from 400 kg/h to 1600 kg/h in the VWS range and from 2000 kg/h to 6700 kg/h in the larger VW series.

9 Superheaters and economisers

Superheaters for either water tube or tank type boilers can be divided into two classes, convection and radiant. In the former the tubes or elements are heated by the convection currents of gases passing over them, and in the latter they are heated by direct radiation from flame, hot brickwork or, in the case of coal firing, the fuel bed.

The advantages of superheated steam over saturated steam can most readily be understood when it is pointed out that superheated steam has a greater volume and contains more heat units, for a given weight, than saturated steam at any given pressure; on this account it can be made to do more work more efficiently.

Superheating reduces the loss of efficiency through condensation in reciprocating engine cylinders and, in the case of turbines, reduces frictional losses and erosion, due to condensation, in the blading.

The superheat temperature usually employed in conjunction with steam reciprocating engines is between 288°C and 343°C whereas in the case of turbines, 454.4°C is commonly used. A number of marine turbine installations are operating with steam at 510°C and several at over 537°C.

Types of superheater

The design and arrangement of a superheater vary according to the type of boiler in which it is installed.

In the case of Scotch boilers the superheater has been developed in various forms, all of which have had to accommodate themselves to an already well-tried and thoroughly established design of boiler. Modern water tube boilers, however, are designed with the superheater placed in the most suitable position for the temperature required, and form an integral part of the complete unit.

Scotch-boiler superheaters

Superheaters normally employed in conjunction with Scotch boilers are of two types, smoke tube and combustion chamber. In both, solid cold drawn steel tube elements are used, the increase in steam temperature obtainable with the first-mentioned type being about 93°C, and with the latter, about 176°C.

Smoke-tube superheaters

A smoke-tube superheater is illustrated in Figure 9.1. It consists of a series of elements inserted in the smoke tubes, the ends of which are connected to inlet and outlet headers in the smokeboxes. The diameter of the tubing used for the elements varies according to the bore of the smoke tubes, so that ample passage is left in these tubes

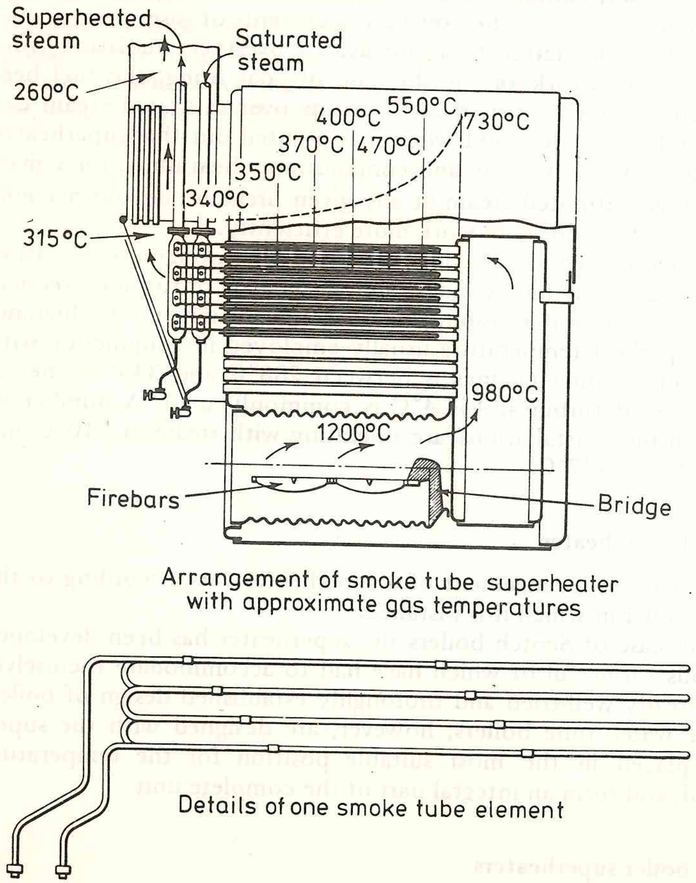


Figure 9.1 Smoke tube superheater

for the gases. The position of the return bends of the elements in the smoke tubes determines the degree of superheat obtainable; it is usual, however, to keep these bends at a sufficient distance from the ends of the tubes to allow an expander to be used in the back ends without the necessity of withdrawing the elements.

The headers are either of cast steel or are pressed-steel forgings of rectangular section, the top flange being screwed on and expanded to the header neck. The bottom of each header is fitted with studded door attached by steel studs. A drain valve is located in the centre of the door.

The elements themselves, with their return bends, are the vital part of the superheater, and their construction is a highly specialised process. The usual methods of construction are either to acetylene weld a forged return-bend cap on to the two tube ends or to machine forge the two tube ends to form an integral bend. The various forging operations for this latter method of construction are illustrated in Figure 9.2.

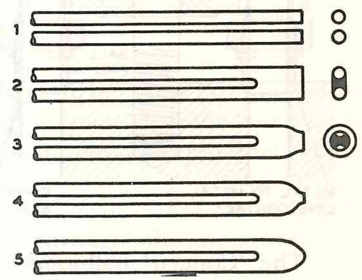


Figure 9.2 Forging operations for superheater elements

The terminal ends of the elements are expanded into steel collars, the bores of which are grooved so that during the expanding operation the tube flows into the groove, thus giving additional security against pulling out. The elements are attached to the headers by means of studs and dogs. Each stud and dog clamps two of the

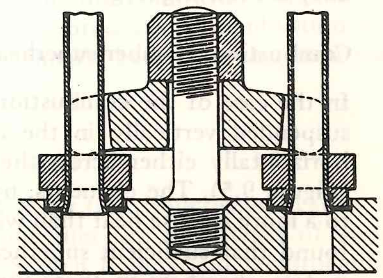


Figure 9.3 Detail of element to header joint

steel-collared ends into the machined recesses of the headers, the joint being sealed by a copper-asbestos ring (see Figure 9.3).

'Concen' ball joint

An improved type of element-to-header connection made use of a ball-type joint, known as the 'Concen'. This connection is suitable for high pressures and, apart from many non-marine applications, was extensively used in superheaters for marine water tube boilers, a typical example was the C.P.S. 'Beaver' class vessels which operated at 58–62 bar pressure and 454°C steam temperature.

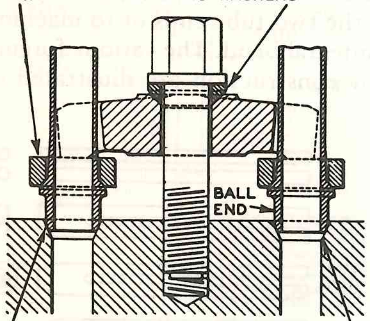


Figure 9.4 'Concen' ball joints with tap bolt attachment

The 'Concen' ball-joint connection is illustrated in Figure 9.4. The ball end is formed integrally with the superheater tube by an upsetting process, and is subsequently machined and ground to correct form. The ball ends made a metal-to-metal line contact with the conical seatings in the headers, into which they are clamped in pairs, by dogs and centre bolts, in a similar manner to those previously described. A feature of these connections is the fact that they are self-aligning.

Combustion chamber superheaters

In the case of the combustion chamber superheater the elements are suspended vertically in the chambers, and the headers are placed horizontally either across the front or across the back of the boiler (Figure 9.5). The elements, by virtue of their position, are subjected to a more intense heat than with the smoke tube type, and it has been found that sufficient superheat can be obtained by fitting elements in two chambers in three furnace boilers, and in three chambers in

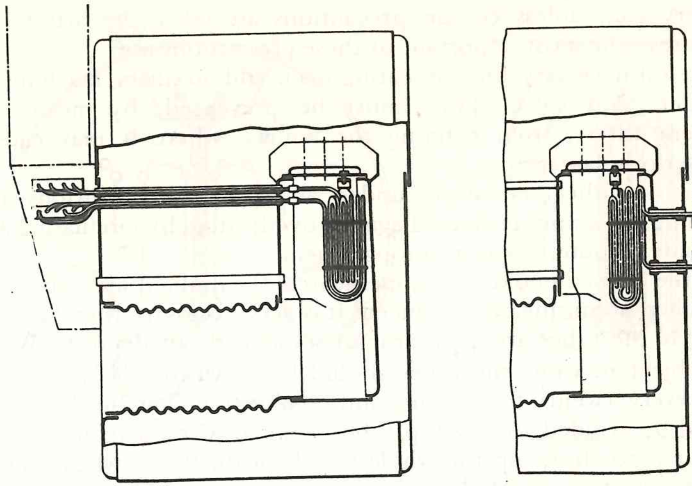


Figure 9.5 Combustion chamber superheaters (left) headers in smokebox (right) headers on back

four furnace boilers, thus leaving one furnace clear for the raising of steam. The design of the elements is such that the inlet steam passes through the tubes subjected to the most intense heat, and in view of the situation of the elements it is even more important with this type, than with the smoke-tube type, that an adequate circulation of steam be maintained through the superheater to prevent damage by overheating.

The elements are connected by screwed ball-ended union joints to communicating pipes which lead to the headers. When the headers are in the smokebox these communicating pipes pass through smoke tubes, and when the headers are across the boiler back, the communicating pipes are led through tubes fitted between the combustion chamber and boiler back end-plate (see Figure 9.5). Heat-resisting steel baffles are fitted in the combustion chambers, above the furnace throats, so that the products of combustion are directed through the superheater elements before passing into the smoke tubes.

Precautions for Scotch boiler superheaters

Before passing on to the subject of water tube boiler superheaters, it is considered advisable to point out that the advantages of using superheaters in conjunction with Scotch boilers and reciprocating machinery can, unless certain precautions are taken, be offset by other losses. The most important of these precautions are:

1. The oil necessary for lubricating main and auxiliary machinery cylinders and valve chests must be prevented, by means of efficient filters, from entering the boilers, where it may cause very serious damage.
2. The superheaters must, under all and any conditions of steaming, be amply protected against overheating by circulating an adequate amount of steam through them.
3. In the case of smoke-tube superheaters the draught area through the tubes is considerably reduced. It is very necessary therefore to see that the tubes are kept clear of sooty and salt deposits. With this object in view, the tubes should be blown regularly at least once every twenty-four hours, and combustion-chamber leakages should be avoided. A few top tubes leaking, where expanded, are sufficient to choke up the whole nest beneath them, when superheater elements are fitted.
4. 'Carryover' (entrained moisture and associated solids passing from a boiler with the steam) should be avoided. 'Carryover' deposits solids in superheater elements and headers, and can be caused by carrying too high a water-level, having too high a dissolved and suspended solids content or through the presence of oil in the boiler.

Desuperheaters

Regarding the second precaution mentioned above, it is considered advisable to point out that, in port, when perhaps only a few auxiliaries are running on superheated steam, this steam may only be a small fraction of the steam being generated. Such being the case, it is possible that the superheater elements may become overheated through lack of circulation through them of an adequate amount of steam. One remedy is to mix as much superheated steam into the wet steam line as possible; unfortunately, when this is done to any great extent, cylinder lubrication in the auxiliaries becomes essential, and this can be, and often, is the cause of the presence of oil in the boilers.

Another remedy is the fitting of desuperheaters. When these are fitted *all* the steam generated by a boiler is passed through its superheater, any steam required for saturated services being obtained by passing the required amount of the superheated steam back through the boiler in the solid drawn-steel coils of the desuperheater.

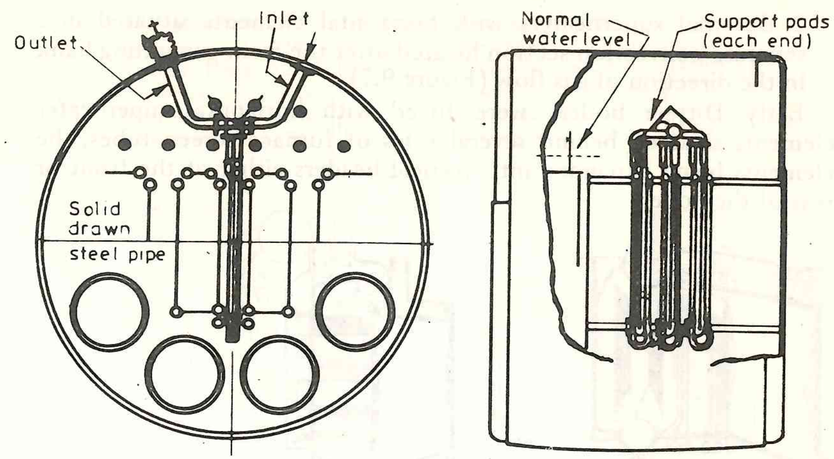


Figure 9.6 Coil-type desuperheater used in connection with Scotch or Howden-Johnson boilers

The desuperheaters used in connection with Scotch or Howden-Johnson boilers consist of solid drawn-steel pipe elements suspended from inlet and outlet headers clamped inside the boiler to the upper main longitudinal stays. The elements hang vertically in the wide water spaces between the tube nests, and the headers are connected by pipes to the inlet and outlet valves from the boiler shell (see Figure 9.6).

Relief valves

Smoke-tube and combustion-chamber superheaters are always fitted with relief valves. These are fitted to relieve the pressure in the event of the fires being set away, with superheater drain valves and steam 'to' and 'from' superheater valves shut. It is normal practice for these relief valves to be adjusted to lift slightly in excess of the boiler working pressure. (For water tube boilers, see Chapter 16).

WATER TUBE BOILER SUPERHEATERS

Superheaters, as fitted to present day water tube boilers, are of two distinct types:

1. Integral superheater with vertical elements sandwiched between furnace screen tubes and boiler main bank tubes (Figure 9.7);

2. External superheaters with horizontal elements situated in a separate convection section located after the main generating bank in the direction of gas flow (Figure 9.7).

Early D-type boilers were fitted with horizontal superheater elements situated behind several rows of furnace screen tubes, the elements being expanded into vertical headers either at the front or rear of the boiler.

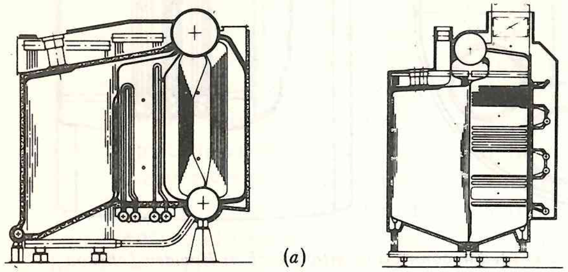


Figure 9.7 (a) integral superheater (b) external superheater

These boilers suffered operational difficulties which often resulted in sailings delays and high maintenance costs. One of the major difficulties was their inability to cope with fuels having high vanadium bearing ash which, in many cases, caused heavy bonded slag deposits to bridge across tubes in high temperature zones, particularly in superheaters.

This slagging not only attacked the hot surfaces of superheater tubes and supports, causing wastage which eventually led to failure, but also built up in some tube bank areas with the result that cleaner areas had to cope with much increased gas speeds. This, in turn, caused local overheating and sometimes premature tube failure. It was in an effort to combat these troubles that Foster Wheeler designed their first ESD (External Superheater) D-type boiler – the arrangement of which limited the gas temperature at the superheater and reduced its tube-metal temperature, it also reduced the slagging and corrosion of supports which occurred with high temperature superheaters located only a few rows from the furnace.

Some idea of the relative heating surfaces and gas temperatures of the two types can be seen from Figure 9.8.

Integral superheaters.

These superheaters were originally fitted in earlier installations with their U-tube elements horizontal and terminating in headers at the

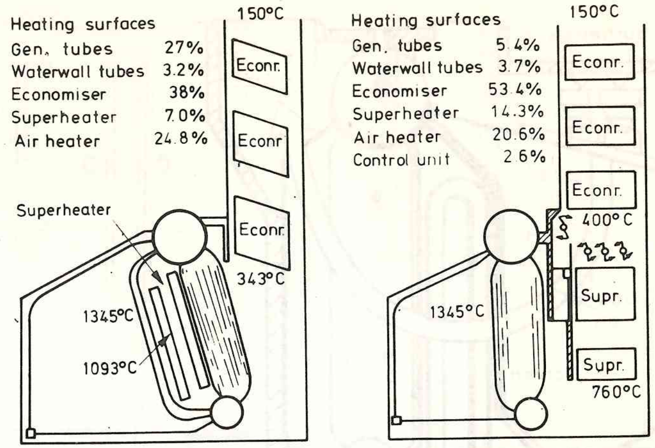


Figure 9.8 Foster Wheeler boilers (left) D type (integral superheater); (right) ESD type (external superheater)

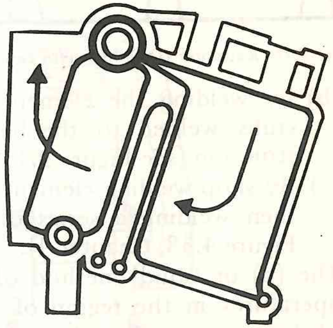


Figure 9.9 Combustion Engineering V2M-8 boiler with vertical superheater

front or rear of the boiler (see Figure 9.8). Nowadays, they normally have their tubular elements vertical with headers across and under the boiler. This arrangement gives better drainage, improves gas flow and is less prone to troubles from slag deposits (Figures 9.9 and 9.10).

Headers and tubes

The headers used are normally of forged or fabricated steel construction, circular or rectangular in section. The U-tube elements being attached by one of the following methods:

(a) By expanding and bellmouthing, in which case the headers have to be fitted with numerous access doors.

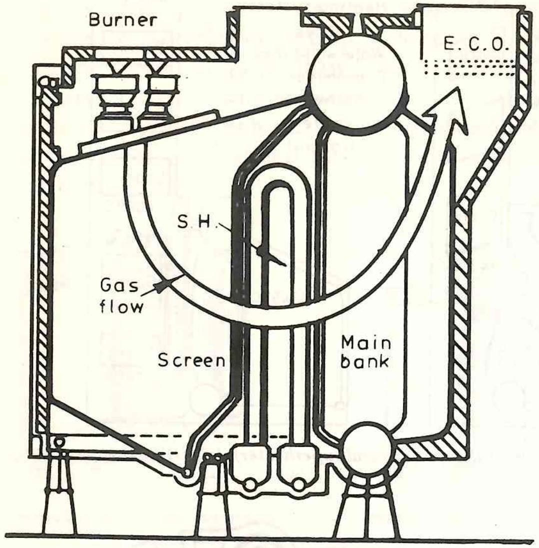


Figure 9.10 Kawasaki UM boiler with vertical superheater

(b) By welding the element ends to numerous inlet and outlet stubs welded to the headers for that purpose during construction (see Figure 9.11 and 9.12).

(c) By shop-welding elements to sub headers to form panels, and then welding a series of these panels to main headers (see Figure 4.53, Chapter 4).

The (b) or 'solid' method of attachment is used when superheat temperatures in the region of 454°C are used, the stub to header welds being stress-relieved on completion.

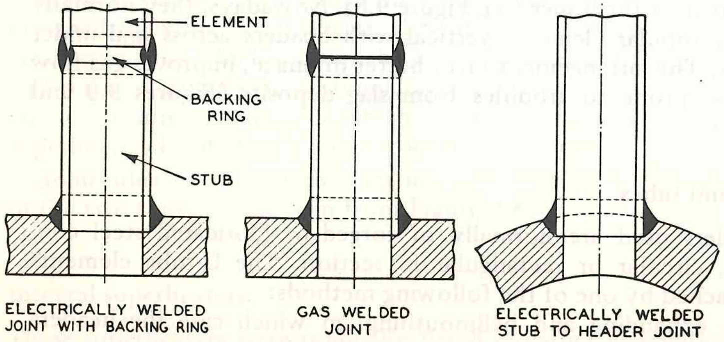
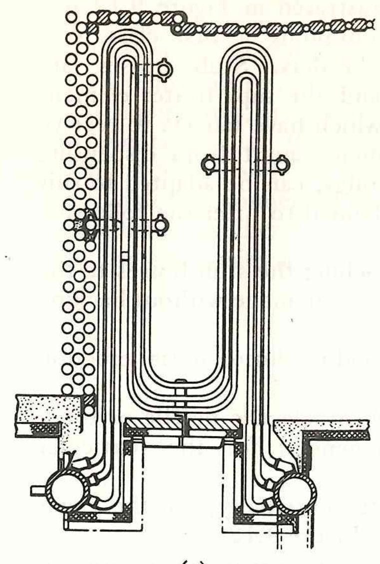


Figure 9.11 Methods of attaching superheater elements



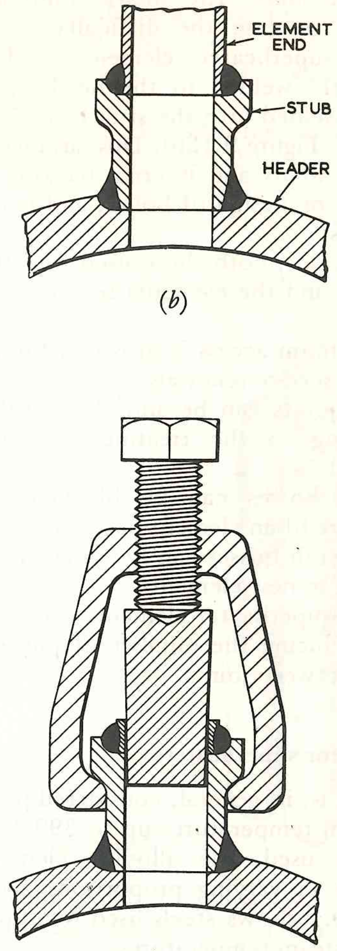


Figure 9.12 Melric joints applied to the superheaters of a Babcock & Wilcox selectable superheat boiler
(a) arrangement of superheater header and element
(b) detail of Melric joint
(c) method of blanking off from outside of header in event of element failure

The stubs, and the welds at each end of them, are well outside the gas path over the superheater, and on that account are not subjected to such severe conditions as the actual elements themselves.

The Melric joint. The 'Melric' joint illustrated in Figure 9.12 was developed to ease the difficulty of obtaining a first class weld between superheater elements and headers. Stub bosses are permanently welded to the headers, and the superheater element ends are welded into the stub bosses, which have faucets to receive them (see Figure 9.12b). This arrangement, apart from dispensing with butt welds and internal backing rings, can be adapted to suit any make or design of boiler, and is claimed to offer the following advantages:

1. All welds, both those used for attaching the stub bosses to the headers and the elements to the bosses, are made without backing rings.
2. Maximum access is provided for welding during initial erection and for service renewals.
3. The joints can be annealed locally by electric muffle or torch according to the treatment recommended for the particular material.
4. Stub bosses can be blanked off, externally, in the event of failure of an element in service (see Figure 9.12c).
5. The stub bosses can be remachined with a seating tool prior to welding in new elements.
6. Two superheater elements can be bifurcated to form one stub, thus reducing the number of joints by half and giving twice the space between joints.

Materials for superheaters

Mild steel is, in general, considered permissible for superheater tubes with steam temperatures up to 399°C; above this temperature alloy steels are used, the alloying elements being molybdenum and chromium in varying proportions according to the duty required.

Table 9.1 shows steels used for superheater headers and tubes at different steam temperatures.

Table 9.1 Steels for superheater headers and tubes

Steam temperature	*Headers*	*Tubes*
Up to 398.9°C	Mild steel	Mild steel
398.9–426.7°C	Mild steel	½% molybdenum steel
426.7–468.6°C	½% molybdenum steel	1% molybdenum ½% chromium } steel
468–510°C	1% chromium ½% molybdenum } steel	2¼% chromium 1% molybdenum } steel

Although, when assessing the permissible scantlings by present-day classification society rules, the actual properties of the steel at elevated temperatures, in conjunction with the predicated operating metal temperatures, are taken into account.

As mentioned at the beginning of this chapter, installations working at 510°C and over are now in service, but although materials are available in commercial use for steam temperatures up to 570°C it is doubtful whether, at the present time, the high first cost would justify the economies achieved.

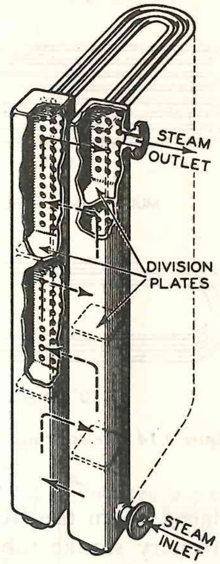


Figure 9.13 Welded-in division plates on early boiler superheater

It is usual to fit welded-in division plates in the headers so that the steam is forced to make several passes through the superheater, the inlet and outlet branches sometimes being on the same header, dependent on the number of passes (see Figure 9.13).

The division plates simply consist of pieces of plate welded in position inside the headers, each with a bottom corner snipped-off for drainage purposes. The U-tubes in earlier D-type boilers were at a slight angle to the horizontal, and on that account were self-draining, the headers being suitably located at either the front or back of the boiler casing (see Figure 9.13). The superheater elements are normally positioned just behind the fire rows of boiler tubes in which most of the steam is generated. In this way the superheater is subjected to the same variations in furnace temperature as the fire rows, and a fairly constant degree of superheat is obtained irrespective of rate of evaporation.

'Melesco' superheaters

Some types of Yarrow boiler and also many D-type boilers were fitted with 'Melesco' superheaters, Figure 9.14. This superheater consisted of a bank of horizontal multi-limbed elements extending between saturated steam inlet and superheated steam outlet headers

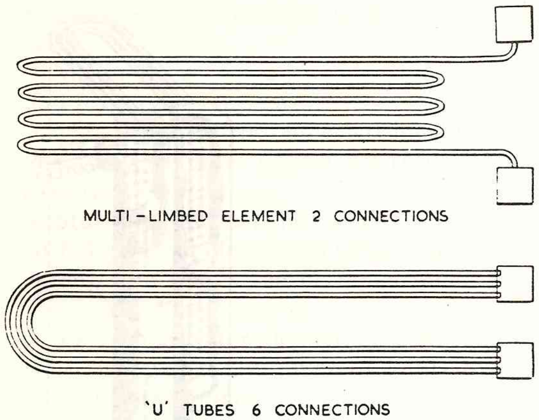


Figure 9.14 'Melesco' superheater

placed down the front of the boiler. It was in fact very similar to the ordinary smoke tube superheater as used on Scotch boilers, the use of multi-limbed elements reducing considerably the number of welded connections to headers. With this arrangement a reasonable steam velocity and satisfactory steam distribution were obtained with a single pass, even when steaming at low power.

A foreseeable disadvantage of multi-limbs versus U-tube elements is that blanking off a defective multi-limb would have a much more pronounced effect on steam flow than the same action on a U-tube.

Contemporary integral superheaters, as previously stated, are arranged with their U-tubes vertical and headers across and under the boiler – single and double superheaters are used dependant on steam conditions. Having the U-tubes vertical has eliminated the sagging and lack of drainage troubles often experienced with the older horizontal types.

The weight of the vertical U-tube panels is taken by the transverse

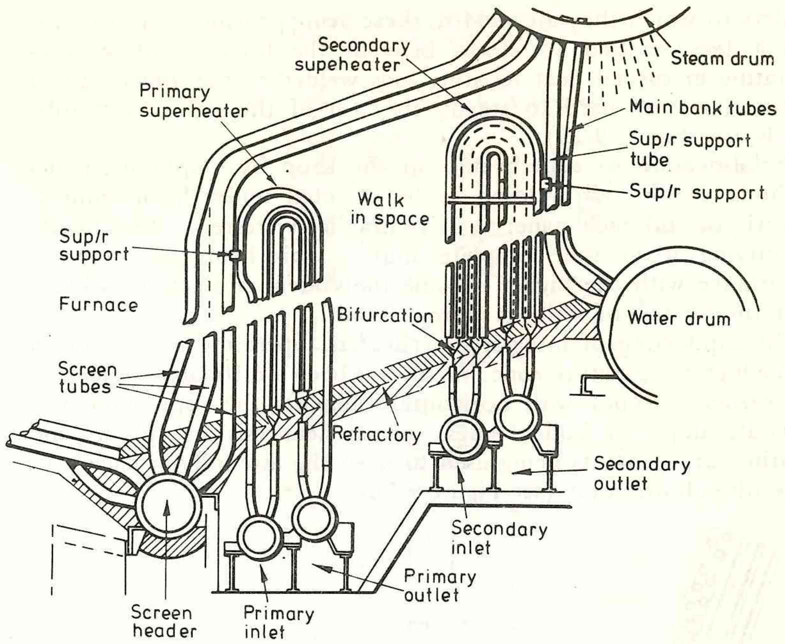


Figure 9.15 Arrangement of double superheater in D type boiler

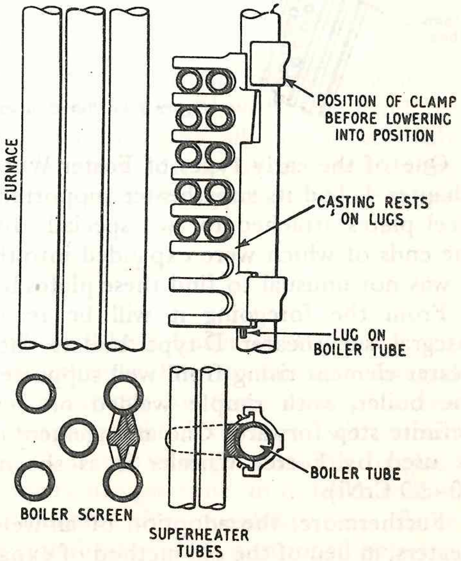


Figure 9.16 Replaceable superheat support showing upper clamp raised

headers to which they are welded, these being provided with suitable sliding feet secured to stools beneath the boiler. Sliding stays operating in special heat resisting lugs welded to the upper part of screen tubes are used to steady the top of the superheater tube panels, (see Figure 9.15).

Prefabrication of superheaters in the shop by employing panel methods enables all welding to be effected under 'programmed' conditions, and each panel to be hydraulically tested before finally embodying it in the complete unit – this being of increased importance with the higher chrome molybdenum steels now being used, the welding of which is more difficult.

The supporting of integral superheaters, operating as they do in such a high temperature zone, has always been a difficult problem. In the earlier D types with horizontal elements the supporting was generally done by boiler tubes, special heat-resisting spacers and securing arrangements being used to keep the assembly in place, but these often burnt away (see Figure 9.16).

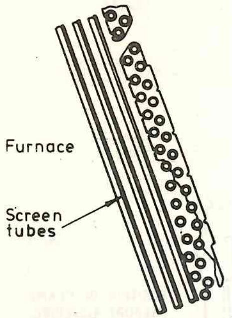


Figure 9.17 Burnt superheater support plates

One of the early types of Foster Wheeler boiler, as mentioned in Chapter 4, had its superheater supported by a series of heat-resisting steel plates attached to two specially fitted large bore water tubes, the ends of which were expanded into the steam and water drums – it was not unusual to find these plates burnt away (see Figure 9.17).

From the foregoing it will be readily apparent that in these integral superheater D-type boilers the change to vertical superheater element rising from well supported headers, across and under the boiler, with simple welded on supports and spacers, was a definite step forward. One arrangement of the supports and 'buffers' as used by Foster Wheeler is as shown in Figure 9.18 (material 50–50 CrNi).

Furthermore, the adoption of all-welded construction for superheaters, in lieu of the old method of expanding the element ends into

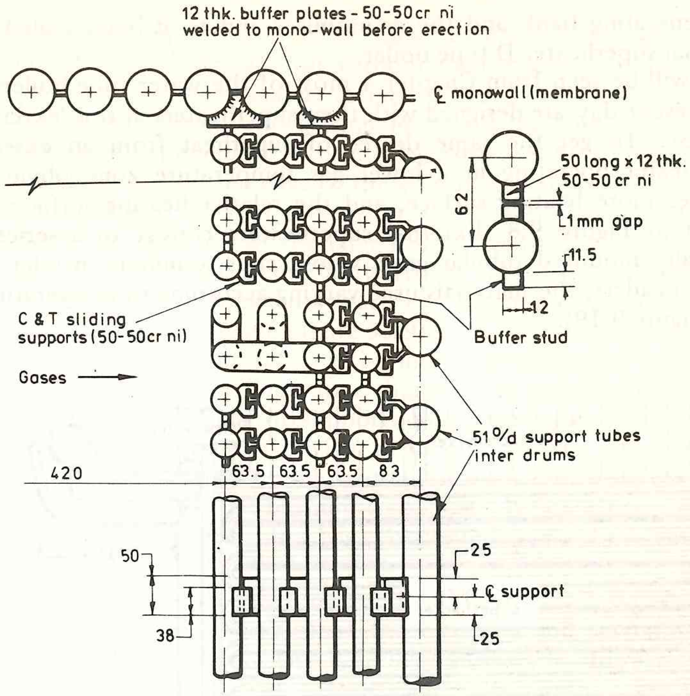


Figure 9.18 Superheater supports for integral superheater in Foster Wheeler D type boiler

the headers, has enabled the multitude of header doors and joints – necessary for expander access, to be dispensed with. One handhole per section, i.e. between pass baffles, being all that is normally necessary to enable baffle securing welds to be effected during construction, and to permit future internal inspection of the superheater.

External superheaters

The advent of the Foster Wheeler ESD boiler in 1949 saw the introduction of the external superheater. Prior to this time integral superheaters separated from the furnace by three rows of screen tubes were general. In the design of the ESD type, with steam conditions of 43 bar and 510°C, it was thought desirable to place this superheater in a lower temperature gas zone, in order to reduce metal temperatures and eliminate the possibility of flame impingement. This led to the superheater being positioned between the generating bank and the economiser and to it being called the external superheater D-type boiler.

As will be seen from Chapter 4 most of the water tube boilers of the present day are designed with their superheaters in this 'external' position. To get the same degree of superheat from an external superheater operating in a lower gas temperature zone obviously requires more heating surface, and the relative heating surfaces are shown in Figure 9.8. External superheaters consist of a series of vertically mounted tubular grids whose ends terminate in inlet and outlet headers, the materials used varying according to temperatures, (see Figure 9.19).

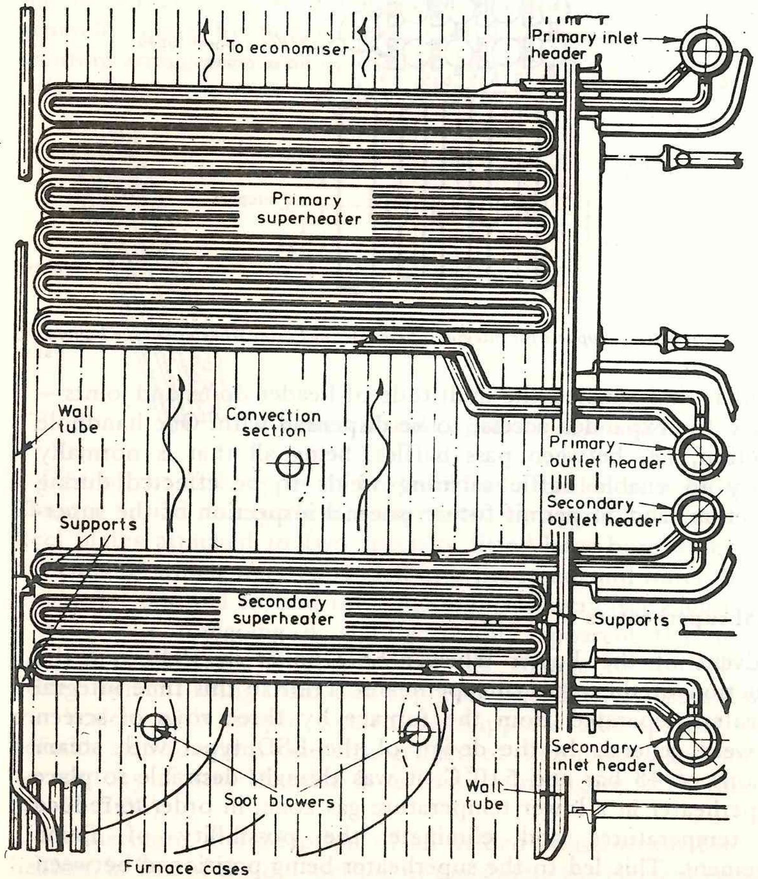


Figure 9.19 Arrangement of superheaters in external superheat boiler

Superheater supports, even in these external types where gas temperatures are lower, are not without their troubles. In the earlier ESD boilers the superheater elements lying fore and aft were arranged to hang from athwartship heat resisting cast steel beams. Troubles were experienced with burning away of the actual hangers and also the lower slotted edge of the athwartship support beams.

Realising that it is easier to support superheater elements of short leg length, the designers of the later ESD types turned the elements through 90°, so that being athwartships they are considerably shorter and can be supported at each end by simple saddles welded to adjacent boiler tubes (see Figure 9.19).

For superheater supports to exist under the prevailing high temperature conditions it is imperative that heat be quickly taken away from them. Earlier types of supports were clamped to boiler tubes (see Figure 9.16), and these when new could well be efficient, but directly some oxidation of the mating surfaces occurred, the heat flow was interrupted and burning took place. Welding the supports to the actual boiler wall tubes has contributed greatly to solving this problem.

In view of the wide range of temperature to which superheaters are subjected, it is essential that the elements and assembly as a whole be free to expand. This is usually allowed for by permitting the elements to slide in their supports and by anchoring them at one end only, the other end having a slotted expansion joint.

Water tube boiler superheaters, unlike Scotch boiler superheaters, are invariably considered as part of the boiler, and as such are directly connected to the steam drum without the steam passing through any stop valve. It is important that under all rates of evaporation sufficient steam is passed through the superheater elements to prevent overheating, and on this account the boiler safety valves are normally fitted on the superheater outlet header — this ensures that in the event of a sudden slowing or stoppage of the machinery at sea, the safety valves will lift and ensure a good passage of steam through the superheater. When, as is sometimes the case, additional saturated steam safety valves are fitted on the steam drum, it is usual for these to be loaded in excess of the superheater valves, so that in this case also, the superheater valves will lift first and so safeguard the superheater.

On the occasions of sudden slowing of the machinery, or when manoeuvring, it is possible for the superheat to reach higher temperatures than are desirable, either in the superheater or prime mover, it is therefore advisable to lower the temperature on such occasions. In the following section, means of achieving this will be discussed.

SUPERHEAT CONTROL

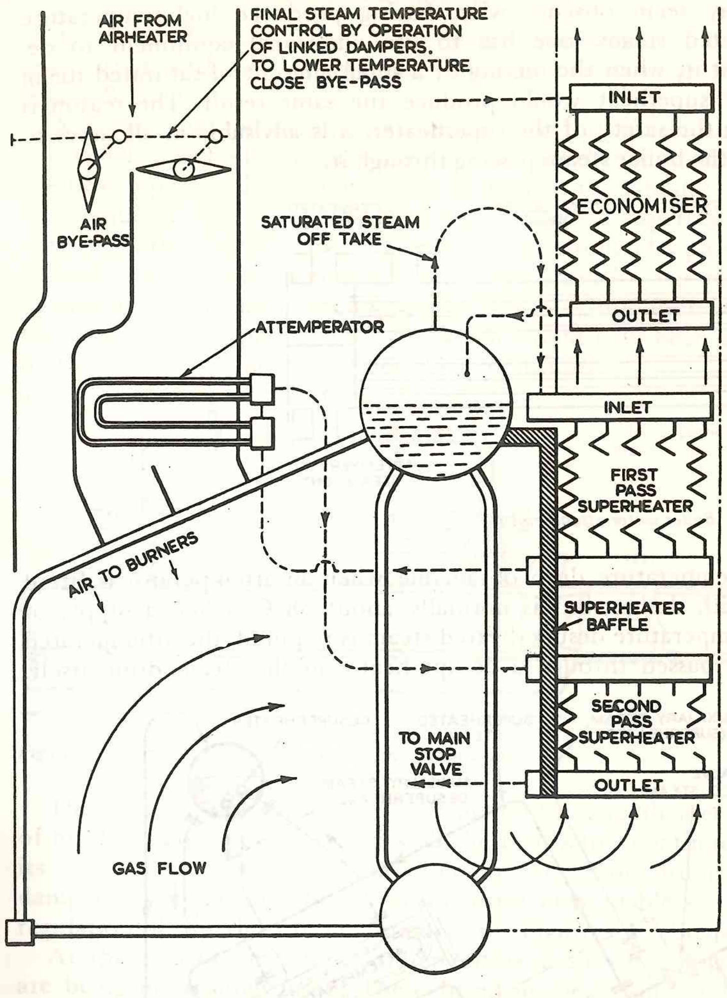
Scotch boilers

In the case of Scotch boilers, the usual method of steam temperature control is by means of 'mixing valves' which, when opened, allow saturated steam to pass into the superheated steam line. Mixing valves must be used with caution, it being borne in mind that the more they are opened, the less steam there is passing through the superheater.

Water tube boilers

With water tube boilers, steam temperature control is achieved by several different methods:

(a) By regulating the amount of gas flow over the superheater tubes by means of dampers, as in the Yarrow double-flow design and Babcock & Wilcox selectable superheat boiler.
(b) By using a spray attemperator (this being a unit in which feed water is sprayed into the superheated steam).
(c) By the fitting of desuperheater coils in the steam drum.
(d) By installing the superheater in the boiler in such a position that the amount of heat passing over it can be regulated by varying the location of the actual oil burners in use as in the Foster Wheeler controlled superheat design (see Figure 4.22, Chapter 4).
(e) By using a separately fired superheater (rarely used).
(f) By using an air attemperator (this consists of elements formed of extended surface tubing connected to inlet and outlet headers) steam from the first pass of the superheater flows directly through the attemperator and back to the last pass of the superheater.
(g) By using a boiler-water attemperator. This attemperator, which is simply a tubular heat exhanger, has its water side (external to the tubes) directly coupled by large-bore connecting pipes to the boiler steam drum, and in fact in this way becomes a pressure part of the boiler itself (see Figure 9.21).
Inside the pressure shell is a steel tube plate into which are expanded the ends of steel U-tubes. A controlled amount of superheated steam is passed through the U-tubes, the reduced-temperature outlet steam from the attemperator being used for auxiliary purposes and also, if required, for reducing the temperature of the main steam from the superheater.



Fiugre 9.20 Superheat temperature control by air attemperator

The air attemperator as described in (f) is located in the forced-draught air-supply ducting to the boiler, and air for combustion is used as the cooling medium. Air by-pass and air shut-off dampers are fitted and linked together, so that by varying the settings the air flow across the attemperator surface may be regulated and the desired final superheated steam temperature obtained (see Figure 9.20).

It may seem obscure why, having produced high-temperature superheated steam, one has to use additional equipment to desuperheat it, when the mixing of a small amount of saturated steam into the superheat would produce the same result. The reason is that, for the safety of the superheater, it is advisable at all times to have all the boiler steam passing through it.

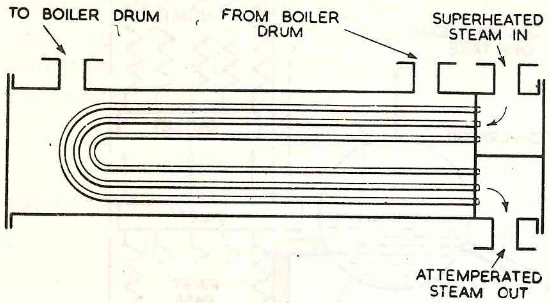


Figure 9.21 Boiler water attemperator

The temperature drop obtainable when an attemperator is fitted varies with design, but is normally about 38°C. When a supply of lower-temperature desuperheated steam is required, the attemperated steam is passed through a desuperheater in the steam drum itself.

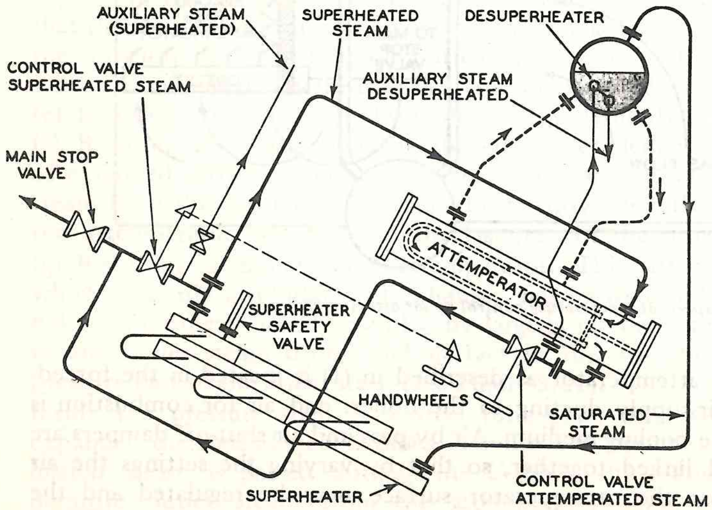


Figure 9.22 Diagrammatic arrangement of steam connections for boiler fitted with attemperator

A typical diagram showing the steam connections for a boiler unit fitted with an attemperator and desuperheater is shown in Figure 9.22.

A further method of superheat control used in a large number of Foster Wheeler boilers is that used in the ESD II type. In this design the heat input to the superheater is limited to the amount of superheat required, this being effected by providing the superheater itself with an outlet damper, and also a damper-controlled by-pass. In this by-pass an up-flow economiser or 'control unit' – in reality an extension of the main economiser – is fitted, this unit absorbing the heat under by-pass conditions, which would have been absorbed by the superheater under damper-open conditions.

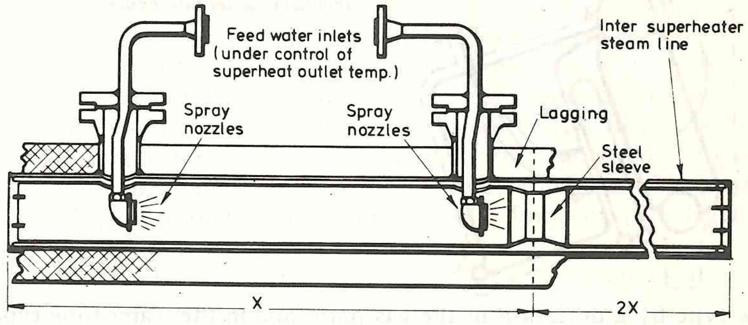


Figure 9.23 Arrangement of inter-stage spray attemperator

The 'control unit' of similar construction to a superheater consists of headers and tubes, and carries all the feed-water continuously on its way from the main economiser to the steam drum. Linked dampers over the superheater and control unit enable satisfactory regulation of superheat to be obtained (see Figure 4.13, Chapter 4).

At the present time spray attemperators as shown in Figure 9.23 are being increasingly used. These fitted in the steam line between the primary and secondary superheaters embody nozzles which spray controlled amounts of feed water into the steam for regulating the boiler superheat outlet temperature.

RADIANT AND SEPARATELY FIRED SUPERHEATERS

The superheaters already described, both for tank and water tube boilers, are not exposed to the direct radiant heat of the boiler furnace; in all cases the actual superheater tubes are shielded – in the

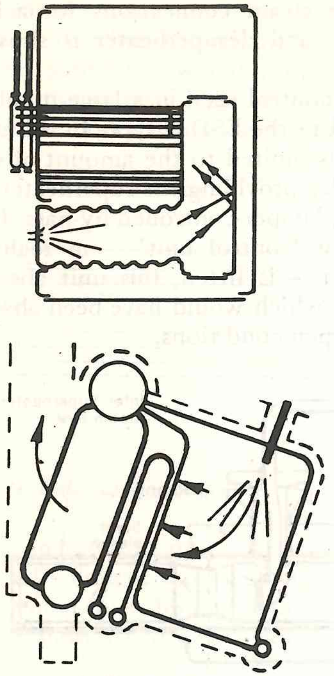


Figure 9.24 Shielding of superheater tubes (above) in tank boilers (below) in water tube boilers

tank type by a deviation in the gas path, and in the water tube type by rows of generating tubes (see Figure 9.24).

Radiant superheaters

A radiant superheater is one in which the tubes are directly exposed to the furnace radiation. Boilers with radiant superheaters are not frequently encountered and are similar in some respects to reheat boilers – notably the Combustion Engineering V2M8 – in as much as they both pass steam, requiring heating, through tubular elements enclosed in a separately fired furnace, the exit temperature of the steam being used to regulate the firing of the separate superheater or reheater furnace.

Water tube boilers with radiant superheaters were developed in the USA subsequent to steam temperatures reaching their considered permissable maximum for use in conventional turbine construction. In order that positive control of this permissible maximum temperature could be obtained, a separate furnace, bounded by superheater tubes, was added to an ordinary two-drum boiler. The products of combustion from the superheater furnace passed through

the adjoining boiler-tube bank into the main furnace and continued through the second tube bank to the economiser and uptake.

The rate of firing of the superheater furnace is regulated automatically by the temperature of the outgoing superheated steam, and a positive temperature control is thus obtained during manoeuvring and other special conditions. Steam raising with this type of boiler can be accomplished quickly without risk of damage to the superheater. The radiant superheater, however, requires very careful operation, as any sudden slowing of the machinery may cause an undue rise in steam temperature.

Separately fired superheaters

The radiant superheater described above is separately fired. There are, however, other water tube boiler designs with separately fired superheaters in which the superheater tubes are screened by generating tubes, and are not of the radiant type.

The separately-fired superheater most commonly encountered in marine use is incorporated in three-drum boilers with twin furnaces, the superheater being situated *within* either the middle or gas-outlet tube banks, and the superheat temperature being regulated by employing burners in the inner or outer furnaces. (See Figure 4.22, Chapter 4).

Separately fired superheaters of a type entirely independent of the boilers have been fitted to a few Scotch-boilered vessels.

The working pressure obtainable with tank boilers is limited, but with a separately fired independent superheater, the steam temperature can be raised to 454°C. This results in considerable increase in turbine efficiency, without the disadvantage of impaired accessibility of boiler combustion chambers through using extended superheater elements in the smoke tubes, or combustion-chamber superheaters.

ECONOMISERS (*see also Chapters 11 and 18*)

Most water tube boilers whether with integral or external superheaters are fitted with economisers for feed heating and extracting within practical limits the maximum amount of heat from the fuel before releasing the combustion gases either to atmosphere or to an air heater.

Generally speaking economisers consist of mild steel inlet and outlet headers between which are welded multi-loop steel tubes with either steel fins, or cast iron finned sleeves, shrunk-on. Over these pass the flue gases and thus transfer some of the heat contained in the gases to the feed water which is caused to circulate through the tubes. Economiser construction has not perceptibly altered during the past twenty-five years, the most important advance being the adoption of welding in lieu of expanding for the attachment of elements to headers.

Figure 9.25 shows a part element of a Foster Wheeler Green economiser, in which 115 mm o.d. cast-iron gills are shrunk on to 50 mm o.d. mild-steel tubes. These tubes are supplied as U-bend elements which are welded to stub tubes on the inlet and outlet headers and are interconnected by welded-on bends to form the required number of feed-water paths. The stub tubes are an integral part of each header and hand holes are located opposite each tube end to allow internal inspection and emergency plugging of a water path should an element fail in service.

As will be seen from Figure 9.25, the elements are carried in mild-steel support plates, being secured by locking rings at one end and free to expand through sealing rings at the other.

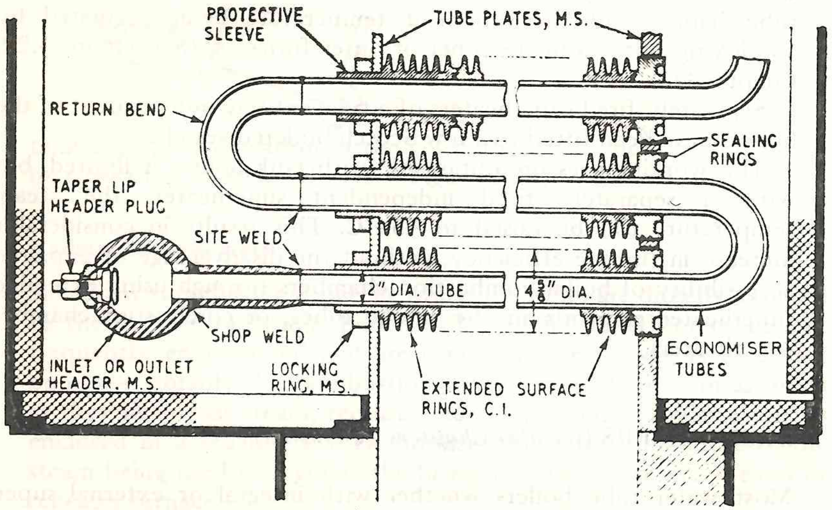


Figure 9.25 Diagrammatic arrangement of extended surface economiser

The economiser casings are fully insulated and doors are fitted at each end for access to the headers and return bends.

It is usual to build up the economiser separately from the boiler and to install it in one piece after satisfactory hydraulic test.

In some modern installations the economiser is arranged in two or more sections, see Figure 9.27, the primary or upper low temperature section having cast iron gills (as in Figure 9.25) and the secondary or lower high temperature section having steel gills (as in Figure 9.26), the water flow being counter to the gas flow.

It should be noted that one end of the finned elements of the low temperature section is positively located by a collar and locking ring while the other, to take care of differential expansion and maintain gas tightness, is provided with a sliding piston ring joint. While this is good engineering practice, leakages at the sliding joints due to tube plate distortion and other reasons sometimes occur, with the result that accumulations of soot in the end boxes cause serious corrosion of the element return bends – these boxes should be kept clear.

Economiser inlet and outlet headers are normally made from solid drawn steel tube with welded-on end caps, and present day practice, as in the case of superheater headers, is to embody welded-on stub tubes as an integral part. The finned elements extending downwards, form individual water paths from inlet to outlet header, and are welded to these stubs. Handholes, with suitable closing arrangements, are provided for internal inspection purposes and for the plugging of a water path should an element fail in service.

The inlet and outlet headers are only secured to the economiser casing at one end, the other being free to allow for expansion. Vent and drain valves are normally provided on the headers, and when isolating valves are fitted to the economiser a relief valve is provided which would relieve excess pressure should the economiser be unintentionally isolated whilst the boiler is steaming.

Water washing equipment is normally fitted at the top of the economiser and soot blowers beneath each bank (see Figure 9.27).

A typical feed diagram embodying economisers is shown in Figure 9.28 and it will be noted that in this particular case isolating valves are fitted to the economiser, and that feeding through the regulator can still be effected, either from the main or auxiliary feed line, with the economiser isolated. If however, in such a case, an economiser has to be isolated through defects, whilst the boiler is steaming, it is important that further damage be limited by keeping the gas inlet temperature below 370°C, and also to ensure that any steam generated within the isolated economiser has a ready escape path.

In view of the high pressures at which they are required to remain tight, it would be inept to leave the subject of superheaters and economisers, without some reference to the closing arrangements of their header handholes. Oval handholes, gaskets and doors have given a lot of trouble through leakage and are being superseded by round types with improved gaskets.

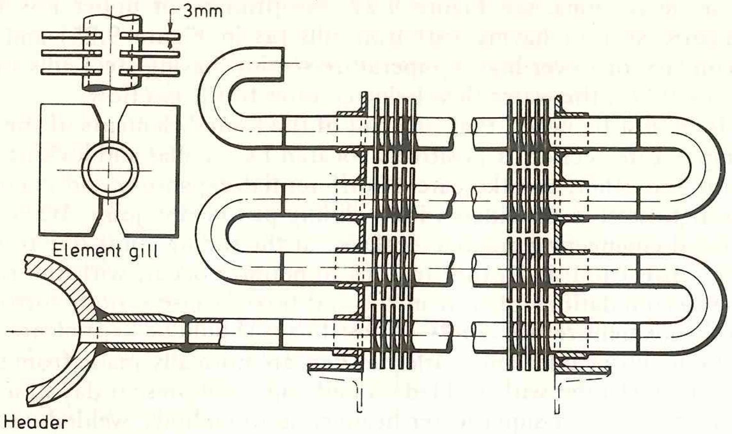


Figure 9.26 Shielding of superheater tubes (left) In tank boilers; (right) in water tube boilers

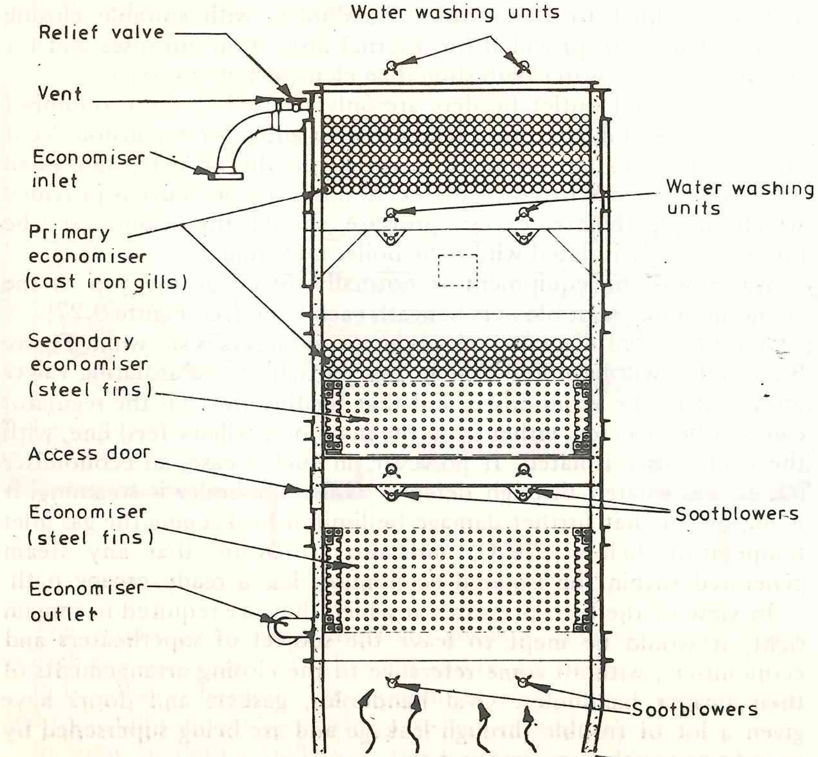


Figure 9.27 Arrangement of primary and secondary economisers

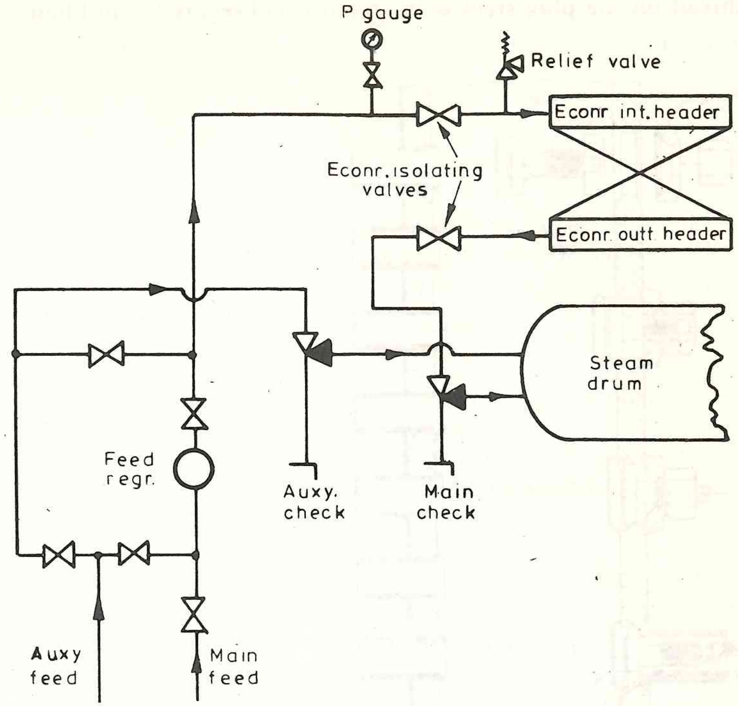


Figure 9.28 Typical feed diagram incorporating economisers

FOSTER WHEELER TAPER LIP PLUGS

Installation and removal

The installation and removal of a taper lip plug is shown in Figure 9.29. The lips on the plug prevent withdrawal once the plug is in position; insertion or removal is achieved by giving the plug a sideways twist.

To install a plug, clean the aperture carefully, seeing that the joint face is in good condition and clean the plug and gasket, making sure there are no defects in the conical faces. The plug should be placed in the header after being secured to a wire about a foot long passed through a hole in the plug stem. Thread the gasket over the wire and insert in the aperture with the rounded edge on the plug taper. Bring the plug into position and assemble the plate then lubricate the thread on the plug stem with graphite and secure the nut hand-tight.

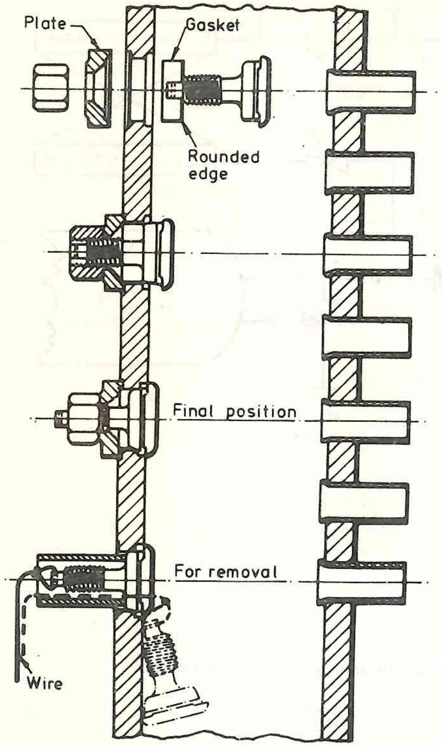


Figure 9.29 Installation and removal of taper lip handhole plugs

See that the gasket fits squarely into the recess in the plate and tighten the nut with a spanner, making sure that the plate is in contact with the header machined face. A small spanner on the flat of the plug stem will prevent the plug rotating. The leverage obtained by a standard spanner is sufficient to make a good joint but tighten the nut on first raising steam after installation. Undue force should on no account be used in tightening the nut.

When removing a taper lip plug, unscrew the nut and plate and pass a length of wire through the hole in the plug stem. Drive the plug into the header, using a piece of tube large enough to pass over the

stem of the plug. When it is not intended to renew the gasket reference marks should be made on the plug and header, to ensure that the plug is reseated in the original position. Clean and examine the joint faces before replacing the plug and do not reseat a plug on an old gasket more than once.

Temporary repair

Leakage from a taper lip handhole plug may be made good on a temporary basis whilst the boiler is under pressure. When the leak has been located boiler pressure is relied upon to keep the plug in place and the repair procedure is as follows:-

(a) Remove the nut, washer and plate from the defective plug.
(b) Clean the machined face of the header in way of the plate.
(c) Clean the top and bottom faces of the plate.
(d) Fit a joint ring below the plate as shown (see Figure 9.30).
(e) Fit a copper joint ring above the plate and use a cap nut to re-tighten the plug.

It is stressed that the above method should be looked upon as a temporary measure. Continued leakage between the plug and seat will result in damage to one or both; a permanent repair must be put in hand at the earliest opportunity.

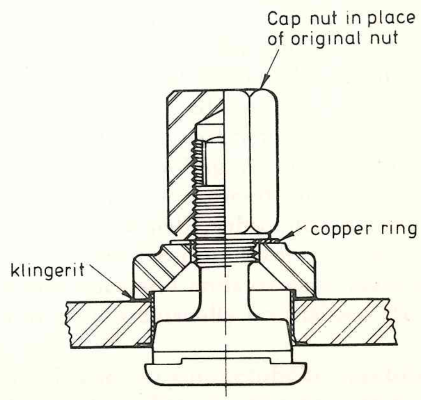


Figure 9.30 Emergency repair of taper lip handhold plugs

It will be noted that the temporary repair described can only be carried out if the plug nut is easily removable. Attention should be paid to the freedom of the thread whenever a plug is removed, the threads being coated with graphite before each occasion of replacement.

10 Materials used in construction

In the very early days of steam power, boilers were made of cast iron with leaden or wooden tops and even with wooden shells hooped like barrels, often with flat surfaces. Pressures were very low, being only 12–15 lbf/in^2. The original Scotch boilers were made from wrought iron plates, with the shell generally of a quality known as Best Staffordshire, which could be obtained in plates up to about 7–8 ft in width with a tensile strength parallel with the grain of about 23 tonf/in^2 and across the grain of 19 tonf/in^2, the elongation only being of the order of about 5–10 per cent. Iron boilers in a remarkable state of preservation are quite common in land installations even to this day.

THE ADVENT OF STEEL

The advent of steel, a material having a much higher tensile strength and greater ductility than iron, marked the beginning of a new era in boiler history. This necessitated a revision of the rules and regulations regarding boiler construction in use at that time.

Steel as now used for boiler plates is rolled from slabs or billets cogged from the best or lower parts of ingots made by the electric or basic oxygen process, the upper third of the ingot being affected by the contraction cavity or 'pipe' created by cooling. As an alternative to rolling from billets, the liquid steel may be formed into slabs by means of a continuous casting process, the slabs subsequently being reheated and rolled into plates. To ensure freedom from lamination adequate discard is called for on the sides and ends of each plate as rolled, and plates 40 mm thick, and over, are usually normalised after rolling.

Tubes are normally made of steel, and for smoketube or staytube purposes the steel should be of tested quality. In the case of stay tubes which are in direct tension between tube plates, it is important that in any tube nest the tubes are of uniform quality, so that each tube renders its share of support to the tube plates. The support given to tube plates by the plain tubes is neglected when boiler calculations are made. The tensile strength is not an important quality – the material should have good anti-corrosive properties and be capable of being expanded without cracking.

MANUFACTURING PROCESS

Steel as used for boiler making has not only to comply with the inspecting authority's tests but has to be made by a satisfactory manufacturing process, and normally steel made by the open-hearth, electric furnace or oxygen process is acceptable.

Steel is made from a brittle, non-ductile metal of low tensile strength, known as pig-iron, which is produced by blowing preheated air through a blast furnace containing an intimate mixture of iron ore and coke. Limestone is added to the mixture for the purpose of aiding the fusion of impurities and their absorption in the slag. The heated air is blown in through the bottom of the furnace and ascends through the mixture. The blast, or heated air, burns the carbon in the lower layers of coke to form carbon monoxide, which, passing upwards through the furnace, robs the iron ore of its oxygen, converting it into metallic iron.

The metallic iron running downwards through the burning coke collects at the bottom of the furnace, is tapped off periodically and cast into so-called 'pigs'.

Composition of pig-iron

The iron ore used in the production of pig-iron contains oxides other than iron, such as silicon, manganese, sulphur and phosphorus. These oxides are also reduced by the blast, and then the metallic iron produced becomes contaminated by these elements. Carbon is very soluble in molten iron, and during the time the metallic iron is running downwards through the burning coke it absorbs between 3.5 and 4 per cent of carbon.

Table 10.1 Typical pig-iron analyses

	Haematite	*Basic 1*	*Basic 2*
Carbon	3.5 to 4.5%	3.5 to 4%	3.5 to 4%
Silicon	1.75 to 2%	0.75 to 1%	0.75 to 1%
Sulphur	0.04% max	0.04% max	0.05% max
Phosphorus	0.04% max	1.75 to 2.25%	0.75 to 1.5%
Manganese	1% max	1 to 2.5%	2.5 to 4%

From the foregoing it will be apparent that the chemical composition of pig-iron is a variable quantity dependent on the type of iron ore used in its production. Three typical pig-iron analyses are shown in Table 10.1.

Production of steel from pig-iron

The production of steel is effected by removing from the pig-iron the carbon and other elements in excess of the quantities necessary for steel, and by adjusting the remainder to the requisite proportions necessary to give the mechanical properties required in the resulting steel. Because the carbon and other elements have a greater affinity for oxygen than iron has, if oxygen, either atmospheric or as oxide of iron, is introduced into a mass of molten pig-iron, the manganese, silicon, carbon and in favourable circumstances the phosphorus will be reconverted to their oxides. The carbon will be eliminated as carbon monoxide, and the other unwanted elements will float to the surface of the metal in the form of slag.

Sulphur is more difficult to remove, and has to be kept low in the original pig-iron.

STEELMAKING PROCESSES

Steelmaking processes are subdivided into two categories – acid or basic – according to the phosphorus content of the pig-iron, which in turn determines the nature of the furnace lining employed. When the charge contains too much phosphorus, lime is added to the mixture for the purposes of absorbing it. Lime, however, combines with silica, the material normally used for an acid furnace lining, and on that account the lining of the furnace then has to be of a 'limey' or 'basic' nature.

It will be understood from the foregoing that the main difference between the acid and basic processes is that in the first the raw materials charged into the furnace require careful selection, as this process, while permitting the reduction of the silicon, manganese and carbon, does not affect the sulphur or phosphorus content, and therefore any excesses of these will be present in the finished steel. In the basis process it is possible to use material containing relatively larger amounts of phophorus, as this is subsequently reduced by the addition of lime to the charge; the sulphur content, however, is removed erratically throughout the blow, but is usually kept low and in some cases the molten pig iron is initially treated with soda ash and calcium carbide to remove this element.

The amount of carbon in a charge can be reduced by the addition of iron oxide or increased by the addition of anthracite or other carbon-containing compounds. Steel scrap is fed into the molten charge and forms a cheap 'make-weight' and, at the same time provided it is good scrap, dilutes the impurities in the charge. The temperature of the charge is normally tested nowadays by immersion pyrometer; in the past, round steel rods were used, the operator knowing that when these were cut off sharply on immersion the charge was at pouring temperature.

bessemer steel

In both the acid and basic Bessemer processes molten pig-iron is refined by blowing cold air through it in a pear-shaped vessel known as a 'converter'. No external heating is required as the oxidation, principally of the silicon in the acid process and the silicon and phosphorus in the basic process, produces sufficient heat for the process to be self-sustaining. The temperature can be controlled by additions of steel scrap in order to cool the metal.

The oxidation of the carbon and the unwanted elements takes place substantially in order of their affinity for oxygen, and the sequence can be followed by the appearance of the flame at the mouth of the converter. Initially, there are considerable sparks and little flame, but after a few minutes the flame length increases and becomes progressively more luminous as the blow continues and the carbon decreases. At the end of the decarburisation period the flame drops, and in the acid process the converter is turned down and the metal poured into a ladle where the necessary finishing and alloy additions are made. On the other hand, in the basic process the blow is continued after the flame drop in order to facilitate phosphorus removal and a high degree of control is required.

In both processes, the carbon content is likely to be below the requirements for the finished steel, and so it is necessary to re-carburize by additions of coke or ferro alloys to the ladle. Bessemer steel often contains high nitrogen, which is generally undesirable in constructional steel mainly because of its effect on the strain ageing characteristics of the material. It is not considered suitable for applications where high ductility is of prime importance, and on that account is not acceptable for use in boiler construction.

Most of the steel used in boiler and pressure vessel construction is

now made in either basic oxygen converters or electric furnaces. The open hearth furnace is still used to a limited extent but, in general, is being replaced by the basic oxygen converter or the electric furnace.

The basic oxygen converter

In the Bessemer process the high nitrogen content was due to a high rate of absorption from the air blast during the late stage of the process when phosphorus was being removed.

When the production of oxygen in large quantities became practicable, attempts were made to replace the air blast in the Bessemer process with oxygen but the refractory lining of the converter would not withstand the high temperatures which were generated.

In the basic oxygen converter this difficulty was overcome by making the bottom of the vessel solid and introducing oxygen

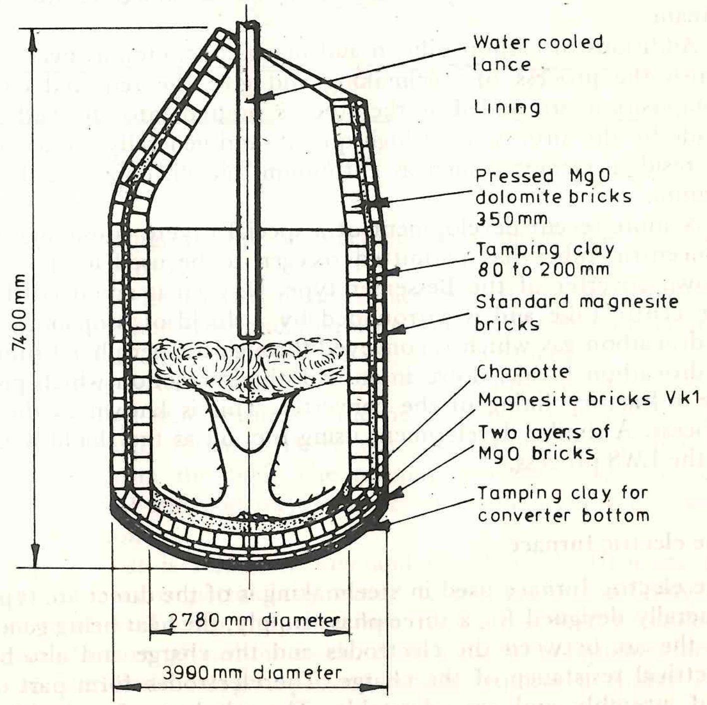


Figure 10.1 Basic oxygen converter

through the top by means of a watercooled lance as illustrated in Figure 10.1. The vessel is lined with basic refractories i.e. limestone or magnesia base. Converters of this type have capacities up to about 300 tonnes and can be tilted about a horizontal axis for charging and discharging.

The converter is charged with molten iron produced in the blast furnace and kept molten in a large capacity holding furnace until required. Up to about 20–25% solid steel scrap can be used in the initial charge.

The oxygen is blown into the converter for a standard period of time and the carbon content is reduced to a very low value. It is possible to remove the slag at an intermediate stage and this contains a high proportion of the sulphur and phosphorus. A second slag can be formed to complete the refining process and this double slag technique results in a steel with very low sulphur and phosphorus content. When the phosphorus content of the original iron is over about 1% it is necessary to modify the process by injecting additional quantities of lime in powder form, this is added in the oxygen stream.

Additions of carbon, silicon and manganese, etc., as necessary, to finish the process of steelmaking and give the required chemical composition are added as the steel is poured into the ladle. Steel made by this process is of high quality and generally has a low level of residual elements such as chromium, nickel, copper and molybdenum.

A more recent development of a special tuyere consisting of two concentric tubes has permitted oxygen to be used in the bottom blown coverter of the Bessemer type. Oxygen is admitted through the centre tube and is surrounded by a shield of propane or other hydrocarbon gas which is conveyed through the peripheral tube. The hydrocarbon breaks down in an endotheric reaction which protects the refractory lining of the converter. This is known as the OBM process. A similar development using fuel oil as the shield is known as the LWS process.

The electric furnace

The electric furnace used in steelmaking is of the direct arc type and generally designed for a three-phase supply, the heat being generated by the arc between the electrodes and the charge and also by the electrical resistance of the charge. The electrodes form part of the roof assembly and are adjustable. The whole roof assembly may swing out to allow the furnace to be charged through the top and

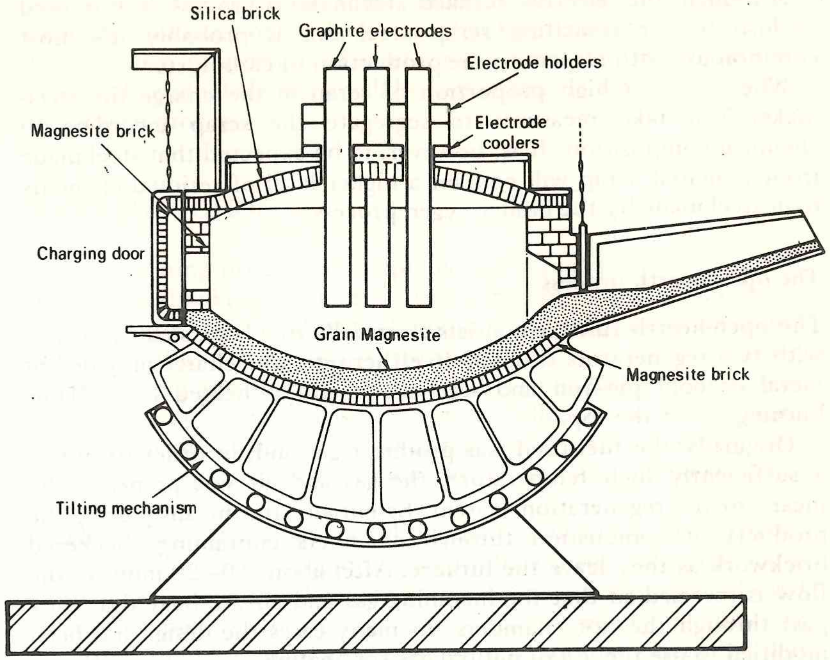


Figure 10.2 Diagrammatic arrangement of electric-arc furnace (Basic lined)

also for discharging, or the arrangement may be similar to that illustration in Figure 10.2.

The furnace is lined with basic refractories. It can be tilted to discharge the finished steel and therefore, the double slag procedure can be operated as described for the basic oxygen process.

Electric furnaces were first developed for the production of alloy steels because high temperatures could be attained more easily than in the open hearth furnace. There was also the advantage of less contamination from the fuel. The refining process is by reaction between the metal and slag, oxygen injection can be used to increase the rate of reaction.

The capital cost is relatively low and the thermal efficiency is good. The process is particularly suited to melting and refining a charge of solid steel scrap and, therefore, its use has been extended to the manufacture of carbon steels. It is a useful complementary facility to the basic oxygen process which requires a charge of molten metal.

Although the electric furnace steelmaking process is not used exclusively for remelting scrap steel this is probably it's most common use with respect to the production of carbon steels.

When using a high proportion of scrap in the charge the steelmaker will take measures to segregate the scrap according to chemical composition. It is, however, to be expected that steel made from remelted scrap will contain a higher level of residual elements than steel made by the basic oxygen process.

The open-hearth process

The open-hearth furnace consists essentially of a large shallow hearth with two regenerators situated on either side. The charge may be hot metal or cold pig-iron and steel scrap and is heated by a flame burning across the top.

Originally the fuel used was producer gas and, in order to obtain a sufficiently high temperature, the gas and air was preheated by means of the regeneration system. Essentially this means passing the products of combustion through chambers containing checkered brickwork as they leave the furnace. After about 10–20 minutes the flow is reversed so that the incoming gas and air are heated as they pass through the hot chambers. In many cases the design has been modified to use fuel oil or natural gas for heating.

As the working temperature of the open-hearth furnace is limited by the safe working temperature of the refractory roof, it is essential that high-melting-point refractories are used.

In the basic open hearth furnace the walls and bottom are built of basic refractories. This permits the removal of sulphur and phosphorus, however, the original furnace design does not provide for removal of the slag at an intermediate stage in the process. For this reason these elements will not be reduced to the low values obtained in the basic oxygen process as described but will be suitable for most applications.

Open hearth type furnaces have been built with a facility for tilting and in these cases the double slag procedure can be used.

The acid open hearth furnace is built entirely of silica base refractories and for this reason it is not possible to remove sulphur and phosphorus. The choice of raw materials for the charge is therefore, very limited and it is unlikely that the process is now operated.

The main disadvantages of the open hearth process are the low thermal efficiency and the long refining period. These have been improved by oxygen enrichment in the combustion zone and oxygen

injection into the bath. By these methods an efficiency similar to the electric and basic oxygen processes has been claimed.

When a high proportion of steel scrap is used it is inevitable that the level of residual elements will be higher than in steel made by the basic oxygen process.

PLATE PRODUCTION

When the refining process is completed the liquid steel is discharged from the steelmaking furnace to preheated refractory lined ladles where elements such as silicon, aluminium and manganese are added to deoxidise the steel, i.e. to prevent the evolution of gas in excessive amounts during the solidification period. Depending on the extent of this treatment the steel is either fully killed or balanced (semi-killed). When the evolution of gas is not prevented, a rimming steel is produced which is not suitable for boiler and pressure vessel construction.

Traditionally, the liquid steel is then transferred or 'teemed', into rectangular cast iron moulds to produce ingots of suitable size for rolling into slabs and then into plates. The ingots are either allowed to cool completely for storage and surface dressing or they are transferred hot to soaking pits after solidification is completed and are re-heated to about 1200°C before rolling is commenced. Surface dressing is done at a later stage in the rolling process.

As an alternative to casting into ingot moulds the liquid steel may be processed in a continuous casting plant such as is shown in Figure 10.3. The steel is solidified in a short water cooled copper mould and then cooled by water spray before cutting into suitable lengths.

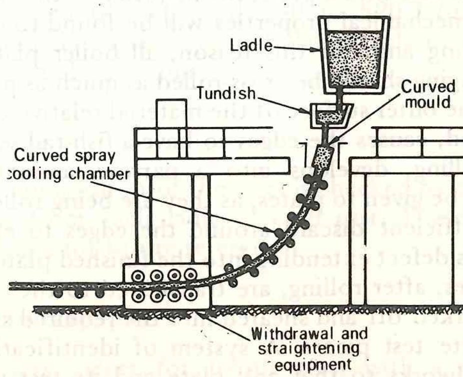


Figure 10.3 Continuous casting

Slabs for rolling into plates may be cast with thicknesses up to 300 mm and widths up to 1800 mm depending on the capacity of the steelmaking furnace and the dimensions of the end product. The continuous casting machine may have a number of casting strands which are all filled from one tundish.

The product of the continuous casting machine will contain a certain looseness in the 'as cast' structure with voids on the micro and macro scale. It is important that sufficient hot work be given to break down the as cast structure and weld up any internal discontinuities. In plate production the final thickness must be less than 25% of the cast slab thickness and many manufacturers will give a greater rolling reduction than this.

Segregation is, in general, less of a problem in continuous cast material than in conventional ingots. There is a better yield of usable steel and the expensive ingot casting pit, soaking pits and primary rolling mills are eliminated.

Rolling and testing of plates

When plates are manufactured from an ingot, as opposed to the continuous casting process previously described, the first operation is termed 'cogging'. This is carried out in the primary rolling mill and considerably reduces the section of the ingot. After portions have been cut off from the top and bottom ends and discarded the resulting slab is then divided into smaller slabs.

From this stage the material manufactured by the continuous casting method and that formed from cast ingots are processed similarly. After reheating, the slabs are rolled in the finishing or secondary mill to produce the thickness of plates required.

If, on rolling a slab into a plate, the majority of the rolling is done lengthwise, the mechanical properties will be found to vary with the direction of rolling and, for this reason, all boiler plates and plate intended for flanging should be cross-rolled as much as possible.

The flow of the outer surface of the material relative to its interior, while being rolled, causes the edges to have a fish-tail section, which with further rolling, develops into a narrow lamination. Special attention has to be given to plates, as they are being rolled, to ensure that there is sufficient discard around the edges to eliminate any possibility of this defect extending into the finished plate.

The steel plates, after rolling, are transferred to the cooling bank, and are then marked off and sheared into the required sizes together with the requisite test pieces. A system of identification must be used at the steelworks so that any plate and its test piece can be traced back to the original furnace charge.

The test carried out on each plate, as rolled, vary with the design, application and manufacturing code to which the boiler or pressure vessel is to be constructed.

The current requirements have become rather complex by the introduction of tests to assess the mechanical properties of the material at elevated temperatures. These have been introduced mainly for design purposes with the view to achieving a reduction in design scantlings which, in turn, often influence final manufacturing costs. When the design working temperature of the pressure vessel exceeds 100°C. therefore, elevated temperature tensile tests may be specified.

It should be noted that in accordance with these latest requirements for material for boiler construction bend tests may not be required as it has been found, by experience, that the mechanical properties of steels having the specified chemical analysis and manufactured by approved methods can be adequately tested by means of tensile specimens alone.

Full details of the latest material specifications may be found in the publications of ISO, British Standards, DIN, ASME, etc, or in the Rules of the classification societies. One of these should always be consulted when dealing with this matter.

The tests referred to above are performed in the steelworks test house and are usually witnessed by an independent inspection authority. The test pieces may be cut lengthwise or crosswise from the rolled material and, in the event of any heat treatment being performed on the material, the test pieces must be treated simultaneously.

In general, the specified minimum tensile strength of carbon or carbon-manganese steel plate intended for boiler shells or drums should be between the limits of 340 to 520 N/mm^2. For boiler furnaces, combustion chambers and flanged plates the limit should be between 400 and 520 N/mm^2.

Chemical analysis

The chemical compositon of the steel is checked by the makers from samples taken from each ladle of each cast. These particulars are carefully recorded for future reference.

Tensile test results for plates

Proportional test pieces for tensile tests with a gauge length of $5.65 \sqrt{(S_0)}$, where S_0 is the cross-sectional area of the test length, are the usual form of the test-pieces required. These are usually of rectangular cross-section with the two rolled surfaces retained for plates up to about 30 mm thick. Round machined test pieces are used for thicker plates. For routine testing purposes test-pieces with other diameters and gauge lengths may be used, but the percentage elongation should be computed in terms of $5.65\sqrt{(S_0)}$.

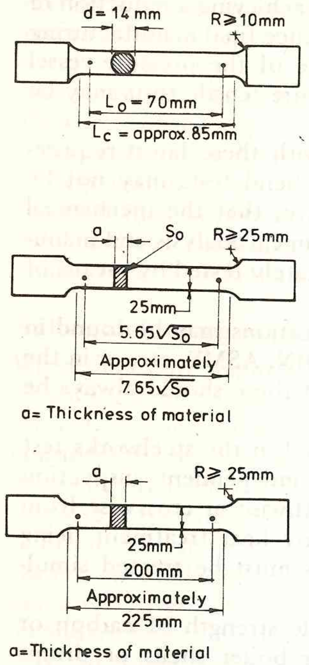


Figure 10.4 Test pieces

Standard test pieces used for testing boiler quality steel are shown in Figure 10.4.

Tensile test results required for bars

In the case of bar material used for boilers, machinery and rivets, the section required is again produced by rolling, although in this case a different type of mill is used. The tests required for bars are similar to those required for plates.

The samples from bars and other small rolled sections may be tested in full section. The cross-sectional area can be calculated either from accurate measurements of average dimensions or by determining the weight of a known length.

Rivet bars are subjected to additional tests, namely, sulphur, printing and dump-testing, before being accepted for rivet making. Sulphur-prints are made of the cross-section of the bar, to prove the non-existence of sulphur segregates in the core. In the dump test short lengths equal to twice the bar diameter are cut from the bar and have to withstand, without fracture, being compressed to half their length.

11 Boiler construction

It would appear that riveted construction for boilers began in the early nineteenth century and, according to early works on the subject, wrought-iron riveted boilers constructed from plates only 3 ft by 1 ft were in use at that time working at pressures up to 10.3 bar.

Riveting has now been almost entirely superseded by electric welding for all forms of boiler construction. The use of welding for boiler-shell seams has resulted in a higher joint efficiency, relatively-thinner shell plating, lighter construction and freedom from seam leakages.

Riveted construction

The types of riveted joints that were commonly used in boiler construction were the single- and double-riveted lap joints, and the treble-riveted double-butt strap joint.

The use of lap joints was formally confined to the attachment of end-plates to shells, and to the internal parts of boilers such as combustion-chamber assemblies. Apart from the lower joint efficiency of the lap joint, it is not, generally speaking, a satisfactory joint for longitudinal seams of shells, as the tendency of the shell to become a perfect circle when under internal pressure strains the joint, which can result in fine grooving and subsequent failure.

On account of the foregoing, except in the case of some small low-pressure vertical boilers, treble-rivted double-butt strap joints were almost invariably used for longitudinal seams.

In the early days of boiler making, rivet holes were punched; many were the different forms of punches used in the endeavours made to obtain clean, undistorted holes, and to lessen the injury to the plate. It was soon realised, however, that to obtain a joint in which all the rivets took their fair share of the load, drilling was absolutely essential, and in first class work all rivet holes were drilled in place with the seams tack-bolted together. After the drilling

operation, the seams were dismantled for deburring of the hole edges and then reassembled for riveting.

Riveting was performed either by hand or machine, the rivets normally being inserted from inside the boiler and knocked up, or pressed up hydraulically, from the outside. Machine-riveting was not without its troubles, for if too great a pressure was used, cracking between rivet holes sometimes occurred; and if the seam was not properly closed, any overheated rivets tended to flow out between the plates.

The machines used for hydraulic riveting of shell seams consisted, in effect, of two long arms connected together through a opening in the shell in such a manner that with one arm inside holding up the rivet, hydraulic pressure could be applied via the other arm for closing the rivet with a spherical die.

On completion of riveting a light caulking of the plate edges inside and outside completed the seam.

Welded construction

Welding as first applied to boilers was of the 'fire' or 'forge' type and was used for the longitudinal seams of furnaces. In such an application it was relatively safe, as any slight lack of fusion in a part which operates under compression did not necessarily result in a rupture.

The advent of electric welding – a system in which molten metal is added to a seam, and which in fusing with the plate edges forms a homogeneous joint – has revolutionised the boiler making industry.

In electric welding, a high-amperage low voltage current is arced across a gap between an 'electrode' or wire and the plate on which the metal of the electrode is to be deposited, the heat of the arc being sufficient for complete fusion to take place between the beads of metal from the wire and the plate.

Riveted Scotch boilers often double-ended with four furnaces each end and working pressures between 12.5 bar and 15 bar were quite usual in passenger liners, and a plan of a typical example with data is shown in Figures 11.1(a) and (b). All-welded Scotch boilers were produced both for main propulsion and auxiliary services, but as steam reciprocating engines were abandoned in favour of diesel engines so the demand for large tank boilers decreased, and all-welded Scotch boilers in smaller sizes were relegated to auxiliary steam services in motorships; particularly tankers where large quantities of steam are required for heating and pumping.

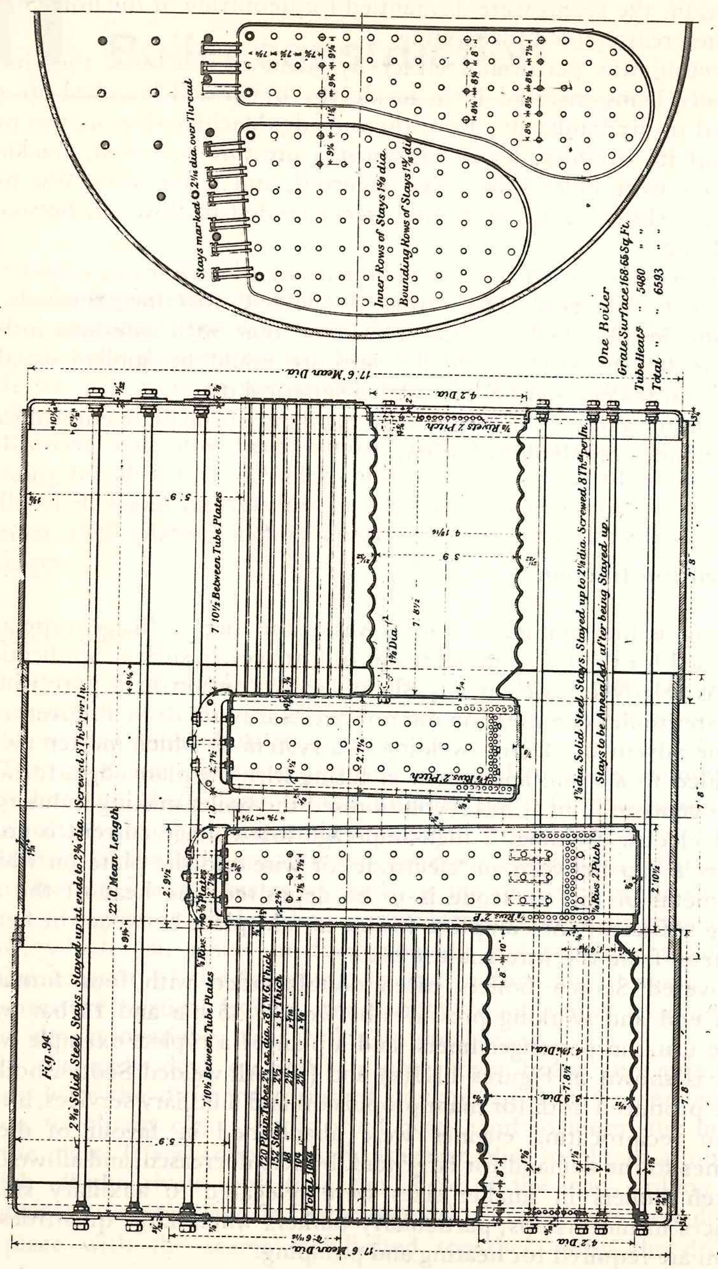


Figure 11.1a Plan view of double-ended Scotch Boiler of the ss 'Mauritania' of 1907

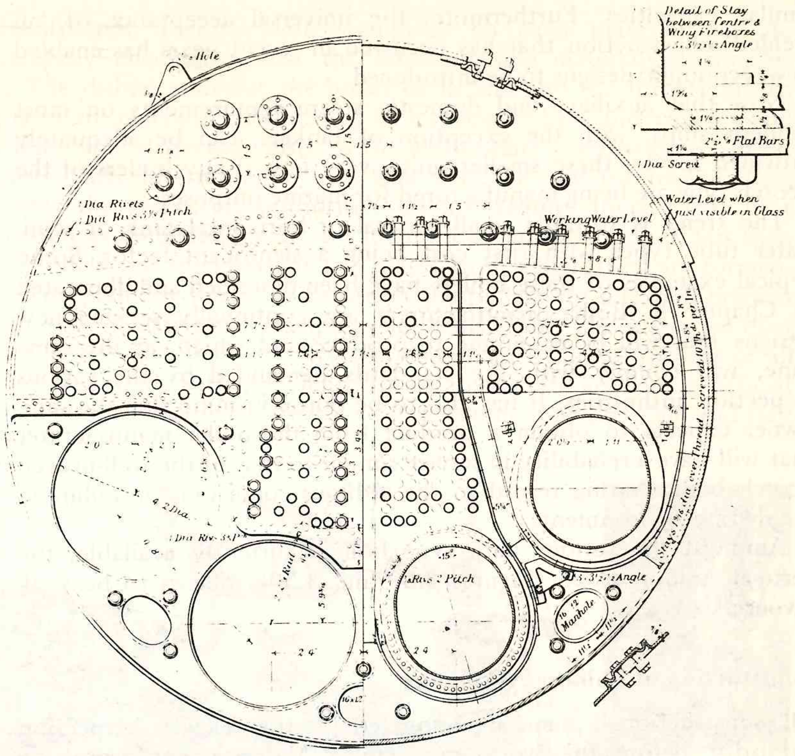


Figure 11.1(b) End view of double-ended Scotch boiler of the ss 'Mauritania'

Boiler Data		
Diameter	*17.5 ft*	*(533 cm)*
Length	*22 ft*	*(671 cm)*
Heating surface	*6593 sq. ft*	*(612.6 m²)*
Grate area	*168.65 sq. ft*	*(15.6 m²)*
Number of furnaces	*8*	
Working pressure	*195 p.s.i.*	*(13.4 bar)*
Total number of boilers	*23*	*Double-ended*
	(+2	*Single-ended)*

MODERN VERTICAL TANK TYPE BOILER CONSTRUCTION

The conventional methods of manufacturing tank type boilers, as described in the previous section, resulted in a strong and practical pressure vessel renowned for its reliability in service. However, the large amount of work required in forming the various plates used to make the combustion chambers, flanged end plates and also corrugated furnaces made the finished product relatively expensive when compared with modern vertical and horizontal boilers of similar capacities. Furthermore, the universal acceptance of 'all welded' construction that has occurred in recent years has enabled new, economic designs to be introduced.

Now that auxiliary and domestic steam requirements on most modern ships, with the exception of tankers, can be adequately provided for by these smaller units, very few, if any boilers of the Scotch type are being manufactured for marine purposes.

The trend is towards small vertical or horizontal tank or semi-water tube types with first cost being a significant factor. Some typical examples of these boilers have been described and illustrated in Chapter 3. Boiler manufacturers are continually seeking new designs that will be economic to produce and which, at the same time, will comply with the standards demanded by the various inspection authorities. It has also to be borne in mind that the ship-owner expects to obtain a product from the boiler manufacturer that will have a reliability in service similar to that of the well-proved Scotch boiler having regard to the arduous conditions prevailing in the marine environment.

Amongst the various tank type boilers currently available, the vertical Aalborg AQ3 (Figures 3.29 and 3.30) appears to be well-favoured.

Construction of Aalborg AQ3 boiler

All constructional plans are approved by the relevant inspection authority before the work commences. Materials conform to a specification agreed to by the inspection authority. The principal materials used in the manufacture of the AQ3 boiler comply with the specifications for steel plates and rolled sections shown in the Table 11.1.

All materials are delivered to the manufacturers with material test certificates issued by the classification society or other inspection authority under whose survey the boiler is to be

Table 11.1 Specifications for steel plates and sections

Component	*DIN Standard*	*Equivalent British Standard*	*Approximate Minimum Tensile strength*
Shell & furnace plates	DIN 17155 H II	1501–151	430 to 520 N/mm^2
Downcomers and tubes.	DIN 17175 St. 35.8	3059–1968 steel 33	325 to 440 N/mm^2
Bar stays	DIN 17100 Rst. 42.2	1502–161 grade 28.	430 to 520 N/mm^2

constructed. Identification stampings on each plate or bar are carefully checked against the corresponding material certificates.

The dished ends for the boiler shells and also the furnace crown plates are machine cold-formed by a specialist firm under survey and these are delivered also with appropriate certification. It is particularly interesting to note that after the cold forming of these plates the inspecting authorities do not require them to be heat treated as their designs do not incorporate internal radii of less than ten times the thickness of the plates from which they are formed.

The plates required to construct the boilers are selected, marked out and identification stampings are transferred. The plates are then cut to size and shape by oxy-acetylene flame. Careful records of all materials used, with the identification marks, are kept in an official data book. Tube plates are drilled to accommodate the plain and stay tubes.

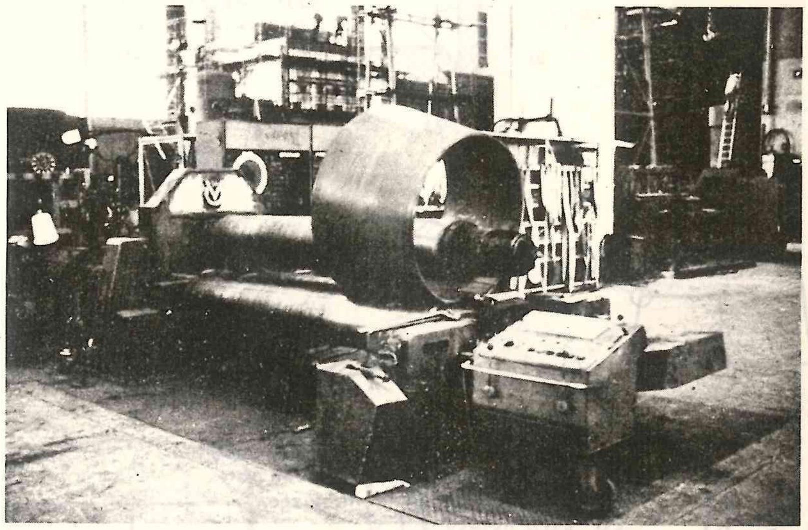


Figure 11.2 Furnace side plate of Type AQ3 boiler undergoing rolling operation (Note the collapsible end housing of plate rolls to enable the rolled plate to be withdrawn)

The actual construction of the boiler commences with the rolling of the shell plates and furnace side plate as shown in Figures 11.2 and 11.3(ii). The subsequent stages in the construction are shown diagrammatically in Figures 11.3 to 11.7.

All principal shell seams are automatically welded using the submerged arc process (see Figure 11.8), a backing run, by inert gas welding, being initially applied. On completion of the internal weld,

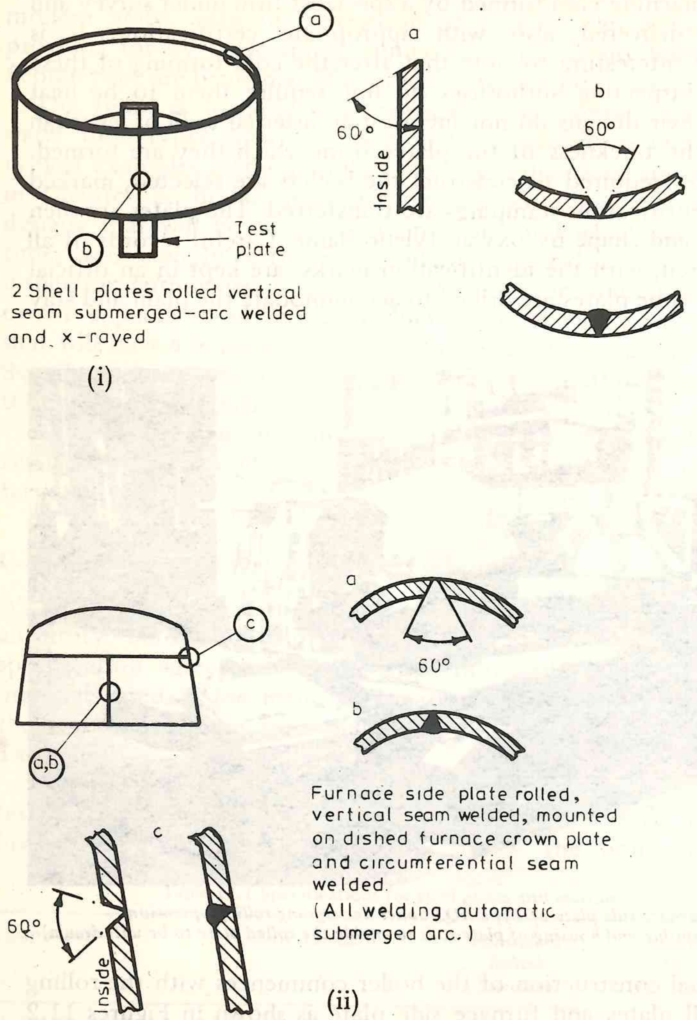


Figure 11.3 Stages in construction of the Aalborg boiler

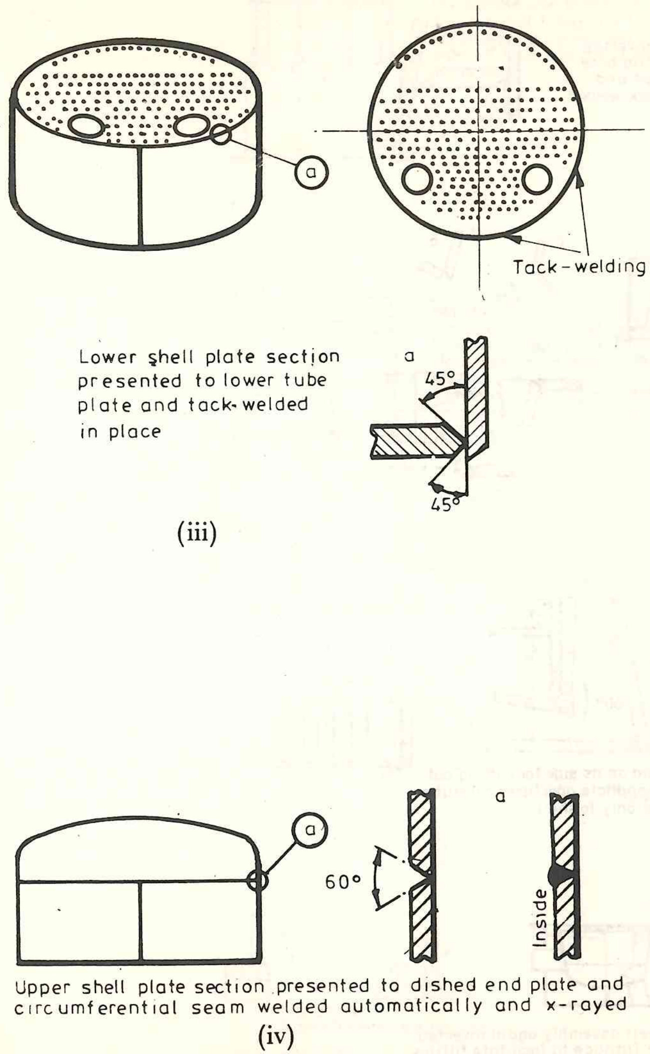
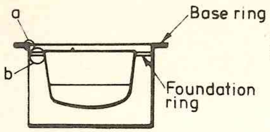
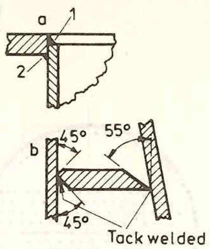


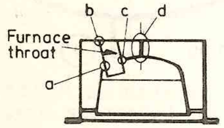
Figure 11.4 Stages in construction of the Aalborg boiler (continued)



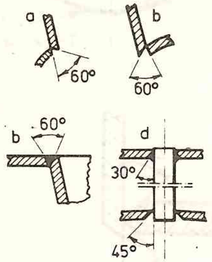
Lower shell assembly inverted to attach foundation and base rings. Furnace inserted and and all connections tack-welded.



(v)



Lower shell assembly set upright for fitting attachment of centre bar stay. Stay and throat fully welded to lower tube plate.



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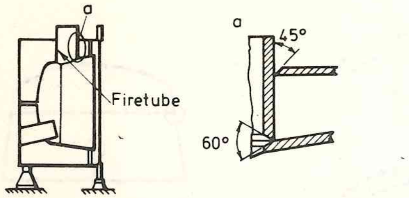
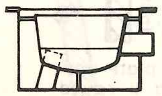


Lower shell assembly laid on its side for cutting out firetube, manhole and handhole apertures. Firetube fitted and tack-welded only to shell.

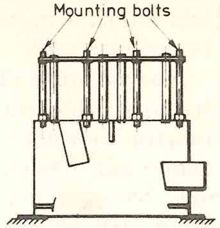
(vii)



Lower shell assembly again inverted to remove furnace to facilitate fitting, aligning and securing of upper tube plate.

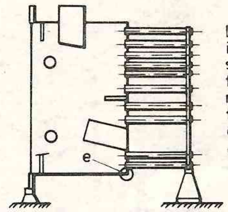
(viii)

Figure 11.5 Stages in construction of the Aalborg boiler (continued)

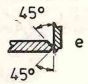


Lower shell section placed upright. Mounting bolts fitted temporarily to align and set the upper tube plate. A number of tubes are then inserted and permanently welded to locate the upper tube plate.

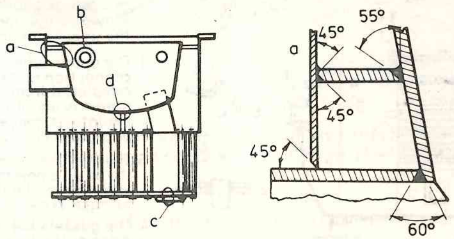
(ix)



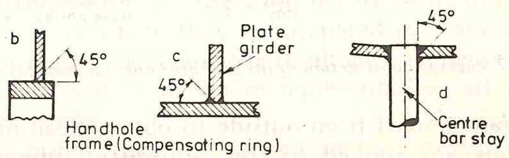
Lower section again laid on its side and all remaining stay and plain tubes permently fitted. All tack-welded connections made permanent except that of the shell. Handhole and manhole compensating ring now fitted and permanently welded.



(x)



(xi)



Lower assembly inverted to receive furnace which is then permanently welded to foundation ring, furnace throat, firetube and centre stay. Plate girders welded to upper tube plates

(xii)

Figure 11.6 Stages in construction of the Aalborg boiler (continued)

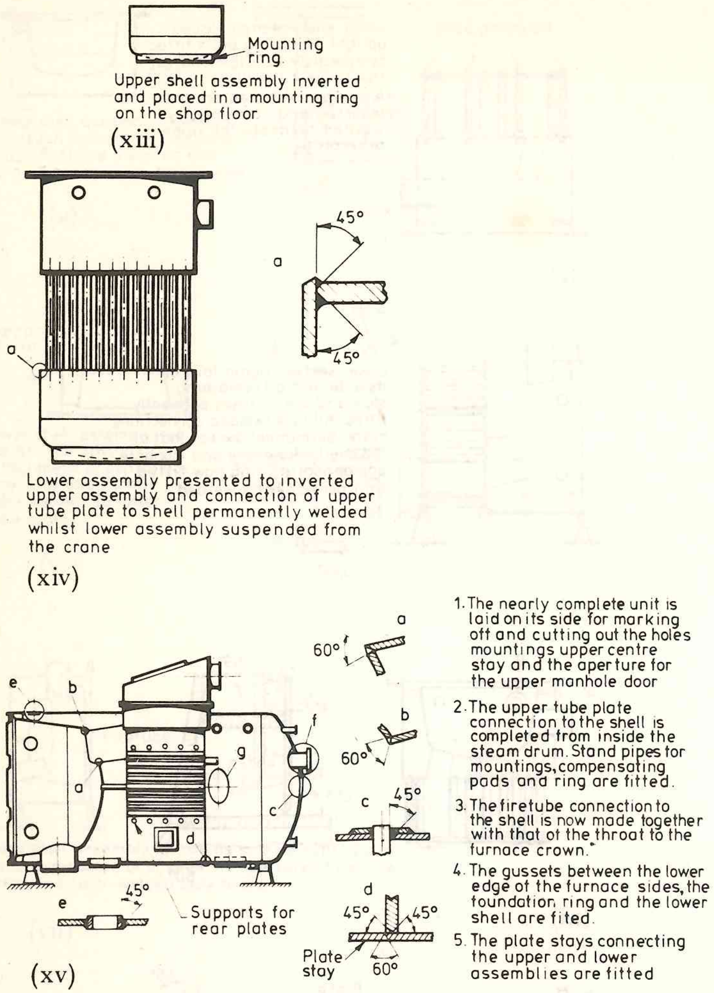


Figure 11.7 Stages in construction of the Aalborg boiler (continued)

it is air/arc gouged from outside to obtain clean material before the final runs are applied by the automatic submerged-arc process.

Plate edges are normally prepared for welding as shown in Figures 11.3 and 11.4 (i, ii and iii), but when the plate thickness is less than 12 mm, the edges are not bevelled preparatory to welding as it has been found that a full penetration weld can be achieved satisfactorily without such edge preparation.

All procedures are in accordance with the requirements laid down by the classification societies and generally comply with the requirements of most other recognised inspection authorities for Class 1 Fusion-Welded Pressure Vessels.

Test pieces are only required for the longitudinal welded shell seams. The test plates are prepared in duplicate but only one set of test pieces is prepared, the remaining test plate being held in reserve in case retests are required. The longitudinal seams are subjected to 100% X-ray examination with test plates attached. It should also be noted that the test plates are of sufficient length to provide

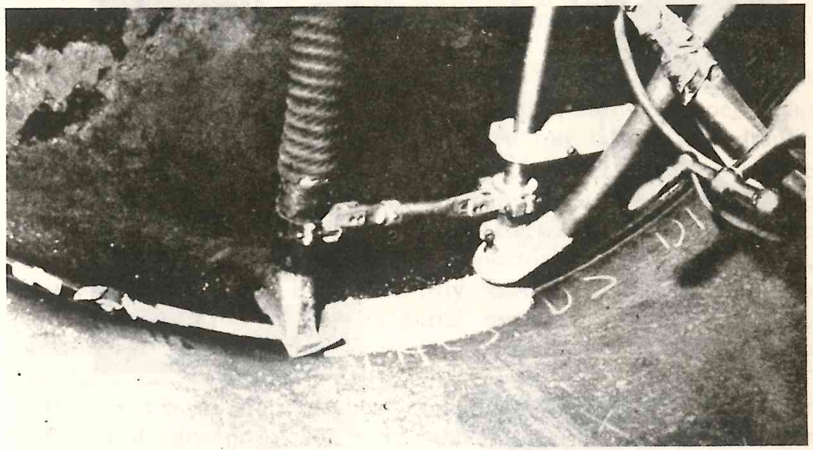


Figure 11.8 Automatic welding of circumferential seam by submerged arc process
Note the vacuum foot for removing excess flux granules on the left and the weld head and flux dispenser on the right

for adequate 'run out' of the weld so that a good homogeneous weld is achieved both in the main seam and in the portion of the test plates from which the actual test pieces are machined. The test plates are stamped for identification before being detached and sent to the laboratory where they are prepared in a similar manner to that shown in Figure 11.26 and the resultant test pieces all proved by an independent institution whose representatives are in regular attendance at the works.

It should be noted that test plates are not prepared for the longitudinal seam of the furnace side plate. This seam, together with the circumferential seam of the furnace, is examined over 10% of its length by X-ray. Other welded seams, such as the circumferential seams connecting the shell sections to the tube plates and the connections of the foundation ring to the shell and furnace, are

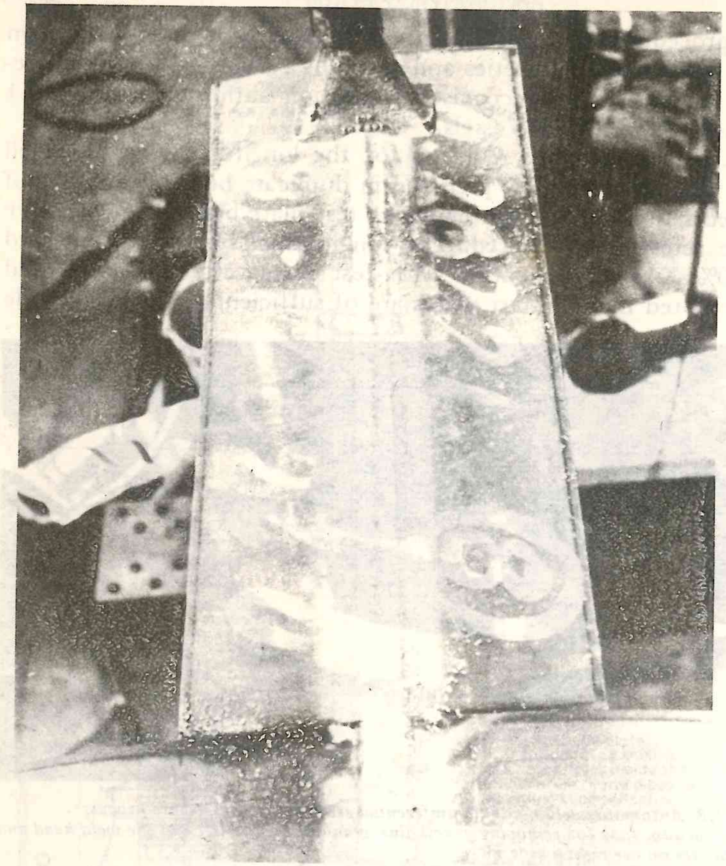


Figure 11.9 Test plate attached to section of boiler shell awaiting stamping before being detached and sent to laboratory. The vacuum foot can be clearly seen in the top centre

examined by other forms of non-destructive testing using ultrasonic, magnetic particle or dye penetrant methods as it is not practicable to prove these by X-ray.

Correct alignment of the various sections and plates forming the shell and furnace is essential. In no case are two plates to be out of alignment with each other by more than 10% of the plate thickness. Special attention requires to be given to maintaining the true circular shape of the shell and furnace. In general, it should not be out of round by more than 1% of the internal diameter.

Special attention is paid to the provision of 'tell tale' holes of 6 mm diameter in each end of bar stays. These holes are drilled about

50 mm deep in order to give timely indication of the formation of cracks in the stays in service.

Stay and plain tubes are expanded in the holes of the tubeplate before being secured by welding and further expanded after completion of the welding.

All lugs, brackets, standpipes, compensating rings and plates including manhole frames are made to conform to the shape of the surface to which they are to be fitted. Reinforcing plates are provided with 'tell tale' holes which are drilled prior to the plates being fitted in order to release any air or moisture trapped between the plates at the time the closing weld is being applied. Although not shown in the sketch, a reinforcing or compensating plate is fitted to the shell in way of the firetube.

Spot checks, by magnetic particle testing technique at the rate of 10% of all welded connections of standpipes, stubs, compensating plates and other attachments are carried out before a hydraulic pressure test of 1.5 times the working pressure is applied to the finished boiler. All welded seams are carefully inspected while the boiler is under the hydraulic pressure. Afterwards, further magnetic particle testing is carried out to the inspector's satisfaction. Finally, an identification plate is permanently fixed to the boiler shell in a prominent position bearing a serial number, approved working pressure, test pressure and the inspection authority surveyor's stamp and date.

It is worth noting that heat treatment of the complete boiler shell is not carried out nor is this a classification requirement. This complies with most acceptable boiler codes for boilers of the AQ3 type when the shell thickness is less than 20 mm.

MANUFACTURE OF WELDED BOILER DRUMS

A brief description of the manufacture of boiler drums is given below. We acknowledge the help of Northern Engineering Industries John Thompson Ltd (General Engineering Division) in the preparation of this section.

Making the plates

Plates for the cylindrical shell of the drum are ordered from the steel mill to specified thicknesses, lengths and widths. The thickness of the plate is dependant upon the pressure and temperature contained within the drums and also upon the tensile strength of the steel chosen.

There are many grades of boiler quality steel available and the selection of the correct grade for a specific application is usually related to economics. The width of the plate is dependant upon the number of courses in the drum which in turn is related to the maximum width of plate available from the mill (usually 3960 mm) and to the manufacturers plant capacity. The quality of the plates is checked at the steel mill by chemical analysis, mechanical testing to determine tensile and yield strengths, elongation etc., and visual examination. Generally plates above 50 mm thick are also subjected to ultrasonic non-destructive examination to determine whether or not detrimental sub-surface defects, laminations etc., are present.

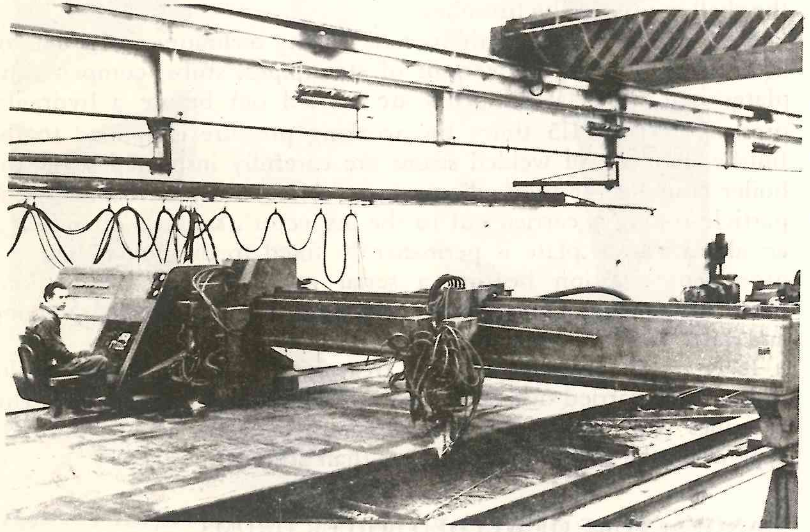


Figure 11.10 Plate on Hancosine magic eye flame planer

After delivery the plates are marked off to the circumferential length of the drum, to the required course width and then gas cut to size (Figure 11.10). The two opposite edges of the plate which when rolled will be at the open ends of the cylinder, are then chamfered for 13 mm at 45° to prevent cracking when the metal flows during the subsequent rolling operation. The plates that comprise the shell of the drum are formed into cylindrical shape by rolling. This rolling machine is fitted with a hinged entablature at one end so that when the plate is rolled into a cylinder the entablature complete with one of the upper roll bearings can be swung clear and the rolled cylinder slid off the upper roll (Figure 11.11).

Where the shell plate thickness is excessive and the drum diameter is small, difficulty can be experienced during rolling in imparting the correct curvature right up to extreme edges of the plate. On these occasions the ends of the plates prior to rolling are preset to the correct curvature by edge bending under a 1200 tonne capacity vertical edge bending press. The rolling operation can be carried out with the plates in either the cold or hot condition.

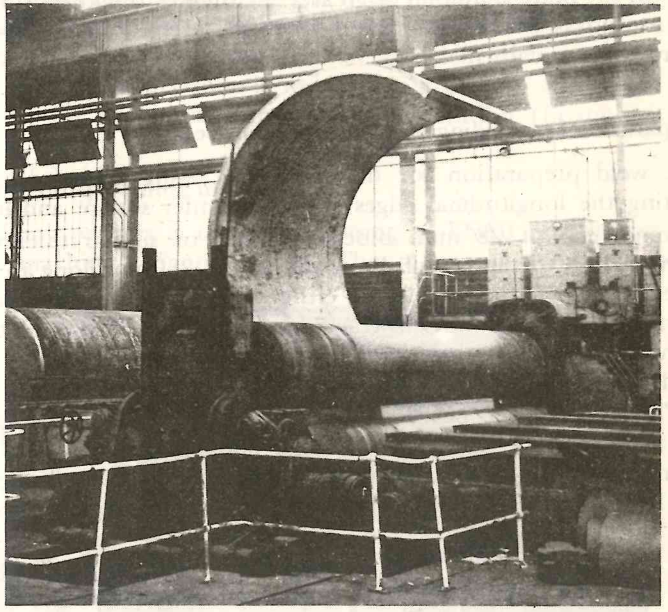


Figure 11.11 Rolling operation

Generally cold rolling is suitable for plate thicknesses of 50 mm or less, with a cold yield strength of 262 N/mm^2 maximum and relatively large diameters of drum. With high yield steels or thicknesses in excess of 50 mm, the load required to deform the plate to produce the cylinder may be in excess of the machines capability in which case the yield strength of the plate is reduced to approx 75 N/mm^2 by heating in a large gas-fired plate heating furnace to a temperature between 950°C and 1050°C. At all times during the heating period the temperature of the plates is monitored and recorded on heat treatment charts. When the plates have reached the desired temperature they are removed from the furnace and rolled to the required size whilst hot.

Welding the longitudinal seam

The next operation is to weld the longitudinal seam of the cylindrical course. There are numerous methods available – the electro-slag process or submerged-arc process being the most common. The choice of process is generally determined by economic considerations. The electro-slag process produces the weld in a single pass, produces a defect free weld and is always used when the thickness of the plate is 50 mm or greater. Below this thickness submerged arc multipass welding is utilised since for several considerations it is more economical.

Preparation for welding by electro-slag process

The weld preparation for this process is easily achieved by flame cutting the longitudinal edges of the cylinder square and leaving a nominal gap of 28 mm. Blocks of steel of similar thickness and composition to the actual drum and about 230 mm long are welded to each end of the cylinder on either side of the butt and form the start and finishing blocks. These blocks as can be judged by their name are for initiating and finishing off the weld process (Figure 11.12).

The walls of the butt are then dressed free of scale and an area 50 mm wide on both the internal and external surfaces of the cylinder, and on both sides of the welding gap, is dressed smooth for the full length of the weld. This ensures that the copper shoes used in the welding process will fit tightly and run smoothly on the surface of the cylinder. The rolled cylinder is then assembled in the vertical position for the electro-slag welding process using wedges, clamps and bridges where necessary to ensure a welding gap of 28 mm at the bottom where the welding will commence and 32 mm at the top where the welding will finish. The additional gap towards the top of the cylinder allows for contraction of the cylinder.

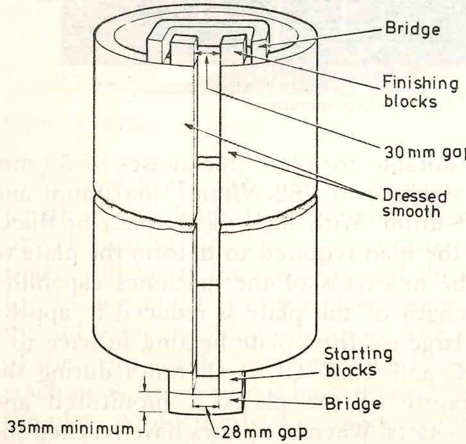


Figure 11.12 Sketch of cylinder showing starting and finishing blocks used in the electro-slag welding process

When the necessary weld gap has been obtained a plate of 35 mm minimum thickness is welded across the bottom starting blocks. A bridge of ample thickness and of a size sufficient to ensure clearance for the internal copper shoe is welded on at the top end to prevent closing of the gap during the welding operation (Figure 11.12).

The electro slag welding machine

The welding process is carried out using an ESAB ES3 electro slag welding machine (Figure 11.13). The maximum length of seam

Figure 11.13 Electro-slag welding machine

which can be welded is 4260 mm with thicknesses ranging from 38 mm to 355 mm.

The ES3 machine uses 3 mm diameter electrodes and can utilise three separate electrodes at currents up to 900 amp per electrode. The machine travels up a vertical column positioned adjacent to the workpiece, or clamped to it by means of two special support clamps.

The power source is a three phase output constant potential transformer delivering up to 900 amp per phase continuously. The output voltage is adjustable on load in six stages from 40 to 60 V. The welding head is mounted on an adjustable speed, reciprocating carriage, enabling the electrodes to be oscillated across the gap.

Table 11.2

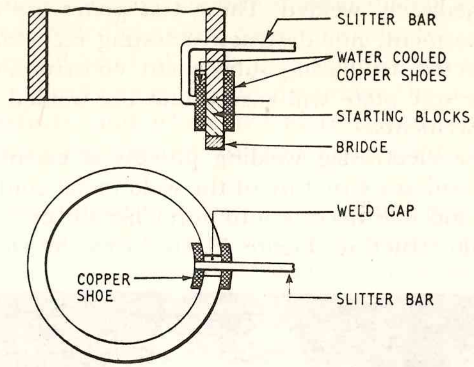
Plate thickness mm	*Number of electrodes* (3 mm dia.)	*Welding speed* m/h
40	1	2.0
70	2	2.2
100	2	1.7
120	3	2.1
150	3	1.7
200	3	1.3
300	3	0.9

The deposition rate is dependent upon the plate thickness being welded and the number of electrodes used. Table 11.2 relates these to deposition rates.

Electro-slag welding process

The process is carried out in the vertical position and involves the continuous depositon of molten metal between the two plates to be joined. Through the weld gap runs a slitter bar and attached to this is a water-cooled copper shoe which is located across the weld gap inside. A further water cooled copper shoe is located across the weld gap externally (Figure 11.14).

The weld is started by placing a ball of wire wool in the start block, covering it with the appropriate flux, and setting the water-cooled copper shoes local to the start blocks. The electric current is then switched on, the filler wire is fed into the wire wool thus causing an arc. The resistance heating effect generates sufficient heat to melt the electrode and fuse the plate edges thus forming a molten metal pool underneath the slag bath. The slag bath and metal pool are kept in position by the water cooled copper shoes which move vertically upwards with the welding head of the machine (Figure 11.15).



Fiugre 11.14 Electro-slag welding process showing position of starting blocks and water cooled copper shoes

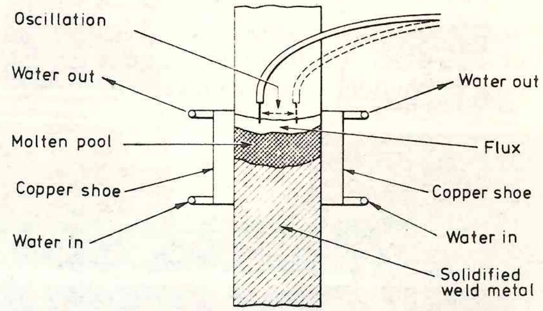


Figure 11.15 Principle of operation of the slectro-slag welding process

Since the heat source is always above the molten metal pool, solidification starts from the bottom allowing gas and slag to rise to the surface, where they escape into the atmosphere or are absorbed into the slag bath. Welding is continued by the process of raising the machine and copper shoes vertically until switching off the power within the finishing blocks provided.

Depending upon the thickness of plate being welded it may be necessary to oscillate the filler wire between the copper shoes. This is a fully automatic operation through limit switches and allowing a dwell time of two seconds at each shoe. It is carried out as the machine and shoes are being raised and the filler wire is being automatically fed into the weld pool.

When the welding of the longitudinal seam has been completed test plates of the same material as the cylinder are set up to the same gap and immediately welded. These test plates are then given the same heat treatment, non-destructive testing etc., that the cylinder will be subjected to during subsequent construction. Mechanical testing of the test plate will ensure that the welded seam meets all contract requirements.

Because the electroslag welding process is essentially a casting process, the resultant structure of the weld metal contains extremely coarse grains and it is necessary to normalise the cylinder in order to refine the grain structure. Figure 11.16 shows the weld metal in the

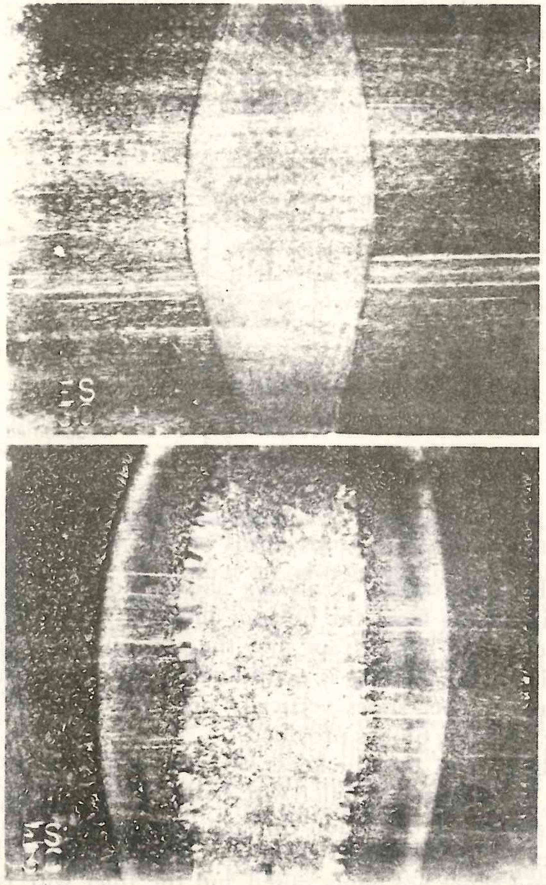


Figure 11.16 Showing macrostructure of slag weld
(above) as welded
(below) as normalised

'as welded' and 'normalised' condition. Immediately after normalising the cylinder is re-rolled to ensure correct circularity.

The longitudinal weld of both the cylinder and the test plate is 100% radiographically examined to determine the possible presence of harmful defects, and where the plate thickness is in excess of 75 mm ultrasonic examination of the welded joint supplements the radiography.

As already mentioned the electro slag welding process is normally used for drums of over 50 mm thickness, most marine drums are less than this figure and would have both longitudinal and circumferential seams welded by submerged arc process. In cases where longitudinal and circumferential seams are welded by different processes, representative test plates are required for each process.

Submerged arc welding process

The equipment used for this process comprises an ESAB A6 column and boom machine capable of welding cylinders of 5500 mm diameter and a longitudinal seam length of 5500 mm (Figure 11.17).

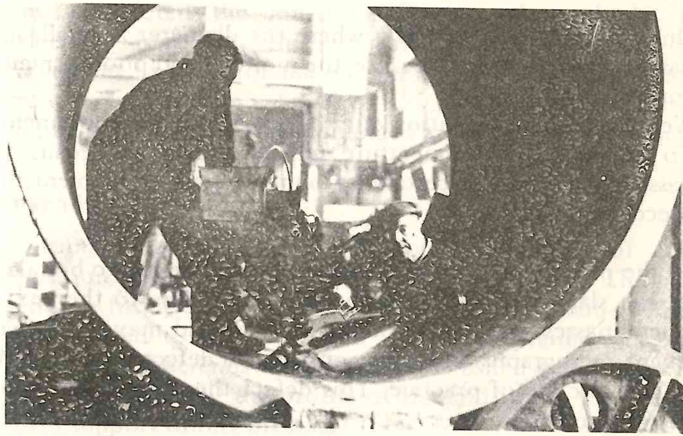


Figure 11.17 Submerged arc welding machine

The submerged arc process is an automatic welding method in which an electric arc is used to melt off a continuously fed wire electrode to form the weld deposit. A burden, or continuous pile of granular powder is laid down just ahead of the electrode. Part of this burden is fused by the arc, which is entirely submerged and this forms the slag which protects the cooling weld metal. The molten powder provides conditions which are very well suited to the use of exceptionally high currents, thereby making possible high welding speeds and deep penetration. There is an almost complete absence of spatter even at high welding currents and the deposition efficiency is maintained with a smooth weld finish and even penetration (Figure 11.18).

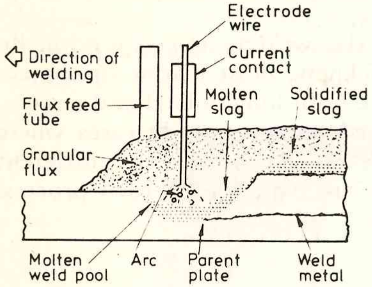


Figure 11.18 Schematic diagram of submerged arc welding process

Generally the submerged arc multipass technique as distinct from the depositon of two or three layers of weld metal is used for the welding of drum seams for the following reasons.

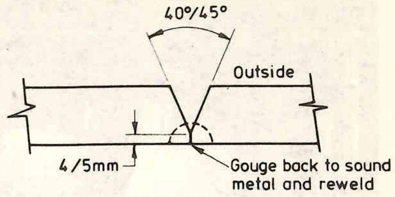
1. On circumferential welding where the diameter is small, multi-pass welding is used because the molten weld pool is small and controllable.
2. Welding current limitation due to capacity of the equipment.
3. To improve low temperature impact resistance because each pass will produce a certain amount of grain refinement in the preceding pass.

With the multipass welding technique great care has to be taken to remove the slag from each pass before proceeding to the next and subsequent passes. Slag that is trapped in a weld may be shown on subsequent radiographs and may constitute a defect unacceptable to the applicable code of practice. This defect then has to be removed and the weld remade.

A typical multipass weld preparation for welded seams is shown in Figure 11.19. Generally the preparation for longitudinal seams is flame cut whilst that for circumferential seams is machined.

To avoid hard zone cracking in the heat affected zones of welds in ferritic steels, it may be necessary to pre-heat the parent metal prior to the commencement of all welding, including tack welds. The pre-heat temperature depends upon the type of joint, the metal thickness, the composition of the steel and the heat imput to each run of welding.

Figure 11.19 Weld preparation for longitudinal seams



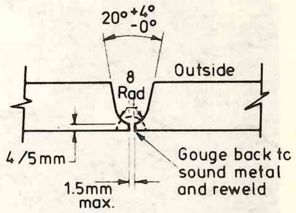


Figure 11.20 Weld preparation for circular seams

Circumferential welds

Having completed the longitudinal seam, the cylinder is then rounded by re-rolling, checked for circularity, marked off and machined on its ends for the circumferential seams. A typical weld preparation is shown in Figure 11.20. The circumferential seams always being welded by the submerged arc multipass process.

Drum ends

The drum ends are fabricated from steel plate of the same composition and tensile strength as the shell plates. The plates are heated in a furnace to a temperature in the range 950–1050°C and are hot pressed to shape under a 900 ton hydraulic ram press (see Figure 11.21). The ends are generally of dished and flanged profile, the top die producing the profile of the end whilst the bottom ring die gives support during pressing.

After pressing, the drum ends are given a separate normalising heat treatment and the weld preparation for the circumferential seam is machined on the periphery of the drum end.

The assembly of the drum ends and shell courses is made and the circumferential seams welded. The final closing seam is manually welded on the inside of the drum, access being obtained through a manhole located in the drum ends.

When all seam welding has been satisfactorily completed, a complete radiographic and/or ultrasonic examination as required is