between top and bottom drums and to all water-wall headers, these being located within the double casings of the boilers. To extract heat from the gases after leaving the boilers, economisers and/or air heaters are normally installed.

Current developments

The Babcock boilers described above are no longer in production but many are still in service at sea. Present-day boiler requirements are met by the MR, M21, and M11M types described below.

BABCOCK RADIANT OR MR BOILER

The MR boiler (see Figure 4.33) consists basically of two connected parts, a fully water cooled furnace and a fully water cooled chamber, containing the integral convection heating surfaces. These two are separated by a membrane screen wall which is gastight apart from an opening at its lower end through which the gases leave the furnace.

The oil burners are mounted in the roof of the furnace. Furnace proportions are chosen, giving a register spacing and proximity to surrounding cold surfaces such that adequate flame clearance and optimum distribution of combustion air is ensured. The products of combustion pass down the whole height of the furnace, giving long flame travel and an extended furnace residence time. These features ensure that combustion of the fuel is completed within the furnace with a minimum air to fuel ratio. Combustion gases leaving the furnace pass through the open lower portion of the screen wall and turn in a cavity before flowing upwards over superheater and economiser heating surfaces.

The superheating surfaces consist of primary and secondary sections each of which are formed on horizontal multi-loop elements. Provision is made for parallel flow of steam and gas ensuring minimum tube temperature consistent with an acceptable steam temperature characteristic at the desired level. Spacing of the superheater elements is such as to encourage cleanliness of the tubes under the normal action of the sootblowers. Final steam temperature is controlled by interposing an attemperator, in parallel, with a by-pass, between the primary and secondary stages of the superheater. Steam flow through the attemperator, and hence the superheater outlet temperature, is controlled by a two-way valve, or two separate valves, the regulation of which is influenced by the steam temperature control equipment. The attemperator consists of a tubular heat exchanger located in the steam drum.

In a modern marine boiler operating with high steam temperature,

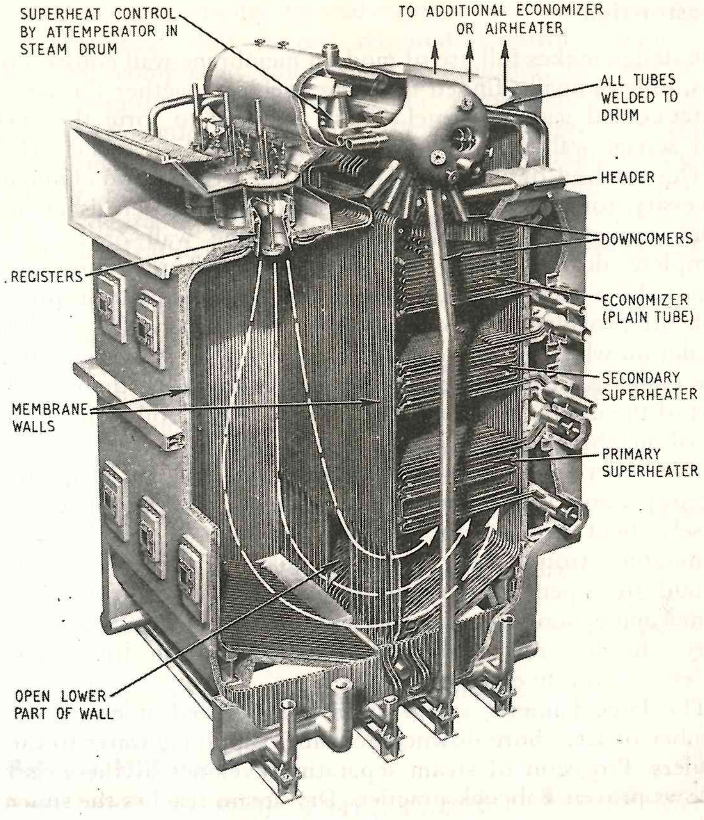


Figure 4.33 Babcock type MR boiler

minimum excess air and a completely water-cooled furnace, a large proportion of the heat transfer from the fuel to the working fluid is via furnace and superheater tubes; so that less generating surface is needed. In the MR boiler, surface additional to the furnace and boiler enclosure walls, and exit screens, is provided by plain economiser tubes. These comprise horizontal multi-loop elements which are arranged in the vertical gas passage above the superheater. On leaving the boiler through an exit screen, the combustion gases may pass to one, or any combination of the following: Babcock stud tube economiser, cast-iron protected steel-tube economiser, or gas air heater. In addition a steam air heater may be incorporated so that normally, heated air will be delivered to the windbox arranged to enclose the registers on the furnace roof.

Construction

The design makes full use of modern membrane-wall construction. In this, longitudinally finned tubes are welded together forming a fully water-cooled gastight panel. These are used to form the enclosure and screen walls of the furnace and convection surface chamber.

This method of construction simplifies erection and eliminates the necessity for a separate gastight steel casing. There is no need to place refractory material behind the tube wall or to provide a complete double casing for the boiler. Where penetrations are required for sootblowers, access doors, etc., adequate air-pressurized seals are provided. The outside of the membrane wall is covered with insulation which is secured to the wall by clips. A light maintenance-free casing is fitted to protect the insulation. With the exception of part of the uptake side wall, all the furnace and boiler enclosure walls are of membrane construction.

The boiler tubes are welded to drum and headers, adequate means for inspection and access being provided. Water-cooled tubes are closely bent around the burner openings in the furnace roof, eliminating troublesome firebrick quarls. Excepting for a lining behind the open pitched uptake side wall tubes in way of superheater and economiser elements and protection for the lower furnace screen header, refractory and insulation within the furnace and boiler are entirely eliminated.

The large-diameter steam drum is supported at either end by a number of large-bore downcomer tubes supplying water to the lower headers. Provision of steam separating cyclones in the steam drum follows proven Babcock practice. Dry steam reaches the superheater and steam-free water passes into the downcomers, so promoting positive and rapid circulation under all conditions of operation. The external surfaces of the steam drum, water-wall headers and downcomers are insulated. All superheater and plain tube economiser elements are supported from the furnace screen wall and uptake side wall tubes. The superheater boxes and plain tube economiser inlet box are supported at each end from the front and rear boiler walls. Access spaces are provided between all banks of tubes in which long retractable sootblower lances are arranged to clean the superheater and economiser surfaces. Fixed-element sootblowers are normally provided for cleaning the heating surfaces just before and beyond the boiler outlet where the gas temperatures are low enough to allow a reasonable life for the sootblower elements.

Operation

Operating methods are no different from those required for any

other modern marine boiler. Special experience or additional training of the operating staff is not required. Control equipment is conventional comprising combustion, oil burner, feed water and steam temperature controls, all to the recommendations of the Classification Societies for *Automatic Controls in Ships*. Normal feed-water treatment is satisfactory provided the specified limits of purity are strictly maintained. As an additional safeguard it may be considered desirable to provide demineralizing or filtration plant. The following features embodied in these boilers are worthy of note:

Welded construction.
No expanded joints.
Factory construction of membrane panels ensures low product cost and reduces erection costs for large sub-assemblies.
Brickwork eliminated.
Burners positioned to utilise full height of furnace.
Long flame travel.
Arrangement of convection surfaces in vertical gas passage, simplifies cleaning.
Excepting drum doors, gasketed joints unnecessary.
Wide gaps between adjacent superheater tubes.
Long retractable sootblowers operating in superheater zone cavities.
Inner and outer casings reduced to a minimum.

The Babcock M21 boiler

The M21 boiler (see Figure 4.34) is a robust unit of the two-drum generating bank type designed on well proven lines. Its low profile makes it suitable for main propulsion installations where the MR radiant type cannot be accommodated. Typical performance figures are:

Output kg/h	34 000–115 000
Superheater outlet pressure bar	35– 83
Superheater outlet temperature °C	400–538
Steam temperature control range % full load	60–100

A wide choice of features is offered to meet individual owner's requirements, and any one of eight combinations from the following six options may be selected without materially changing the overall space required.

1. Single superheater arrangement.

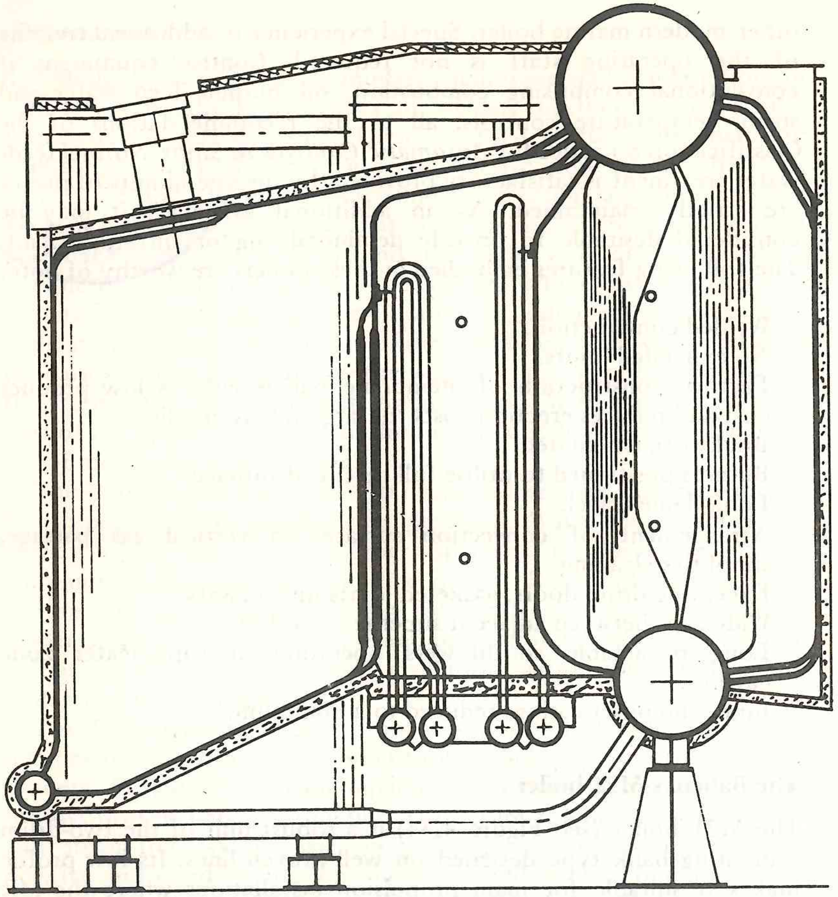


Figure 4.34 Babcock type M21 Bi-drum boiler

2. Double superheater arrangement.
3. Conventional expanded tangent tubes with air and gas-tight double casings.
4. Membrane tube panel enclosure – single cased.
5. Roof mounted burners.
6. Front mounted burners.

Design

The fully water-cooled furnace is of ample proportions allowing good register spacing and proximity to surrounding cold surfaces so that

adequate flame clearance and optimum distribution of combustion air is achieved. Combustion is completed with low excess air before the furnace gases leave through an exit screen formed by an open vertical continuation of the furnace floor tubes. In the cavity beyond the screen is the superheater surface formed from vertical draining U-loops. Being self-supporting these loops are located only by high chrome-nickel alloy spacers welded to the boiler tubes for maximum cooling effect.

The superheater surface is arranged to give optimum spacing between tubes, having regard to the required duty, with wider spaces than can normally be achieved in the double superheater layout. Generous access is provided in this zone for erection, inspection, cleaning and maintenance. Final steam temperature is controlled by interstage attemperation, effected by water spray or a tubular heat exchanger in the drum. Spray water quantity, or steam flow through the heat exchanger, is controlled by valves actuated by signals from the automatic control equipment.

After leaving the superheater zone the products of combustion pass over the main generating tubes, which are arranged in-line and provided with ample access spaces. The gases then leave the boiler proper and enter the heat recovery section located above. With a low feed temperature cycle this normally consists of a Babcock mild steel extended surface economiser, sometimes followed by a cast iron protected economiser. A bled steam airheater is usually fitted to improve the overall cycle efficiency. Alternatively, with a high feed temperature cycle, a gas airheater only is used.

Construction

Furnace chamber. Close pitched bare tubes expanded at their ends are backed by a gas-tight steel casing lined with high quality refractory and insulation. Alternatively membrane wall tube panels provide both water cooling and gas tightness, eliminating refractory and gas-tight casings and thereby reducing maintenance.

Superheater cavity and boiler enclosure. With a bare tube furnace, suitably lined gas tight inner and outer casings are used, the space between being pressurised with combustion air. Otherwise the complete boiler is enclosed by membrane wall tube panels, finished with insulation and protective cladding.

Operation

Operating methods are the same as those employed for any other modern marine boiler and no special experience or training of the operating staff is required. All control equipment is conventional and to the recommendations of the major Classification Societies for *Automatic Control in Ships.* Normal feed water treatment is satisfactory, provided the limits of purity as specified in the relevant standards are maintained.

Well-proven Babcock steam separating cyclones in the drum ensure that dry steam reaches the superheater and steam free water passes into the downcomers. Cleanliness of the gas passes is maintained by the use of long retractable sootblower lances in the superheater zone and fixed head rotating element sootblowers in the main generating bank and heat recovery sections.

The Babcock M11M boiler

Continuing the modern trend to eliminate refractories, especially from furnace radiation zones, the M11M water tube boiler (Figure 4.35) has been designed with enclosure walls made from membrane wall tube panels. Based upon the well-known M11 boiler, this new design enables the virtual elimination of refractory material and gas-tight steel casings, so providing a simple, rugged yet lightweight design. Typical performance figures are:

Output kg/h	11 350	113 500
Outlet pressure bar	10	62
Steam temperature °C	Sat	350

Introduced to provide emergency power on steam ships having a single main boiler, the M11M has a standard of construction similar to the contemporary main propulsion boiler, and may even be arranged with roof-mounted burners. To increase its utilisation factor in this role, heating coils may be fitted in the lower drum which, when supplied with H.P. steam from the de-superheated range, can produce L.P. steam which is then taken from the steam drum to supply 'dirty' or all loss services such as fuel heating, domestic steam and fuel atomisation.

Suitable also for auxiliary duties on motor ships, the M11M boiler can provide low pressure steam for direct use by the consumers or high pressure steam to supply the coils of a steam boiler delivering low pressure steam. In the latter case the M11M operates in a closed cycle, the initial charge of high-quality water being diluted only by occasional makeup to replace any incidental losses.

The M11M can be supplied for pressure between 10 bar and 62 bar in a range of output from 11 350 kg/h to 113 500 kg/h. Steam is

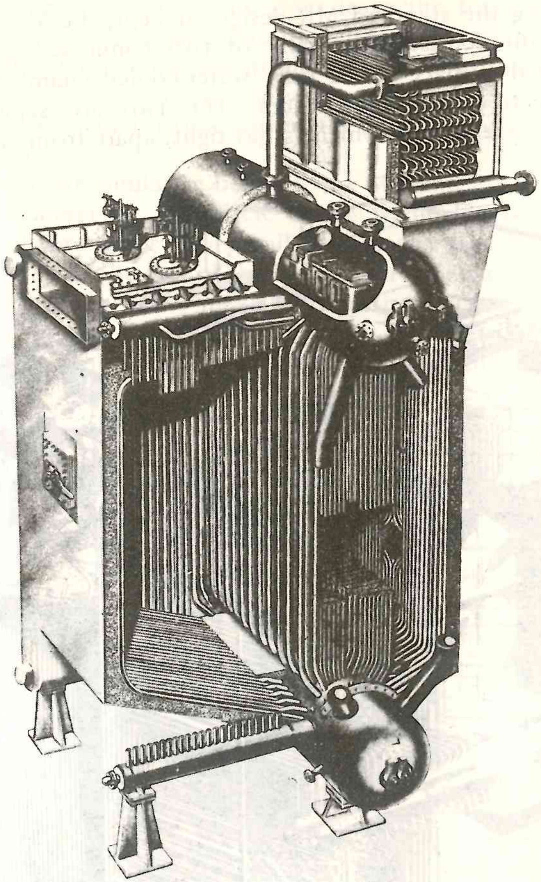


Figure 4.35 Babcock MIIM marine boilers

delivered either dry saturated or, by using a simple superimposed superheater, at up to 350°C.

The Babcock MRR reheat boiler

That a single unit of this type has been fitted for main propulsion steam in a 22 500 kW tanker is a good indication of the advances made in reheat boiler design. As in the MR type this unit embodies complete membrane wall construction to form gas tight panels for all enclosures, screen and division walls. This allows virtual elimination of exposed refractory and ensures minimum maintenance.

Following the standard MR design concept, the MRR boiler (see Figure 4.36) consists essentially of two connected parts: a fully water-cooled furnace and a fully water-cooled chamber containing the convection heating surfaces. The two are separated by a membrane screen wall which is gas tight, apart from an opening at

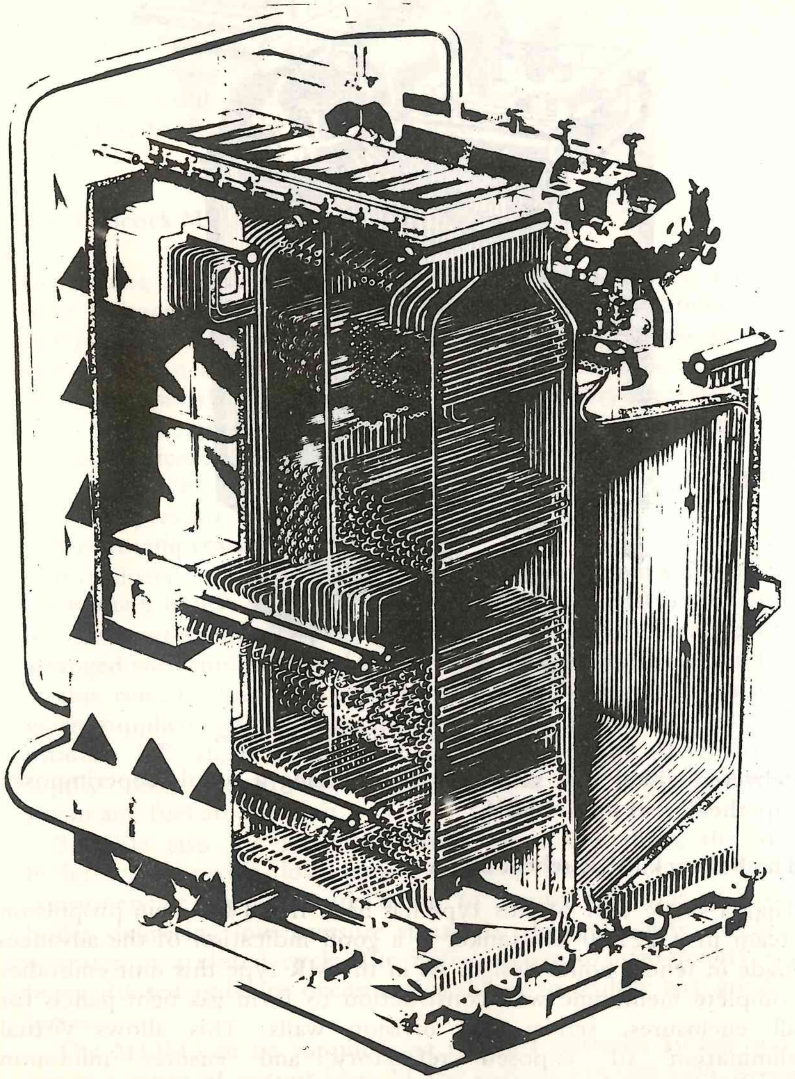


Figure 4.36 Babcock MRR reheat boiler

its lower end through which the gases leave the furnace and pass into the convection chamber. The oil burners are mounted in the roof of the furnace so that the products of combustion pass down the full height of the furnace, allowing maximum flame travel and ensuring complete combustion within the furnace with a minimum air to fuel ratio.

At this point the similarity between the MR and MRR ends. The convection chamber in the MRR boiler is divided by a further membrane wall providing two parallel gas passes (see Figure 4.37). Dampers situated at the top of the boiler, in a cool gas zone, control the gas flow through either pass. Each gas pass accommodates, in the direction of gas flow, a primary and secondary superheater, followed by the reheater in one pass and the bare tube economiser

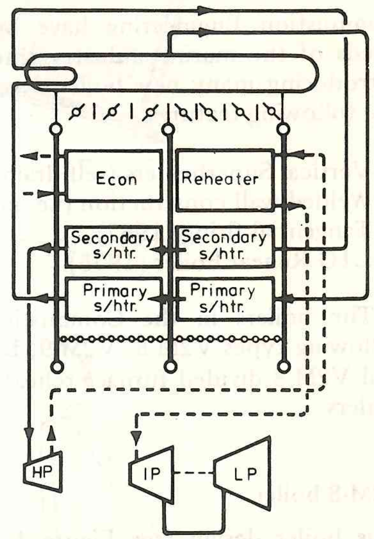


Figure 4.37 Arrangement of convection chamber in MRR boiler

in the other. The proportion of gas flowing through the two passes is regulated by the dampers, thus giving control of the reheat steam temperature.

Whilst manoeuvring, and during harbour steaming periods when no steam flows through the reheater tubes, protection of the reheater is afforded by a combination of the control dampers and the distribution of the superheater surfaces up stream of the reheater.

The superheater surfaces in the reheater pass are so proportioned that when the reheater dampers are closed any leakage past the dampers is cooled by the superheater surfaces to a temperature well below the maximum allowable reheater tube metal temperature. As an added precaution to reduce leakage gas flow, should the dampers become less tight after extended service, provision is made to admit air at windbox pressure up stream of the closed reheat dampers.

The steam temperature is controlled by an interstage attemperator in the manner commonly adopted for the MR boiler. This permits the design final steam temperature to be maintained over a reasonably wide range of loads and corrects the steam temperature if any change results from adjustments to the reheater control dampers.

COMBUSTION ENGINEERING BOILERS

Combustion Engineering have been serving the steam generating needs of the marine industry since the late 1930's and apart from introducing many new boiler designs they claim to have introduced the following features:

Vertical Superheaters (self draining) (1948)
Welded wall construction (i.e. membrane or monowall) (1963)
Tangential firing (1967)
LTG Reheat boiler (1975)

The boilers in the Combustion Engineering range include the following types V2M-8, V2M-9, LTG (low temperature gas), reheat, and V2M-8 divided furnace reheat, together with a range of auxiliary boilers.

V2M-8 boiler

This boiler design (see Figure 4.38) was first used aboard ship in 1972 and since that date over six hundred boilers with either welded wall or tangent tube construction have been built. Noteworthy design features are described in the following paragraphs.

Continuous circuitry. This arrangement (see Figure 4.39) assures positive circulation by more than one path between the steam and water drums and the lower furnace waterwall headers through the installation of large external downcomers, and the direct interconnection of the water drum and the lower furnace waterwall headers.

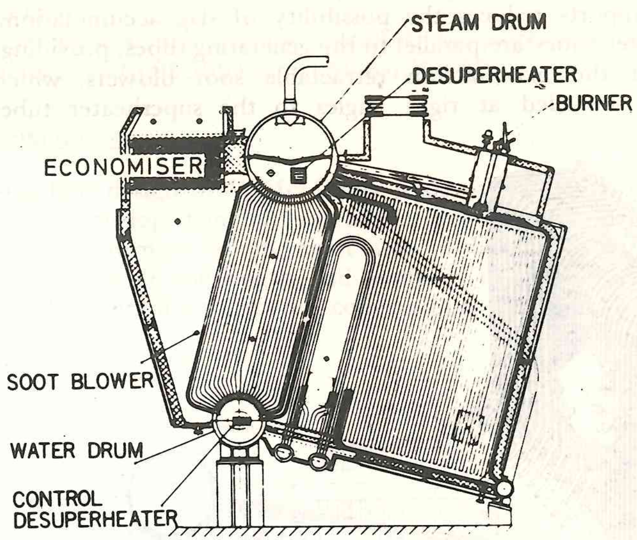


Figure 4.38 Combustion Engineering V2M-8 boiler

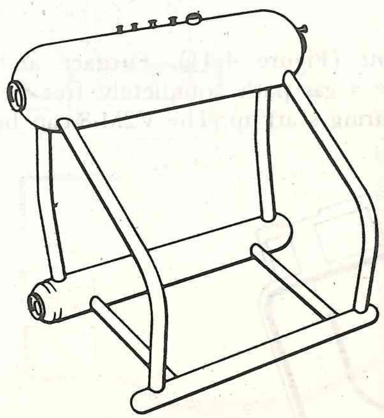


Figure 4.39 Continuous circuitry of V2M-8 boiler

Vertical superheater (Figure 4.40). Lack of horizontal surfaces and bulky supports reduces the possibility of slag accumulation. The superheater tubes are parallel to the generating tubes, providing clear lanes for the mass action retractable soot blowers, which are normally installed at right angles to the superheater tubes. In

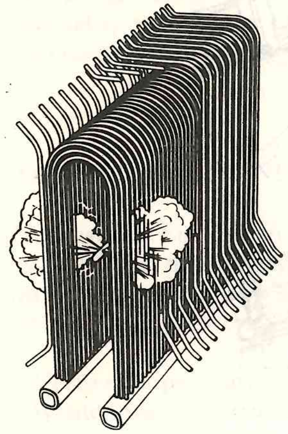


Figure 4.40 Vertical superheater

addition, the vertical superheater is completely drainable, regardless of the vessel's trim or list.

Furnace arrangement (Figure 4.41). Furnace and boiler surfaces are arranged to give a gas path completely free from 'pockets' for effective purging during start up. The V2M-8 can be fired from the

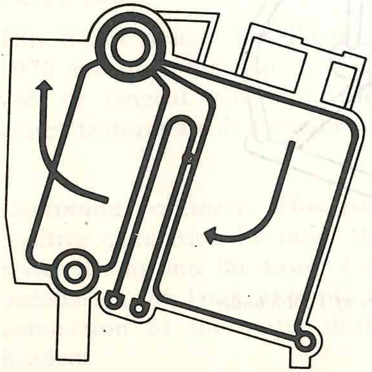


Figure 4.41 Furnace arrangements

roof, front, or side, depending upon the particular machinery arrangement.

These boilers are usually installed in pairs with combined evaporation up to 95 500 kg/h at 59 bar, 510°C.

The V2M-9 boiler

The standard design of V2M-9 boiler is shown in Figure 4.42. This boiler was developed mainly for use in single main-boilered ships. The unusual furnace arrangement was evolved by the designers in order to reduce the length, and tendency to vibrate, of the long main bank generating tubes of a conventional large furnaced D-type boiler.

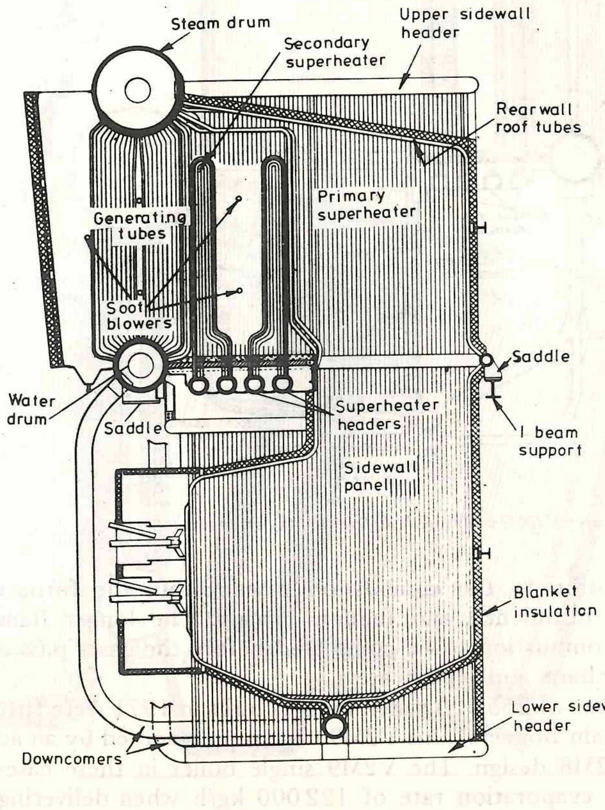


Figure 4.42 V2M-9 tangentially-fired boiler (Combustion Engineering)

A recent development of this boiler is shown in Figure 4.43 from which it will be seen that the most outstanding feature of the boiler is the firing arrangement. In this arrangement a burner is located at each of the lower four corners of the furnace and these are aligned to be tangential to a circle of approximately 0.6 m in diameter at the furnace centre. It is claimed that this arrangement imparts a

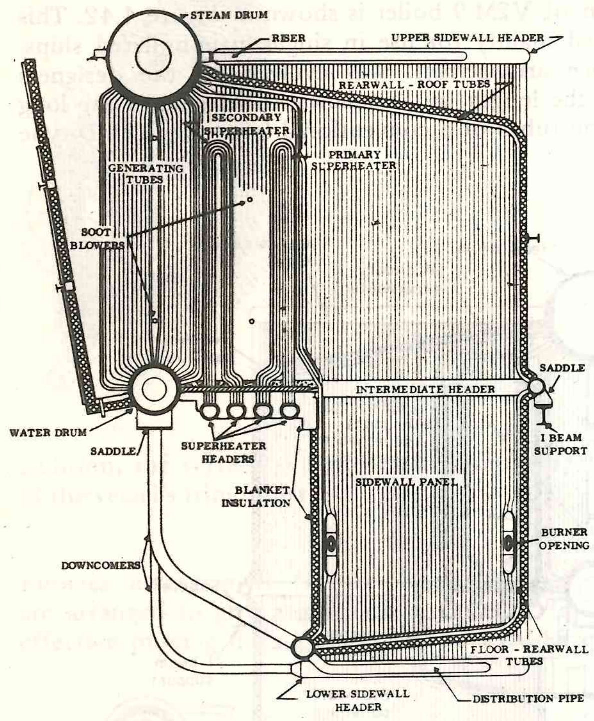


Figure 4.43 Later V2M-9 boiler with different firing arrangement

rotary motion to the combustion gases within the furnace, with improved turbulence and fuel/air mixing. The longer flame path allowing combustion to be completed before the gases pass into the generating bank and superheaters.

A number of 255 000 d.w.t. tankers built in 1971 were fitted with a single main boiler of this V2M9 type supplemented by an auxiliary of the V2M8 design. The V2M9 single boiler in these cases has a maximum evaporation rate of 122 000 kg/h when delivering steam at 62 bar and 513°C. Steam from this boiler supplies a single set of

standard Stal Laval geared turbines, which develop 24 000 kW at 86 r.p.m.

Reheat boilers

Combustion Engineering's approach to reheat differs from most other boiler manufacturers in as much as they have in effect reverted back to the separately fired reheat furnace rather than utilise damper control.

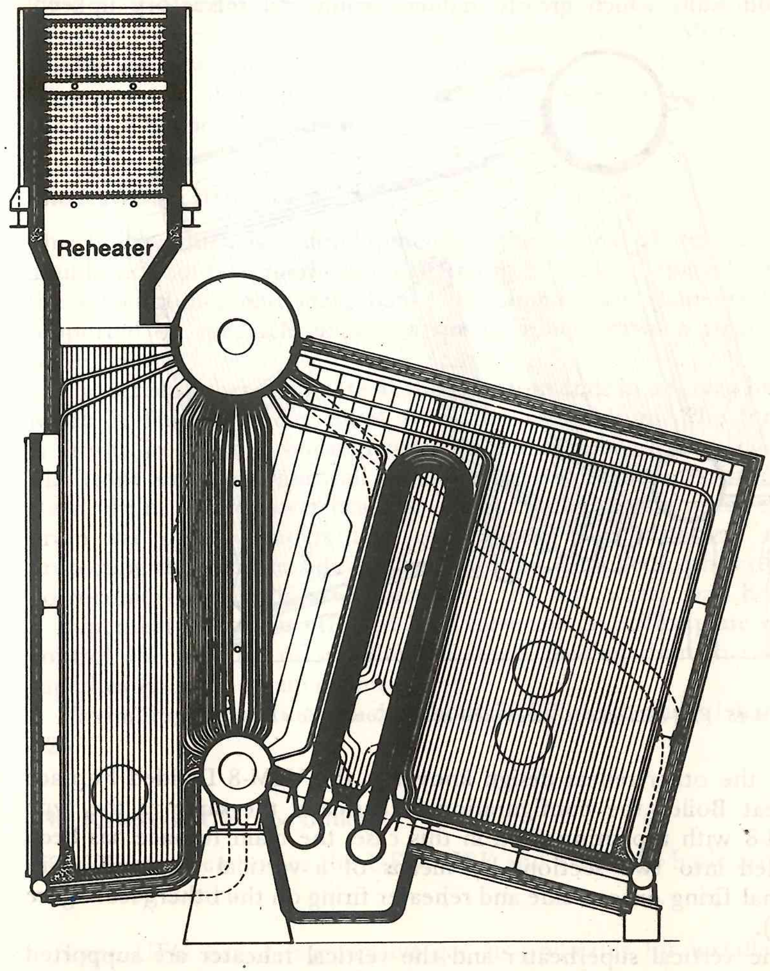


Figure 4.44 V2M-8 L.T.G. reheat boiler (Combustion Engineering)

In one of these reheat designs, the LTG (low temperature gas), a basic V2M-8 or V2M-9 configuration is used and a separately fired water cooled reheat furnace is added after the main generating bank (Figure 4.44). During the reheat mode of operation firing is divided between the boiler furnace and reheater furnace, the reheater being located in a relatively low temperature gas environment. During non-reheat operation, firing of the reheat furnace is stopped, thereby ensuring that the reheater is subjected only to relatively low temperature gases. The main and reheater furnaces are bounded by welded walls which greatly reduce casing and refractory upkeep.

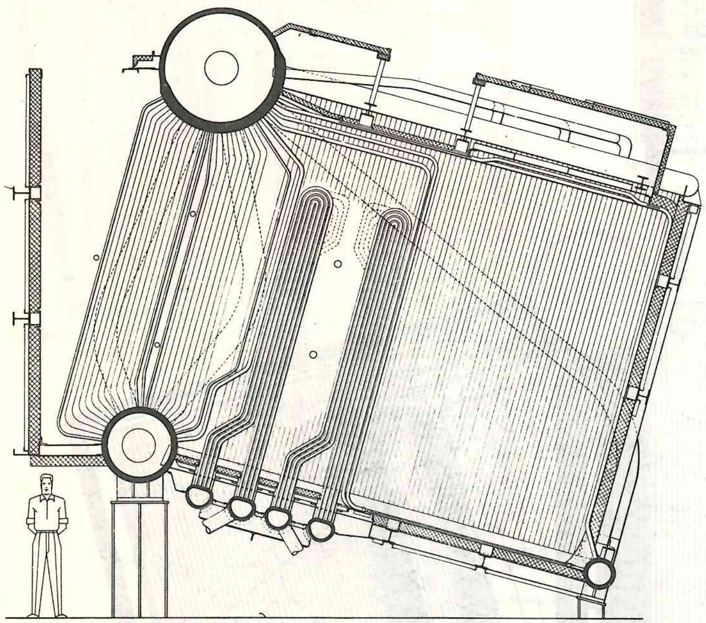


Figure 4.45 V2M-8 divided furnace reheat boiler (Combustion Engineering)

In the other reheat design known as the V2M-8 Divided Furnace Reheat Boiler the configuration is basically the same as the type V2M-8 with top firing. But, in this case, the main furnace has been divided into two sections by means of a vertical waterwall with normal firing on one side and reheater firing on the other (see Figure 4.45).

The vertical superheater and the vertical reheater are supported without the need for tube plates or bulky castings and the wide

space between the elements allows free access to the fire side for ease of inspection and maintenance. As in the LTG type welded water walls are used which eliminate refractories and result in a significant weight reduction.

KAWASAKI WATER TUBE BOILERS

Kawasaki Heavy Industries, Japan claim to have built more than 2300 marine boilers since they were established in 1878, this number includes Scotch, Yarrow, Cochran, Johnson and La Mont types. During the past ten years the predominating type has been the BDU (Figure 4.46), although in recent times this has been superceded by the UF, UM and UTR types.

The Kawasaki BDU boiler

This boiler which is a development of the normal D design, has a double horizontal superheater situated in a 'walk-in' space between the screen tubes and main bank, the superheater elements being supported by spectacle plates on special tubes between steam and water drums.

The screen tubes terminate at their bottom ends in a screen header which is fed by feeder tubes from the water drum. The furnace is front fired and is encased with tangential tubes and refractory. The front and rear waterwall tubes are fed by downcomers from the steam drum to the lower headers, and they discharge into the steam drum via upper headers and roof tubes. The waterwall tubes protecting the furnace side and roof are also supplied with water by downcomers from the steam drum to the side water wall header.

Superheat control is effected by a valve and an orifice plate which control the amount of superheated steam passing thorugh the de-superheater in the steam drum.

Maximum evaporation usually about 70 000 kg/h and 61 bar and 525°C.

The Kawasaki UF type boiler

The UF range embodies the UFG, UFE and UFR, the basic arrangement being similar.

Type UFG has a regenerative gas air preheater for installations embodying high pressure feed heaters.

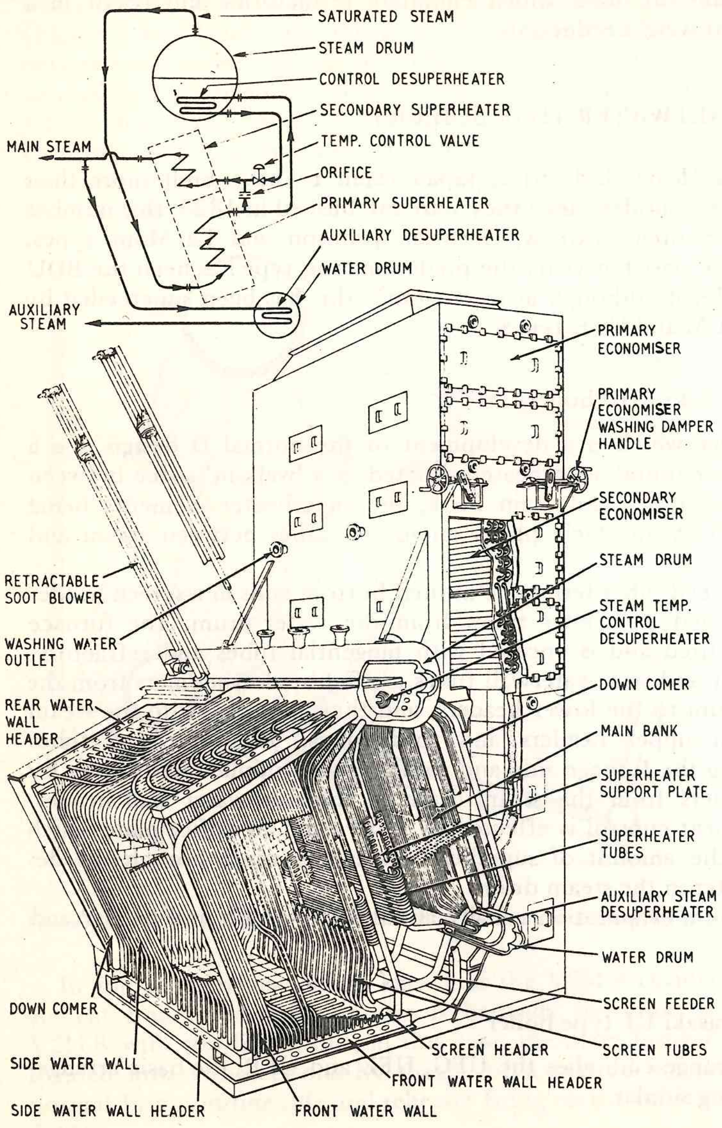


Figure 4.46 Kawasaki BDU boiler

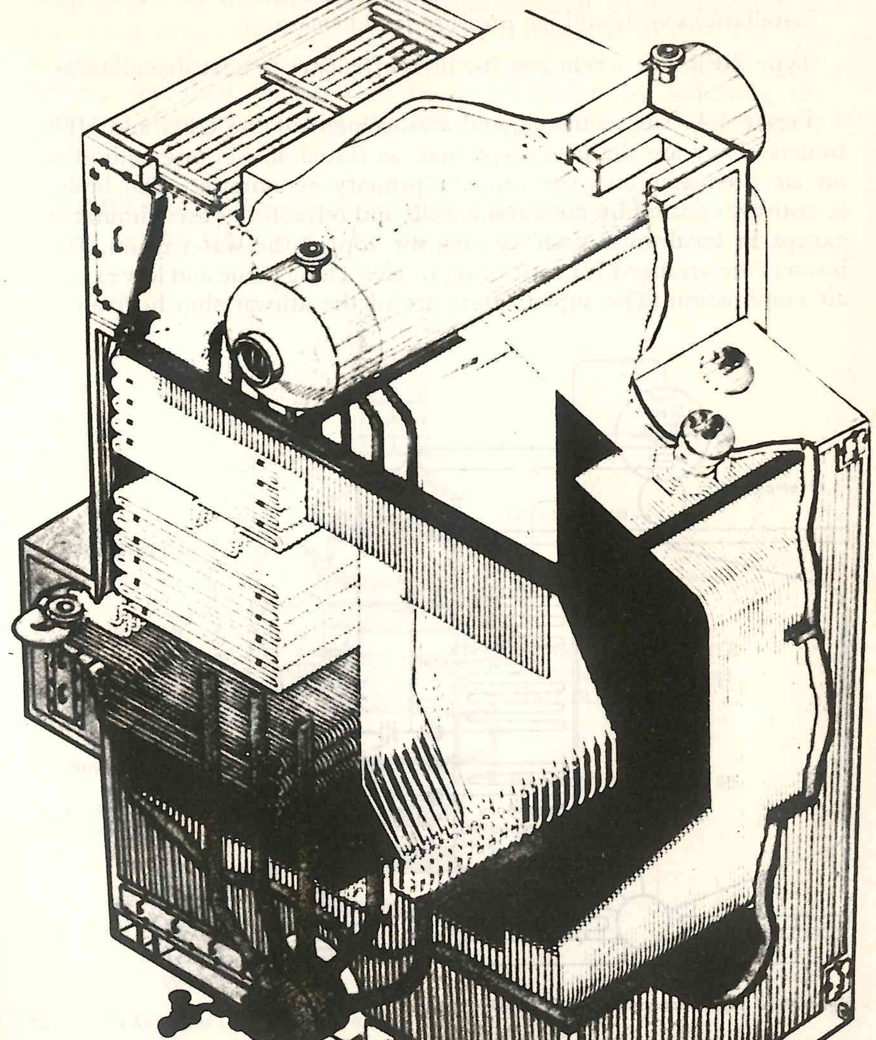


Figure 4.47 Kawasaki UF boiler

Type UFE has a primary economiser and steam air heater for installations without high pressure feed heaters.

Type UFR has a reheater for high efficiency reheat installations.

Figure 4.47 shows the general arrangement of the UFG and UFE boilers. They are similar except that, as stated above, one embodies an air preheater and the other a primary economiser. The boiler is entirely encased by membrane walls and refractories are eliminated except in local areas such as over the top of the water drum. The burners are arranged for roof firing to give a long flame and low excess air combustion. The superheaters are of the athwartship horizontal

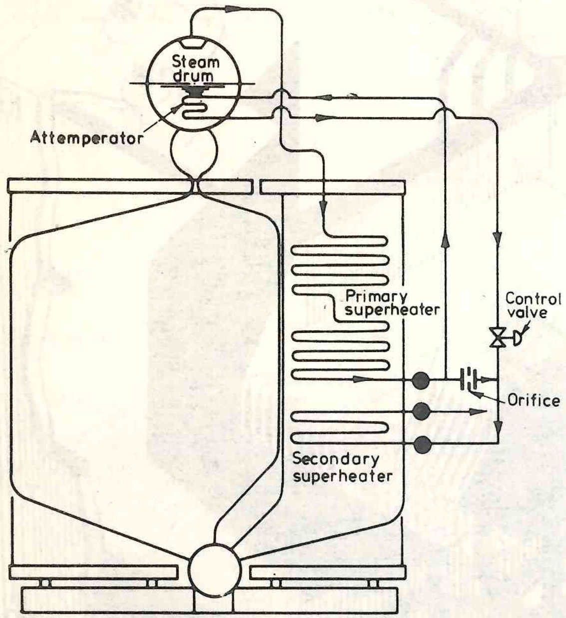


Figure 4.48 Superheat control on Kawasaki UFE and UFC boilers

continuous loop type and are situated in a convection space separated from the furnace by a division water wall. All pressure parts are of welded construction, including tube ends, thus eliminating the possibility of future leakages at tube expansions.

Superheat control is affected by passing all the saturated steam from the steam drum through the primary superheater where it is raised to approximately 450°C, and then by means of a control valve

leading part of this superheated steam through an attemperator in the steam drum, the other part passing through an orifice. The two steam flows then mix and are further heated in the secondary superheater, the final temperature being controlled by adjusting the amount of steam passing through the attemperator (see Figure 4.48).

The UFR or UF reheat boiler (Figure 4.49). This is basically the same design as the UFG and UFE except that the convection section

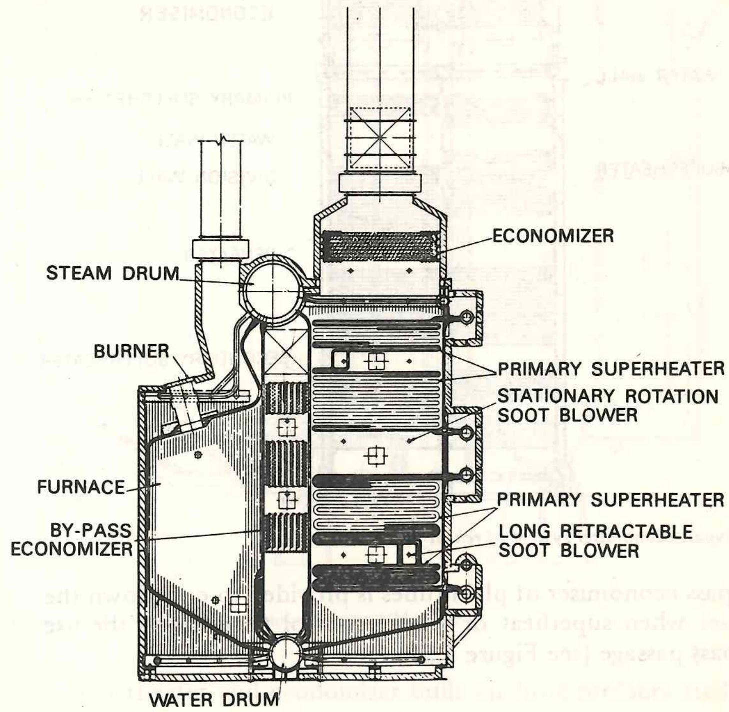


Figure 4.49 Kawasaki UFR and UF reheat boilers

is divided into three passages i.e. superheater, reheater and bypass economiser, each passage having a set of control dampers at its outlet to regulate gas flow. At the outlet of the reheater passage the dampers are duplicated and sealing air is passed between the two as a protection. The secondary superheater extends under the reheater to cool down any gas which might pass into the reheater passage when on non-reheat operation.

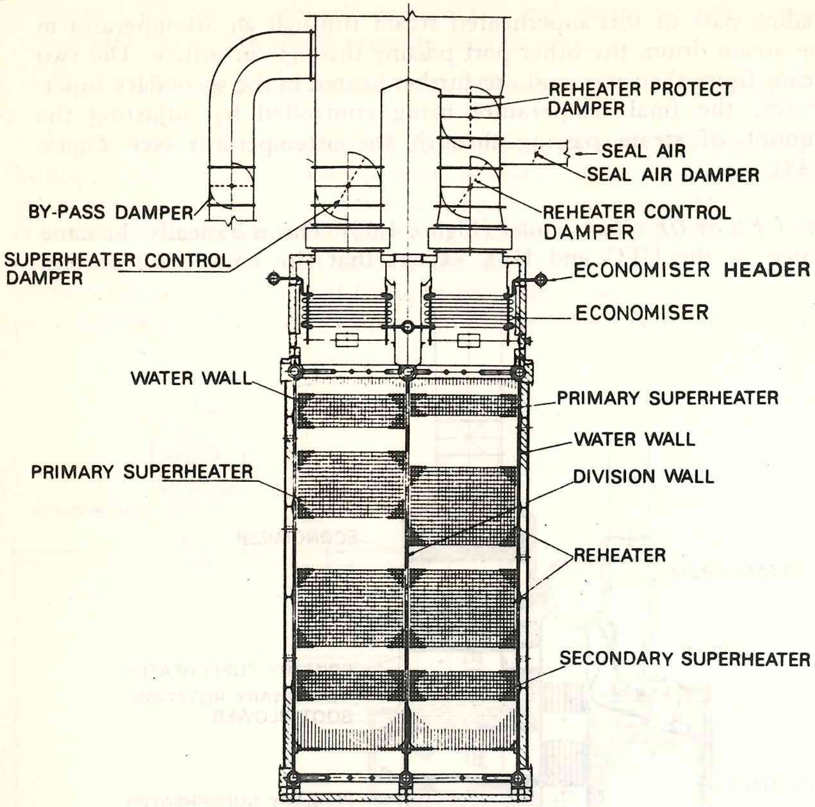


Figure 4.50 Bypass economiser system of reheat boilers

The bypass economiser of plain tubes is provided to cool down the bypass gases when superheat or reheat control necessitates the use of the bypass passage (see Figure 4.50).

The Kawasaki UM boiler

In common with practically all other makers of water tube boilers Kawasaki have a range of D-type boilers with a vertical tube superheater positioned between furnace screen tubes and main bank tubes. These boilers known as the UM range (see Figure 4.51) have the following features:

1. Complete encasement by membrane walls.
2. Roof firing.

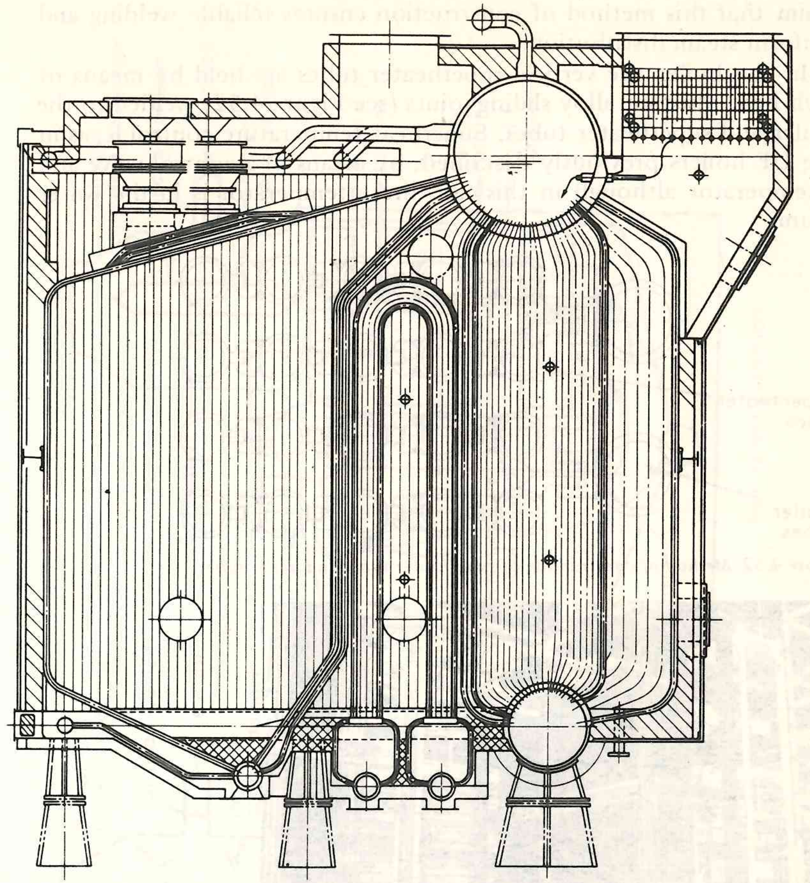


Figure 4.51 Sectional view Kawasaki type UM boiler

3. Superheater and economiser built up from prefabricated panels of tubes.
4. Main bank tubes embody a slight bend to counter tube vibration.
5. All tubes welded at ends except main bank which are expanded.

One feature of these boilers which is claimed to be unique is the panel construction of the superheater as shown in Figure 4.53. The superheater tubes are made into panel units by using sub-headers. After welding and hydraulically testing in the shop, each panel is welded to the main header with connecting tubes. The manufacturers claim that this method of construction ensures reliable welding and uniform steam distribution.

In the boiler the vertical superheater tubes are held by means of high heat resistant alloy sliding joints (see Figure 4.52) welded to the boiler and superheater tubes. Superheat temperature control is, as in the UF boilers previously described, by means of a control valve and attemperator although in this case the attemperator is in the water drum.

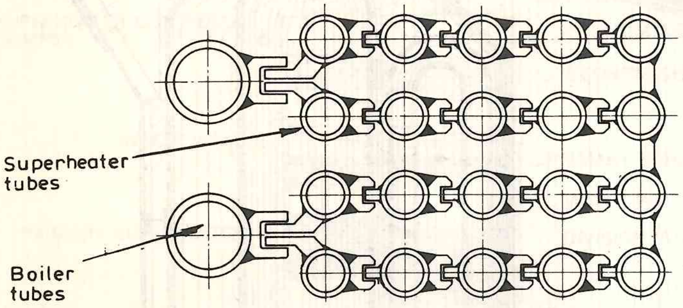


Figure 4.52 Method of construction of superheater tubes and boiler tubes

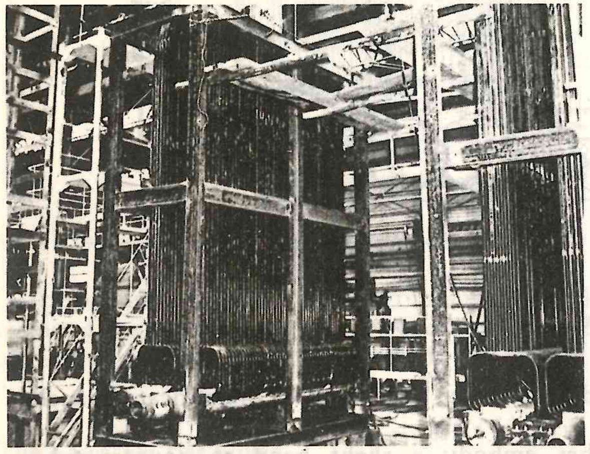


Figure 4.53 Panel construction of Kawasaki superheater

As in the case of the UF design two variations of the design are produced – the UMG with economiser and gas air heater and the UME with economiser and steam air heater.

Steam conditions are 60 bar 515°C. The range includes evaporations up to 143 000 kg/h max. 108 000 kg/h normal for the UMG type and 123 000 kg max. 93 000 kg normal for the UME type.

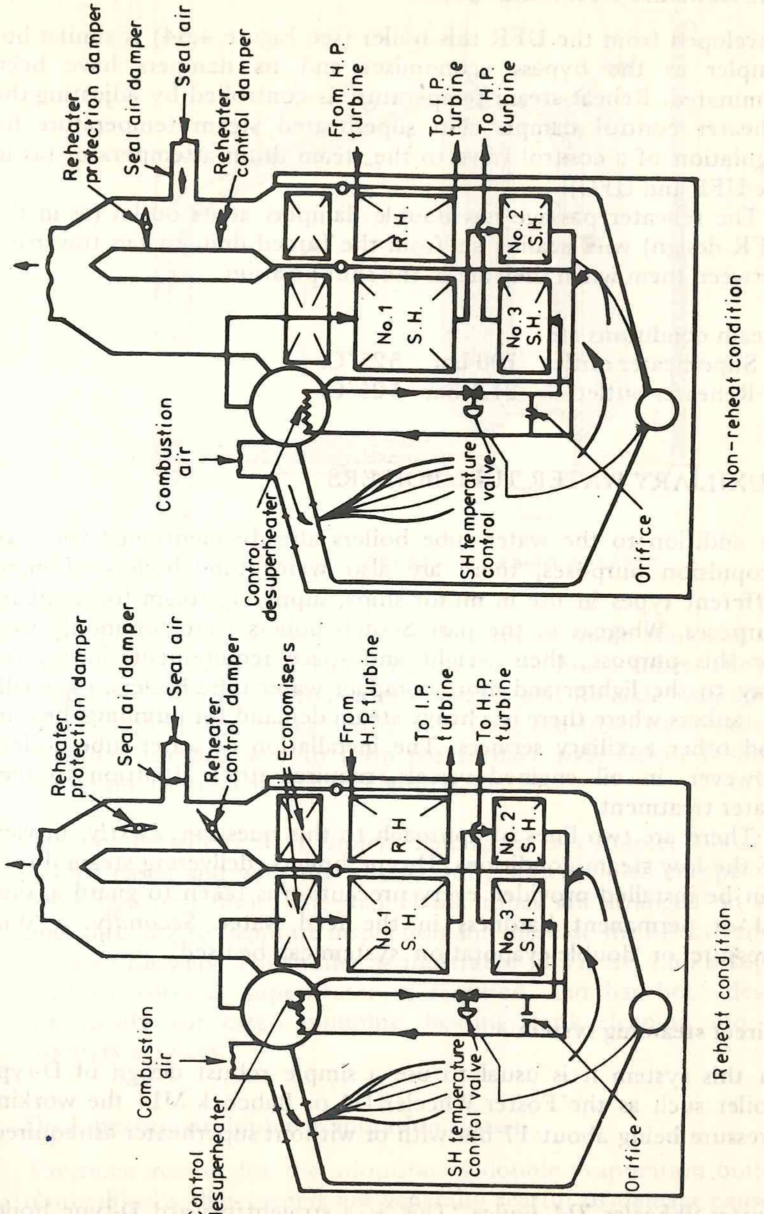


Figure 4.54 Kawasaki UTR reheat boiler

The Kawasaki UTR reheat boiler

Developed from the UFR this boiler (see Figure 4.54) is similar but simpler as the bypass economiser and its dampers have been eliminated. Reheat steam temperature is controlled by adjusting the reheater control damper and superheated steam temperature by regulation of a control valve to the steam drum attemperator (as in the UFE and UFG).

The reheater passage has double dampers at its outlet (as in the UFR design) with sealing air from the forced draught fan traversing between them when they are in the shut position.

Steam conditions are:

Superheater outlet	100 bar	525°C.
Reheater outlet	21.5 bar	525°C.

AUXILIARY WATER TUBE BOILERS

In addition to the water tube boilers already mentioned for main propulsion purposes, there are also water tube boilers of many different types in use in motor ships, supplying steam for auxiliary purposes. Whereas in the past Scotch boilers were commonly used for this purpose, their weight and space requirements have given way to the lighter and more compact water tube boilers, especially in tankers where there is a heavy steam demand for pumping, heating and other auxiliary services. The installation of water tube boilers, however, in oil engined vessels, requires strict attention to feed water treatment.

There are two lines of approach to this question. *Firstly,* in view of the low steam conditions, D-type boilers, delivering steam direct, can be installed provided every precaution is taken to guard against oil or permanent hardness in the feed water. *Secondly,* a 'dual pressure' or 'double evaporation' system can be used.

Direct steaming system

In this system it is usual to use a simple robust design of D-type boiler such as the Foster Wheeler D4 or Babcock M11 the working pressure being about 17 bar with or without superheater as required.

Foster Wheeler D4 boiler. This is a straightforward D-type boiler fully air-cased, having a simplified casing made from flat plate with

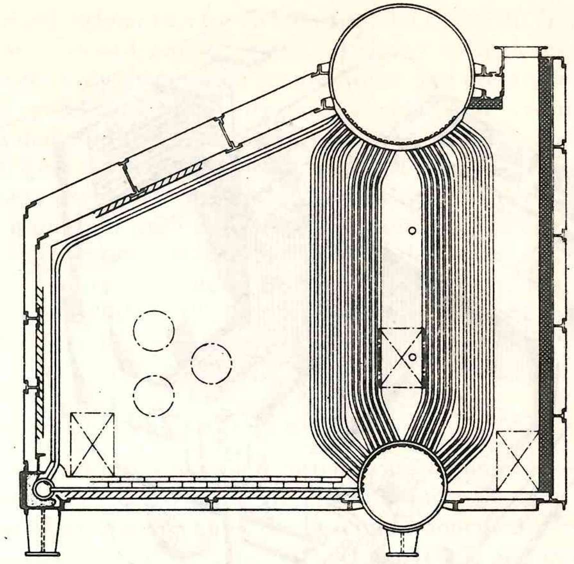


Figure 4.55 Foster Wheeler type D4 water tube boiler

welded stiffeners, access doors to the furnace, main bank and outlet space, and utilising only four patterns for the boiler tubes. The boiler is supplied with or without a superheater and the side wall above is water cooled. The tubes of this side wall, fed from floor tubes, are extended up and over to form the furnace roof before re-entering the steam drum, as shown in Figure 4.55.

Babcock & Wilcox M11 boiler. This again is a simple, robust unit, double cased and with the furnace fully water cooled except for the front wall and floor. The main bank tubes are arranged on an 'in line' pitching to facilitate inspection and increase the effectiveness of the soot-blowers. This boiler as illustrated in Figure 4.56 is supplied with or without superheater as required, and has been designed specifically for cargo pumping, heating, tank cleaning and other auxiliary services.

Dual pressure or double evaporation system

The main reason for the adoption of double evaporation boilers in motorships is that owners are generally fearful of damage caused by oil or other impurities in boiler feed water. The double evaporation

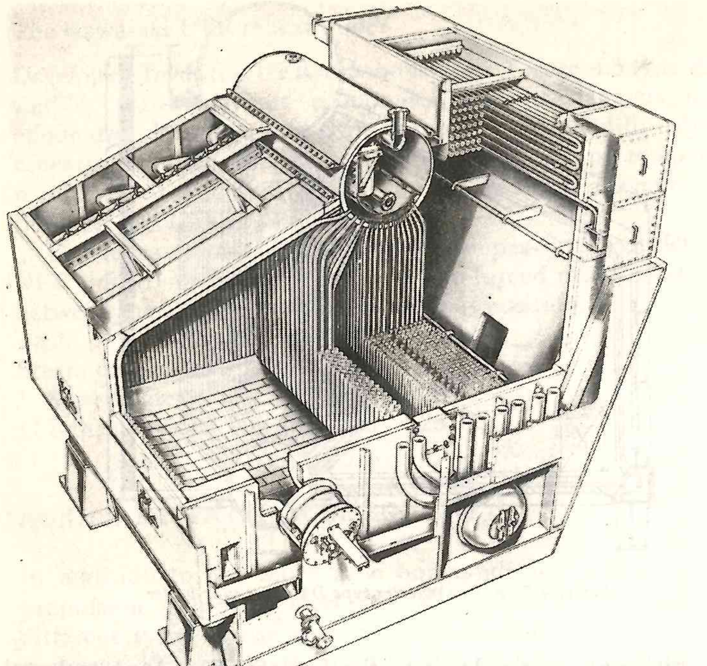


Figure 4.56 Babcock type M11 water tube boiler

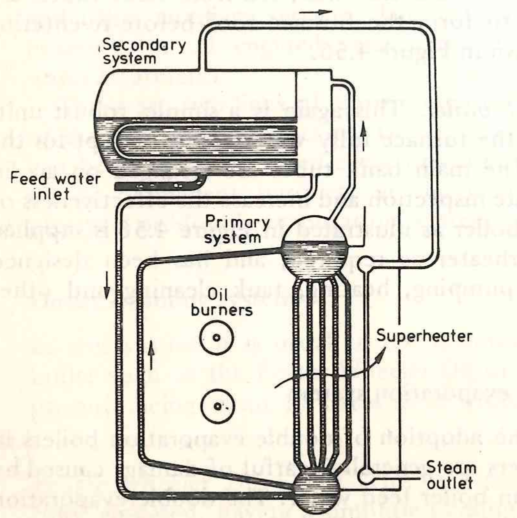


Figure 4.57 Double evaporation arrangement

boiler is proof against this by virtue of the fact that the boiler proper operates on a closed circuit, its initial charge of high quality water being continuously evaporated in the boiler and condensed in a heat exchanger producing low pressure steam, and requiring only occasional make-up to replace incidental losses (see Figure 4.57).

All the feed necessary to produce the low pressure steam is fed into the heat exchanger and, as this is not fired, boiler dangers from feed contamination are non-existent, although efficiency falls off if the heat exchanger becomes fouled up with deposits.

Aalborg manufacture these boilers in two ranges, the AT4 with evaporation of 6000 to 40 000 kg/h and the AT8 with evaporations of 30 000 to 80 000 kg/h.

The Aalborg AT4 double evaporation boiler.

These boilers, normally supplied in pairs, are commonly installed in motor tankers for cargo pumping, heating, tank cleaning and other services, and Figure 4.58 shows the general arrangement.

The primary system operates as a closed cycle and consists of a steam and water drum, connected by generating tubes and down-comers expanded into the drums. The steam and condensate tubes connecting the lower and upper part of the boiler are welded to stubs on the drums and evaporating headers. The secondary system incorporates headers welded into the dished ends of the secondary drum and U-loop elements, which are passed through the manhole, and then expanded into the headers and well-supported to the shell.

To secure efficient water circulation even when lighting up, the combustion gases leave the furnace at floor level and pass around the tubes of the generating bank which are interlaced as a protection against vibration. Cyclone separators in the secondary drum are a well-tried feature which reduce the risk of carry-over, and a manhole on the lower part of the shell permits entry to the space below the evaporating elements.

The complete boiler is enclosed in a pressurised casing with welded-in stiffeners, supporting the secondary drum. The front and rear walls of the furnace are lined with refractory and insulation and the double casing carries the combustion air to the furnace front.

A forced draught fan is usually placed on a foundation welded to the shell of the secondary drum, and the combustion air is preheated when passing through the complete double casing *en route* to the wind box enclosing the oil burner registers. The rotary cup oil burner produces a long and natural flame path which assists combustion, and is equipped with automatic combustion control capable of a very

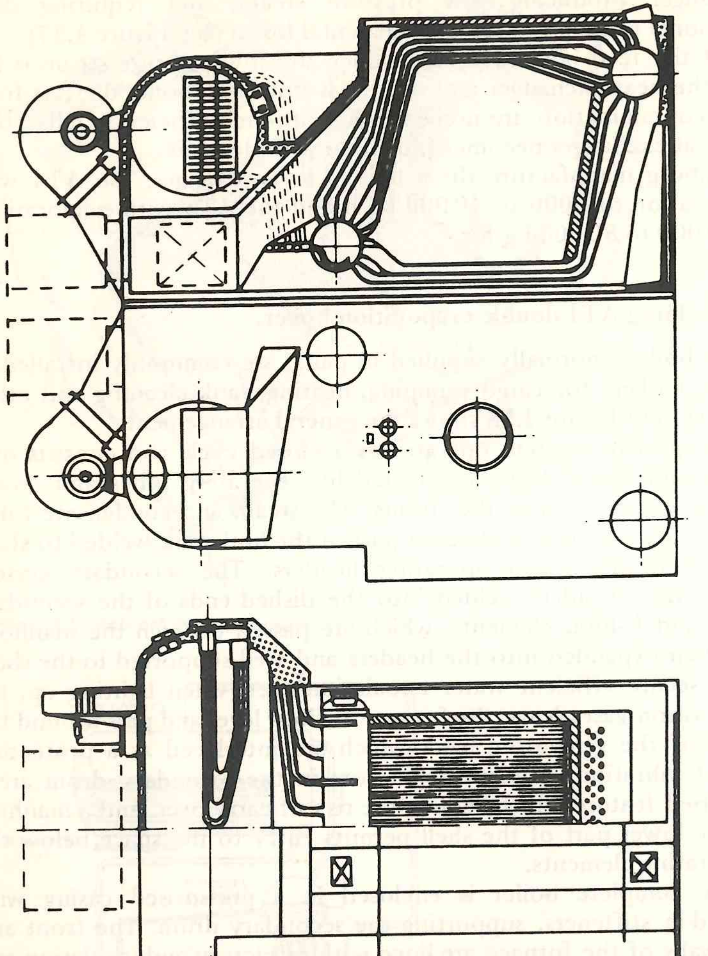


Figure 4.58 Aalborg type AT4 double evaporation boiler

wide operating range – in some cases better than 10-1. Boiler mountings are conventional and as required by the appropriate classification society.

The alarm and fuel shut-off systems are also conventional and again are to the requirements of classification. The systems normally comprise:

Primary system	2 water level sensors, each operating low water-level alarms.
	1 low/low level sensor operating fuel oil shut-off.
	1 high steam pressure switch operating fuel shut-off.
Secondary system	1 water level sensor operating high and low water level alarms, also low/low water level-fuel shut-off.
	1 high pressure switch operating fuel shut-off.

Additionally fuel will be shut off automatically at too low an oil temperature or failure of the flame or forced draught fan.

As the primary system operates on a closed cycle, the initial charge of high-quality water is diluted only by occasional make-up feed to replace any incidental losses. Two high pressure make-up feed pumps are conventional and to the recommendation of the classification societies. If superheat is required, a simple superimposed superheater is provided at the boiler outlet. Protection of the superheater during the lighting-up period is not necessary.

In view of the long out-of-service periods of double evaporation boilers in motor tankers, it is necessary to protect the outer surface of the evaporating elements against oxygen corrosion (pitting). This is done by using steam from the exhaust gas boiler to supply a simmering coil located in the primary water drum, thus maintaining some pressure in both the primary and secondary systems.

Integrated auxiliary steam system – the Aalborg AT8 double evaporation boiler

The double evaporation boiler frequently works in conjunction with an exhaust gas boiler with the secondary drum acting as steam receiver.

The Aalborg AT8 boiler is a higher output version of the AT4, the main differences being:

1. Membrane walls to the furnace.

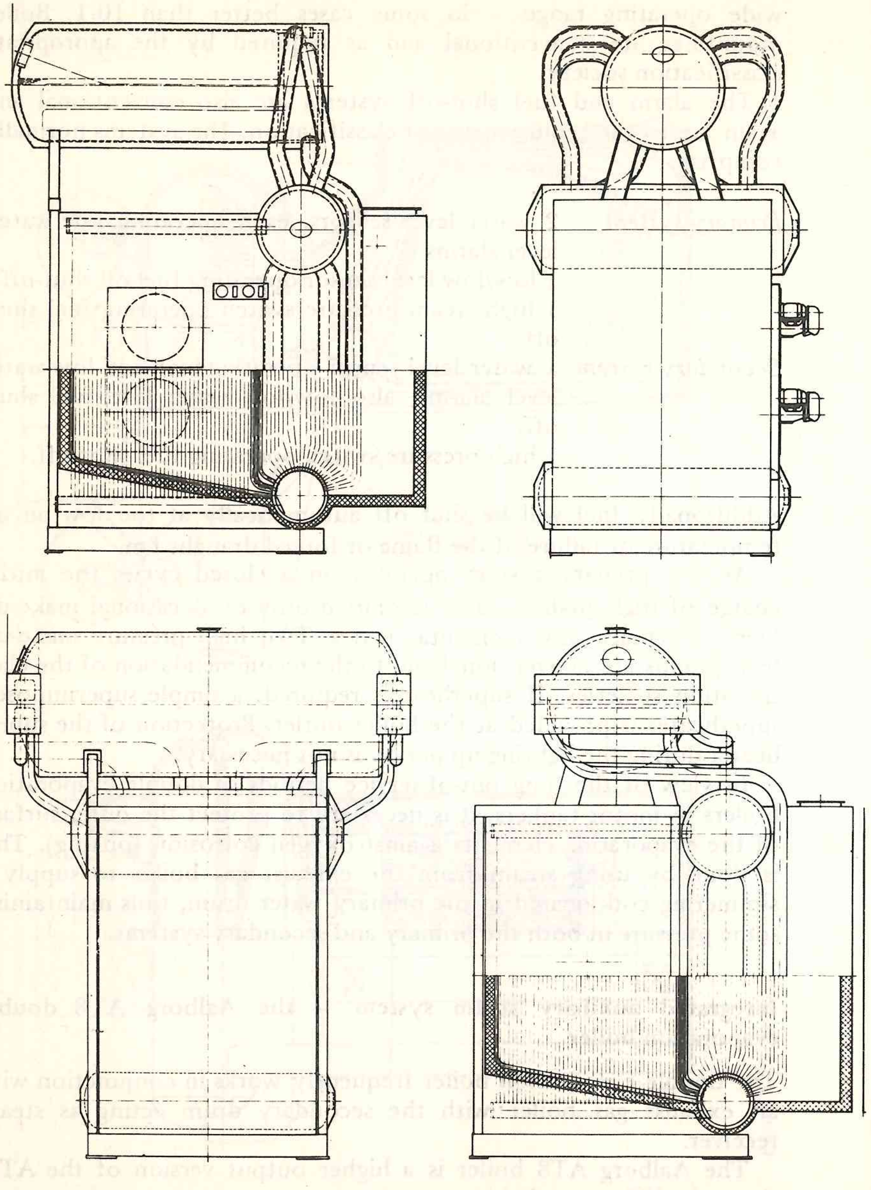


Figure 4.59 Aalborg AT8 boiler with membrane walls – front fired
(above) Integral end header type
(below) Square headers in ends type

2. Unheated external downcomers.
3. It is supplied with either roof or front furnace wall firing.
4. It is supplied with one evaporating header forming an integral part of the secondary drum or with two square headers welded into the dished ends of the drum (see Figure 4.59).

Typical steam conditions for these boilers are 63 bar for the primary and 23.5 bar for the secondary steam, a superheater being embodied when requested.

PRESENT TRENDS

Single boiler installations

In the constant quest for lower overall costs, including initial and operating costs, turbine machinery installations have been designed with a single boiler for propulsion purposes. This generally being supplemented by some form of auxiliary power as a 'get you home' device, in the event of complete boiler failure.

The single boilers of such installations have of necessity to be as reliable as possible, and at the same time, must be capable of operating for long periods between shut downs for cleaning operations, etc.

Features embodied in boilers for this service include:

(a) Large furnaces with conservative heat release rates and ample flame clearances.
(b) Furnaces completely water-walled either with membrane-type walls or closely pitched tubes to cut down brickwork maintenance.
(c) Roof firing to give a more uniform heat release and improved gas flow through the boiler.
(d) Superheaters in lower temperature gas zones shielded from the furnace.
(e) Improved forms and materials for superheater supports.
(f) Improved methods of superheat control.
(g) Improved soot blowing arrangements.

Regarding single boiler operation on turbine driven ships it is generally accepted that emergency arrangements should exist for propulsion in the event of failure of a single boiler. This practice, however, has not been adopted by all classification societies, but Lloyd's Register of Shipping require 'Ships intended for unrestricted service, fitted with steam turbines and having a single water tube boiler, to be provided with means to ensure emergency propulsion in the event of failure of the boiler'. Single-screw motor tankers have only one crankshaft and one tailshaft, and on this basis, provided the boiler of the turbine installation is as trouble free as the crankshaft of the diesel installation, there would not appear to be any just reasoning against the single boiler turbine installation.

Such installations are at sea, but it is more general, particularly in tankers, to find the one large main boiler supplemented by a small auxiliary boiler which besides acting as an emergency 'get you home' is also used for tank heating, tank cleaning services, etc. The 'one-and-a-half' boiler system initiated in Japan by Kawasaki is of the foregoing type and embodies one large high-pressure high-temperature boiler, with either economiser or air heater, for main propulsion, and one low-pressure auxiliary boiler for ship's services and emergency propulsion, see Figures 4.59 and 4.60.

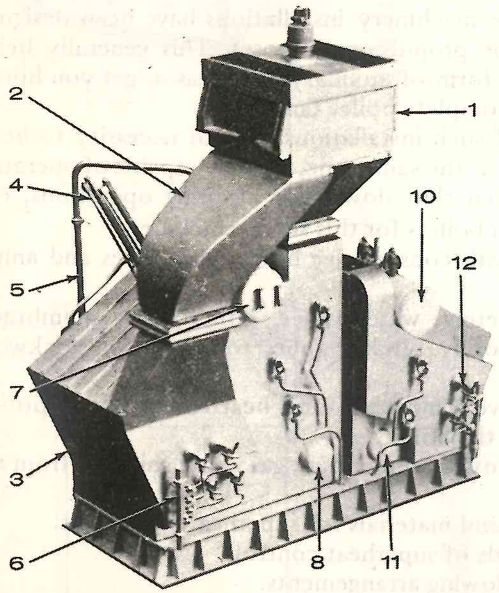


Figure 4.60 Kawasaki type BD-UA boiler with rotary regenerative air preheater (1½ boiler system)

1.	*Regenerative air preheater*	*7.*	*Steam drum*
2.	*Air duct*	*8.*	*Water drum*
3.	*Boiler casing (the profile is shaped so as to suit hull form)*	*9.*	*Economiser*
4.	*Retractable soot blower*	*10.*	*Steam drum (auxiliary boiler)*
5.	*Main steam pipe*	*11.*	*Water drum (auxiliary boiler)*
6.	*Burner*	*12.*	*Burner auxiliary boiler*

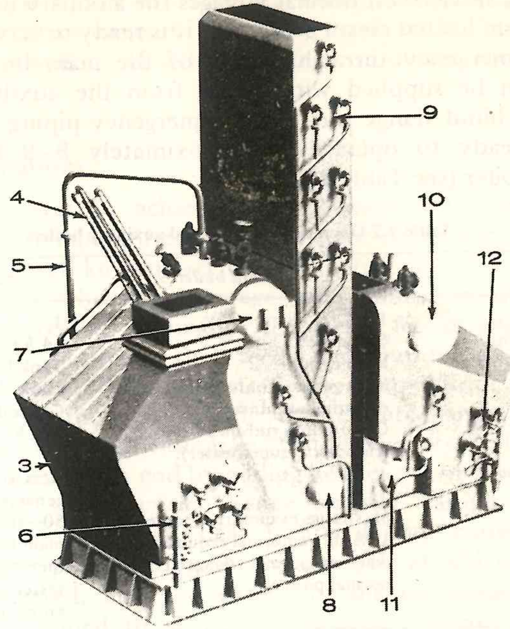


Figure 4.61 Kawasaki type BD-U boiler with economiser (1½ boiler system)
For key to numbers, see Figure 4.60

The advantages claimed are as follows:
1. Cost, weight and space required are reduced.
2. In tankers, additional main boiler capacity for tank cleaning and heating is not necessary (done by auxiliary boiler).
3. The auxiliary boiler is not expensive as high efficiency and high pressure are not required.
4. The auxiliary boiler can be used for propulsion, in the event of main boiler failure.
5. Feed water for the main boiler can be maintained pure as its feed system is separate from that of auxiliary boiler.
6. Main steam piping system is simplified.
7. Maintenance is facilitated and operating controls are simpler.

The particulars and boiler arrangements for the 'one-and-a-half' boiler system are as shown in Figure 4.59 and Table 4.2.

Operation of 'one-and-a-half' boiler system (Figure 4.62)

For normal voyages, the auxiliary boiler serves as a low-pressure steam generator. Emergency piping from the auxiliary boiler to the main boiler is blanked off.

For tank services on normal voyages the auxiliary boiler is used as an L.P. steam heated steam generator; it is ready to serve at any time.

In an emergency through failure of the main boiler, the main turbine can be supplied with steam from the auxiliary boiler by taking the blind flange out of the emergency piping. The ship will then be ready to operate at approximately 8–9 knots on the auxiliary boiler (see Table 4.2).

Table 4.2 Operation of main and auxiliary boilers

	Main boiler	*Auxiliary boiler*
Number	1	1
Steam conditions	61 bar 515°C.	14.5 bar saturated.
Steam supplied for	Main turbine. Main generator and other essential machinery. Cargo pump turbines (through desuperheater).	Tank heating. Tank cleaning. General services, i.e. fuel heating, etc.
Special function	—	Acts as l.p. steam generator.
Boiler capacity	Maximum evaporation to be 10% above normal requirements when on normal voyage at normal power.	30–40% of capacity of main boiler, which is then capable of operating vessel at about 8–9 knots in emergency.

Although the so-called 'one-and-a-half' boiler systems has been described above in some detail it should not be imagined, however, that this system is any way new. Vessels have been in operation for many years with one main water tube boiler supplemented by one or more auxiliary boilers, which in an emergency can be used for main propulsion purposes. Although there are many very large turbine tankers at sea steamed by one high pressure main boiler, supplemented by a small auxiliary boiler which can in emergency be used for propulsion, the present-day tendency is for two similar high pressure main boilers to be installed.

Table 4.3 Typical percentages of boiler installations

One boiler. no aux boiler	*One main boiler. Low press. sat. aux. boiler.*	*One main boiler. Identical press aux. boiler.*	*Two identical main boilers*	*One reheat main Boiler. Low press. sat. aux. boiler*
	61 bar 515°C.	61 bar 515°C.	61 bar 515°C.	100 bar 525°C/ 525°C.
	14.5 bar sat.	61 bar 350°C.		21.5 bar sat.
0	16%	3%	71%	10%

This trend is shown in Table 4.3 which shows for one Japanese shipyard the percentages of different types of boiler installations installed in vessels of 15 000 kW and over, during the past twelve years.

Reheat installations

One of the ways to achieve fuel economy is to increase steam pressures and temperatures, but there are economic and practical limits. It is a well-known fact that the efficiency of a steam-engine cycle is higher when the average temperature at which heat is supplied is increased. Normally, the steam for an engine takes in sensible heat between the feed temperature and saturation temperature, latent heat at saturation temperature, and sensible heat between the saturation temperature and final steam temperature. Thus, reheating, a further way of obtaining fuel economy, achieves this end by adding heat in the higher temperature range of the steam cycle, hence slightly raising the average temperature at which all heat is added, and consequently the efficiency. The point during the steam cycle at which the working steam is reheated, and the extent of the reheating, have to be carefully determined to avoid an unnecessary degree of superheat and hence wastage of heat, when the steam enters the condenser at the end of its expansion.

In practice, highly-superheated steam is supplied to the high-pressure propulsion turbine and then, having done its work there, it is led back to the boiler again for reheating. Thus its heat content is considerably raised allowing it to do increased work when it is again led back to the turbines, and additionally preventing turbine blade erosion through wet steam at the l.p. end of the expansion.

The likely gain in specific fuel consumption is about 5 to 7% on about 18 500 kW. These economies are only obtained, however, at the expense of greater initial cost, a more complex installation, greatly extended steam-piping arrangements and probably higher maintenance bills. Such installations also present difficulties from the manoeuvring aspect, but in large tankers and bulk carriers, with long hauls between terminal ports, they may well be instrumental in cutting fuel costs.

The boilers, or maybe one single boiler, normally proposed for such installations are different, inasmuch as they embody a reheater (basically a second superheater), and this reheater has to be protected when, during astern manoeuvers, no steam is returning to it from the h.p. turbine for reheating.

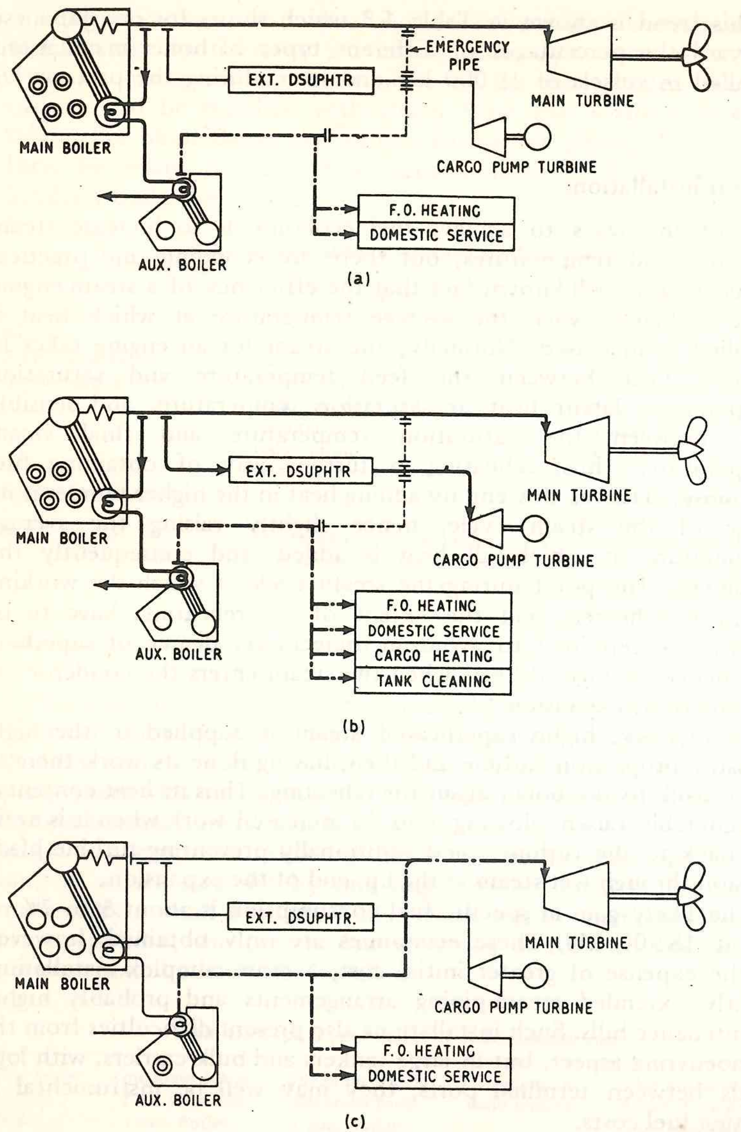


Figure 4.62 Operation of 'One-and-a-half' system in tankers
(a) Normal voyages
(b) Tank services on normal voyages
(c) Emergency running on auxiliary boiler

Reheat boilers

The design of boilers for reheat purposes is to some extent dependent on the nature of the propulsion machinery. A turbo-electric installation has unidirectional turbines and this obviates the reheater difficulties during astern movements which have to be catered for in normal geared installations. Thus, in the 'Beaver' Class vessels of 1946 it was possible to use one comparatively simple boiler as shown in Figure 4.63(a). The combustion gases flow upwards in two passes, one through the superheater and one through the reheater, the reheater being damper controlled for temperature adjustment purposes.

In higher horsepower geared turbine installations the astern manoeuvring difficulties were tackled in a different manner. The turbines were supplied with steam from several main boilers, basically similar except that one of them was fitted with a reheater as in Figure 4.63(b). Thus, on manoeuvring, when in any case full power is not normally required, the reheat boiler burners can be shut down. The foregoing arrangement was fitted in high-powered twin-screw passenger liners in 1957, the one reheat boiler embodying reheaters for both sets of machinery.

Several 200 000 d.w.t. tankers were fitted with reheat turbine installations of approximately 22 500 kW the steam conditions being 84 bar and (512.5°C). The boiler installation consisted of two boilers, one a normal F.W. D-type, and the other a twin-furnace I.H.I. FW reheat boiler as in Figure 4.63(c).

Some units in use in large tankers are shown in Figure 4.64 and others of later design have already been described in this chapter. One of these boilers is used to supply all the steam necessary for main propulsion and for discharging cargo, the only other boiler in the vessel being a small auxiliary of relatively low pressure, to supply steam for tank cleaning and other auxiliary services, also as an emergency standby to get the vessel to the nearest suitable port in the event of main boiler failure. Thus, in such vessels, the main boiler, as in land power station service, is intended to be under steam continually in more or less, constant temperature conditions, the reheater being bypassed under manoeuvring conditions and when in port.

These modern designs have the following characteristics in common:

1. Roof firing.
2. Membrane or monowalls.
3. Damper-controlled divided convection sections at the rear of the boiler containing the reheater, superheater and by-pass economiser.

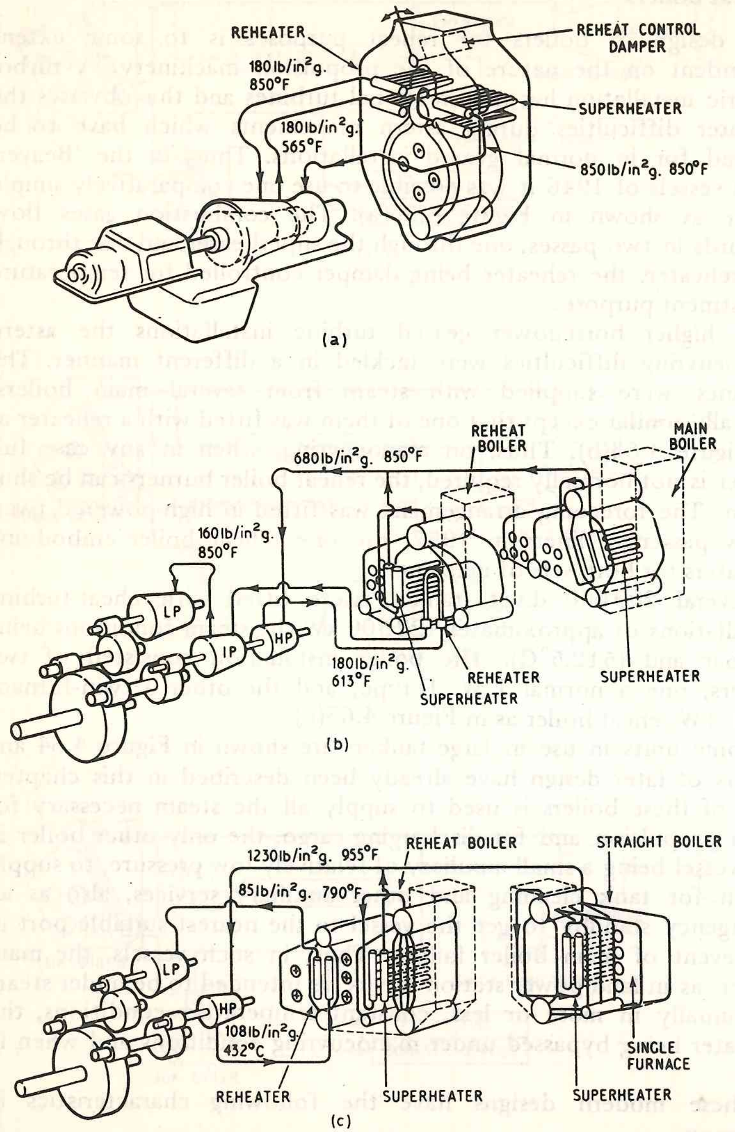


Figure 4.63 Typical reheat boiler installations
(a) 1946 (turbo-electric); 9000 s.h.p.
(b) 1957; 13 500 s.h.p.
(c) 1967; 32 000 s.h.p.

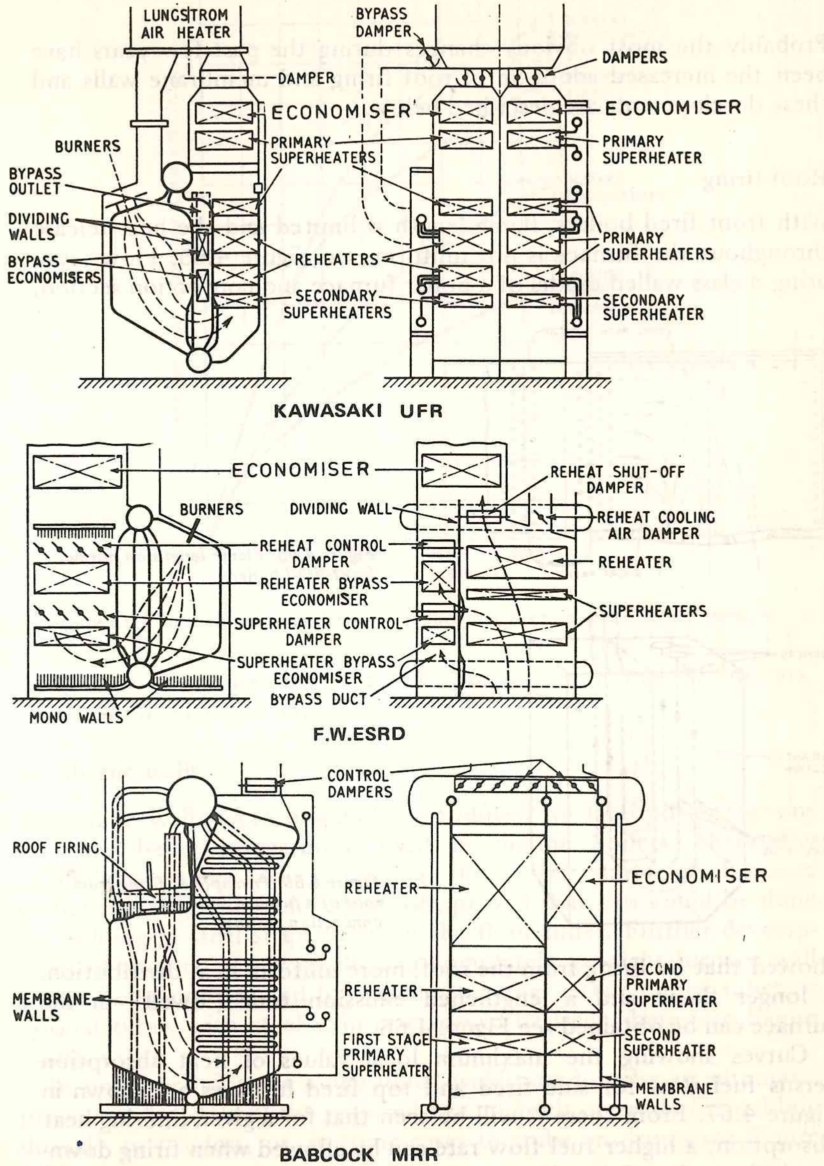


***Figure 4.64** Three types of boiler used in conjunction with auxiliary services in single-boiler reheat installations*

ADVANCES IN DESIGN AND CONSTRUCTION

Probably the most obvious changes during the past few years have been the increased adoption of roof firing and membrane walls and these developments are described below.

Roof firing

With front fired boilers, flame length is limited and the heat release throughout the furnace is not uniform, see Figure 4.65. Flow tests, using a glass walled model of a boiler furnace and convection section,

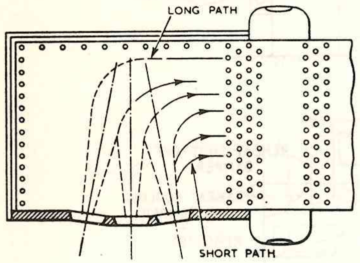


Figure 4.65 Flame length on normal front-fired boiler

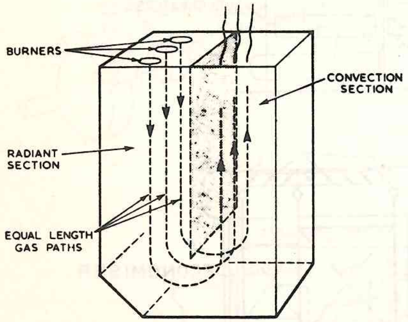


Figure 4.66 Principle of firing from roof of a furnace and using a convection section

showed that by firing from the roof, more uniform heat distribution, a longer flame and a lengthened emission time ('dwell') in the furnace can be obtained see Figure 4.66.

Curves showing the maximum local values of heat absorption versus fuel flow for side fired and top fired furnaces are shown in Figure 4.67. From these it will be seen that for a given limiting heat absorption, a higher fuel flow rate can be allowed when firing downwards than when firing sideways.

Photographs of typical flow patterns obtained in glass walled model furnaces obtained by pumping fluid with metallic particles or

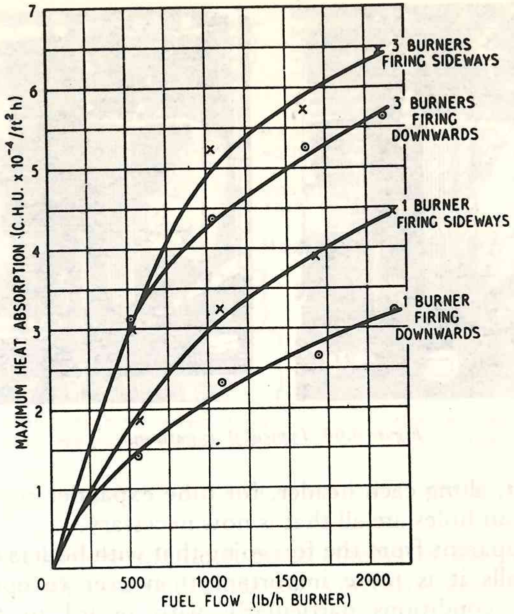


Figure 4.67 Heat absorption related to the fuel flow for side- and top-fired furnaces

air bubbles in suspension, through nozzles simulating the burners, are shown in Figure 4.68.

Membrane walls

Membrane walls were originally introduced for land power stations and are being increasingly used in marine boilers. Originally, experience gained when making the lower parts of furnaces sufficiently tight to hold liquid ash, proved that this could be done by welding in steel strips between the floor tubes. Further development of this technique resulted in completely gas-tight furnace wall panels being constructed by welding together either finned tubes or normal tubes with steel strip interspaced between them (see Figure 4.69).

In both methods the longitudinal welds are done by an automatic process and panels of the required size are built up ready for welding directly to headers, or, in some cases to stubs on drums see Figure 4.70.

The use of welded, in lieu of expanded, tube connection has obviated the necessity of providing a series of handholes each with

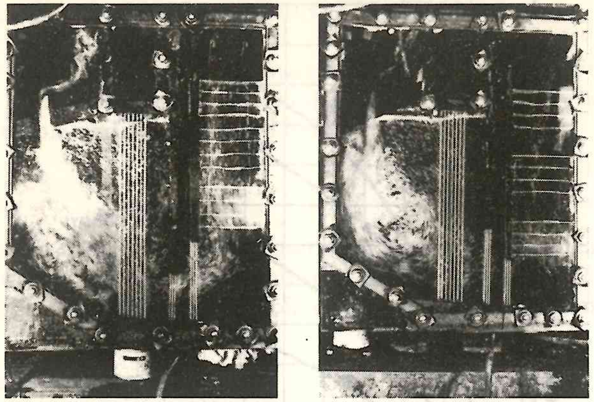


Figure 4.68 Typical flow patterns

its own gasket, along each header, for tube expander access. One or two cleaning out holes are all that is now necessary.

It will be apparent from the foregoing that with boilers embodying membrane walls it is more important than ever to operate them under proper conditions particularly with regard to feed water treatment.

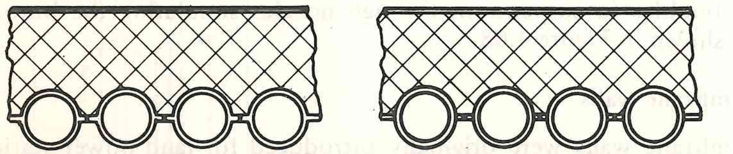


Figure 4.69 Methods of membrane wall construction

A membrane wall tube failure at sea in a boiler of this type is, owing to the welded construction and lack of handholes, difficult to repair, and in the case of vessels with a single main boiler can produce an emergency situation.

The advantages claimed for these types of water-walls are:

(a) The walls for the entire furnace and, if necessary, the convection sections can be prefabricated in the shop.

(b) They are stronger and more gastight than any other type.

(c) Maintenance is low as refractories are practically eliminated.

(d) Water washing of furnace walls and tube banks is facilitated.

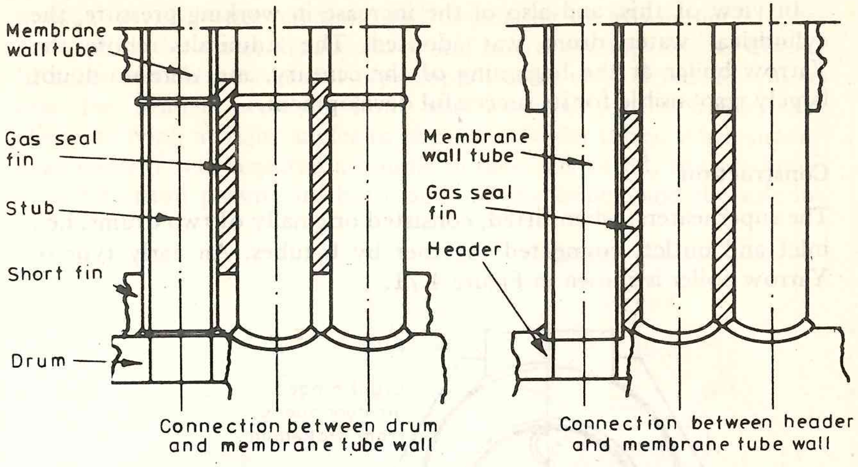


Figure 4.70 Details of connections between drums, headers and membrane tube walls

(e) The gas-tightness of the furnace eliminates the possibility of corrosion of the outer casings by corrosive gases (see Figure 4.70).

HISTORICAL

To conclude this chapter some of the past well known types of water tube boiler, some of which may still be in use, should be mentioned. In particular the Yarrow, which at one time steamed most Admiralty vessels and a number of well-known passenger liners.

Yarrow boilers

The original Yarrow designs were of simple construction, with one top steam drum and two bottom water drums, connected together by straight tubes. These were expanded and bell-mouthed in the usual manner, and large external downcomers were fitted to each of the water drums. The bottom drums, originally known as water pockets, were D-shaped, i.e., semi-circular with flat tube plate tops, with the tube plates flanged to take the wrappers or shells. As might be expected, troubles were experienced in the form of grooving of the pocket corners and stretching of the outer rows of tubes, caused through the flat tube plate tops of the pockets trying to assume, with the wrappers, a circular shape.

In view of this, and also of the increase in working pressure, the cylindrical water drum was adopted. The Admiralty chose the Yarrow boiler at the beginning of the century, and were no doubt largely responsible for its successful development.

Construction

The superheaters, when fitted, consisted originally of two drums, i.e., inlet and outlet, connected together by U-tubes. An early type of Yarrow boiler is shown in Figure 4.71.

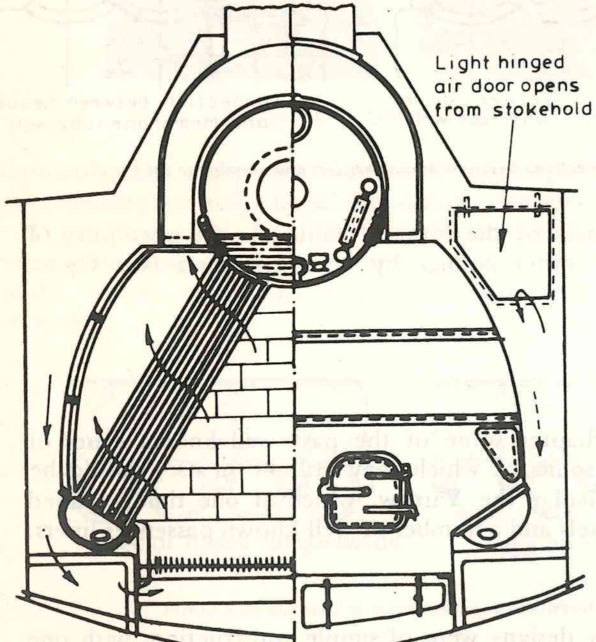


Figure 4.71 Cross-section of early Yarrow boiler

Later Yarrow boilers had a large steam drum connected by straight tubes to three water drums, these drums being designated the four-row, five-row or eleven-row, according to the number of rows of tubes each accommodated. The Yarrow type of superheater consisted of a large-diameter drum situated between and parallel to two of the water drums, the elements being U-tubes expanded into this drum and lying between two of the boiler-tube banks. It was not

unusual to find external unheated circulating or downcomer pipes connecting the water drums above and below the superheater drum. In some installations header-type superheaters were fitted, in which case the headers were in front and external to the boiler, the elements lying at right angles to the actual boiler tubes. When superheat control was required a double uptake was fitted, the products of combustion passing up both sides of the boiler, and the side in

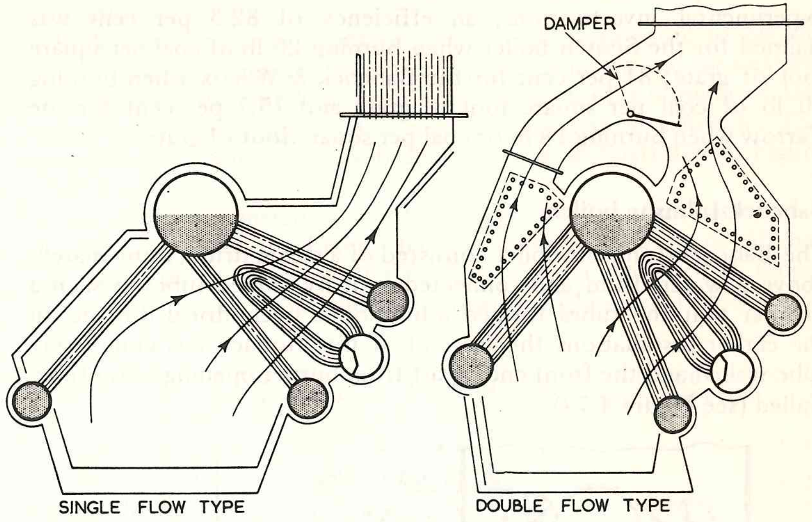


Figure 4.72 Single-flow and double-flow Yarrow boilers

which the superheater was not fitted was provided with a damper so that all, or part, of the gases could be diverted through the superheater. Boilers so fitted were known as the double flow type, whereas those with a single uptake, in which all the products of combustion always passed through the superheater, were known as the single-flow type (see Figure 4.72).

The weight of these boilers was usually taken on feet riveted to the lower water drums, these feet in their turn resting on stools attached to the ship's structure. This left the steam drum more or less free to move as required by tube expansion and contraction.

Performance

The relatively high evaporation rate of the Yarrow boiler was no doubt one of the predominating factors which led to its almost exclusive adoption by the British Admiralty after the First World War. It is worthy of record that in 1904 a Committee of Mercantile Marine engineers in conjunction with an officer from the Service, all appointed by the Admiralty for the purpose of deciding whether the Scotch or water-tube boiler should be adopted in the Navy, reported that Babcock & Wilcox and Yarrow boilers were suitable for use in battleships and cruisers.

The Report of this Boiler Committee showed that in their experimental investigations, an efficiency of 82.3 per cent was claimed for the Scotch boiler when burning 20 lb of coal per square foot of grate; 81 per cent for the Babcock & Wilcox when burning 20 lb of coal per square foot of grate and 75.7 per cent for the Yarrow when burning 18 lb of coal per square foot of grate.

Babcock-Johnson boilers

The Babcock-Johnson boiler consisted of a steam drum, immediately above a water drum and connected to it by curved tubes in such a manner that the tubes formed a horizontal cyclindrical furnace. In the earlier installations the far end of this furnace was completely tube-walled and the front end, apart from burner openings, also tube-walled (see Figure 4.73).

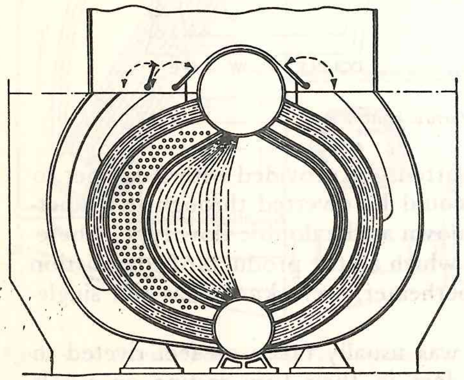


Figure 4.73 Early Babcock-Johnson boiler

Positive circulation at all powers was assured by the fitting of large uncooled downcomers between the drums. The complete boiler was enclosed in a double casing, the space between the two casings being used as a hot-air duct to the burner from the preheater. The superheater was situated within one of the side tube banks of the boiler,

and control of superheat temperature was obtained by utilising the double-flow system for the products of combustion. In this system, as previously described, the gases passed up both sides of the steam drum, the quantity of gases flowing over the superheater being regulated by dampers at the top of the two gas outlets.

As the furnace was almost completely tube-walled, brickwork was kept down to a minimum, the top of the water drum and parts of the front and rear walls being the only places requiring brickwork protection.

Boilers of this type, operating at a working pressure of 60 bar and fitted with reheaters, superheaters, economisers and air heaters, were successfully fitted as single units in each of a number of fast cargo liners which operated a regular transatlantic schedule. The arrangement of the complete boiler unit was as illustrated in Figure 4.74.

The single-unit installations of this type fitted in ships with turbo-electric propelling machinery had a working pressure of 60 bar and steam temperature of 454°C. The reheater was used to reheat the exhaust steam from the high-pressure turbine at 12.5 bar and

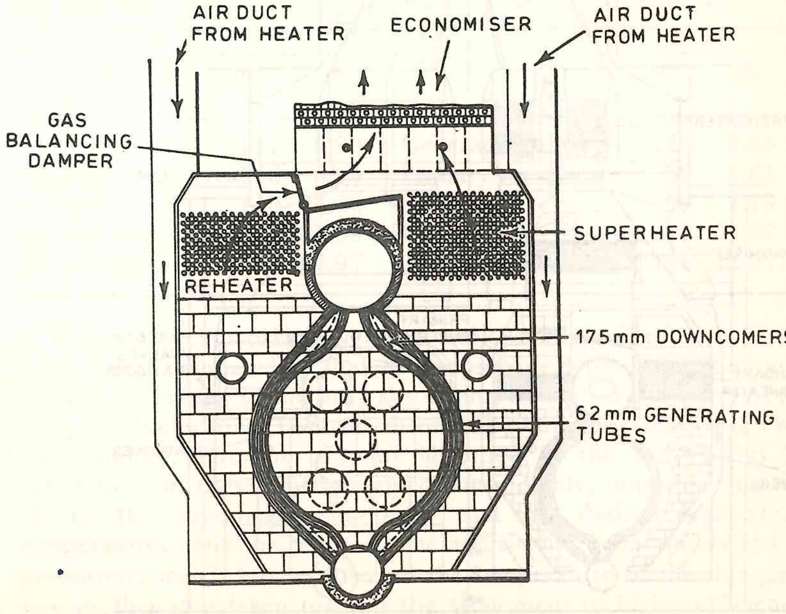


Figure 4.74 Later reheat Babcock-Johnson boiler used in single boiler turbo-electric ships

296°C. temperature back to the original temeperature of 454°C. before being utilized in the low-pressure turbine. It will be noted from Figure 4.74 that there are only four rows of tubes bounding each side of the furnace, and all these can be regarded as generators, adequate circulation was provided by large drum-to-drum downcomers fitted inside the air casing. Dampers were provided for by-passing the superheater, economiser and air heater when lighting up, and also for the regulation of superheat and feed-water temperatures. A main damper at the top of the reheater controlled the 'two-flow' gas system up the sides of the boiler, and this regulated the reheat temperature.

As a matter of interest it should be stated that in the event of failure of the single boiler, the vessels concerned could still proceed at reduced speed, since it was arranged that in such an emergency the main propelling motor could take its current from the auxiliary diesel generators.

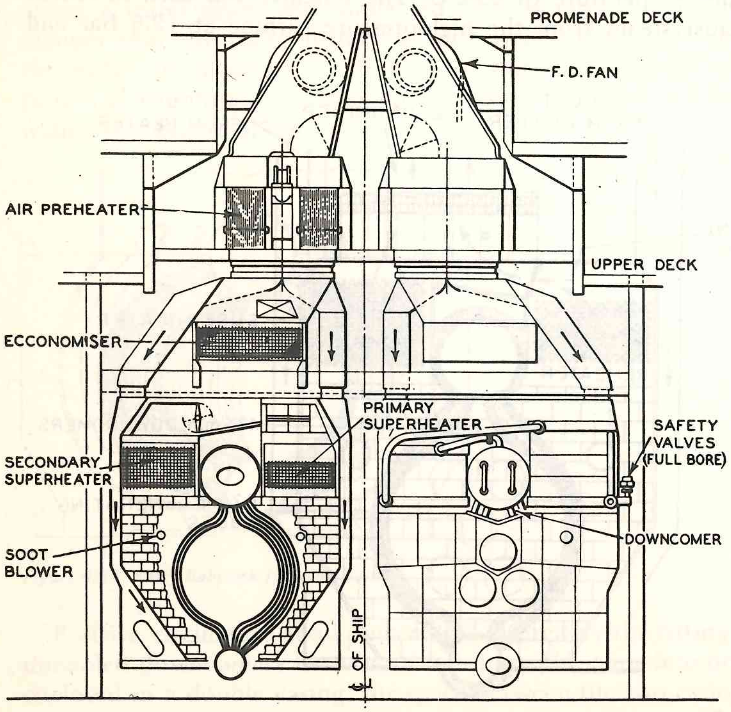


Figure 4.75 Fairfield-Johnson boiler

Fairfield-Johnson boiler

A later example of the Johnson-type boiler which appeared simple and compact, was the Fairfield-Johnson (Figure 4.75). It will be noted that in this design a lower working pressure (30 bar) was adopted than in the previous example (58 bar), although the superheat temperature (438°C.) remained the same.

To raise the temperature of the saturated steam at 30 bar to 438°C. required more superheater surface than to raise steam at 58 bar to 438°C. as in the previously mentioned type. In this design the temperature was raised by the use of a primary and secondary superheater, which were in series, one on each side of the steam drum.

Heating surfaces

The heating surfaces of the 850 and 455 boilers were made up as follows:

Babcock-Johnson (58 bar, 454°C.)			*Fairfield-Johnson* (455, 438°C.)		
	m^2	%		m^2	%
Generator tubes	191	6.93	Generator tubes	140	13.66
Superheater	166	6.04	Primary superheater	39	3.81
Reheater	140	5.06	Secondary	95	9.19
Economiser	385	13.99	Economiser	219	21.27
Air preheater	1870	67.97	Air preheater	536	52.07

The increase in working pressures and temperatures of these water-tube boilers compared to the old low-pressure types brought about a marked difference in the heat absorption of the various parts of the complete boiler unit. The heat absorbed by furnace radiation did not alter unduly, but the amount absorbed in the tube banks by convection, in these units, dropped considerably, more heat passing on to the superheater in order that the desired high steam temperatures could be reached. The addition of economisers and air preheaters, which further lowered the temperature of the flue gases was another step taken towards the attainment of higher efficiency.

5 Dual-fired boilers for oil and liquified natural gas

The middle 1960s saw the introduction of sea transport for liquified natural gas (LNG) and it was soon realised that economies in transport would be affected if the heat in the natural 'boil off' gas was converted into propulsive effort rather than wasting it by venting it to atmosphere.

To burn this gas in the boilers of a steam turbine installation was one obvious answer, and with this object in view Foster Wheeler, in conjunction with the requirements of classification, set about designing their first ESD dual-fired boilers. The design called for very careful consideration particularly from the safety aspect.

LNG (or methane) is transported aboard ship in large insulated tanks built into the vessels' hulls. The liquid gas at about −160°C is pumped into these built-in tanks, whose degree of insulation is such that the amount of evaporation or 'boil-off' is less than 0.3 of 1 per cent per day.

The 'boil-off', being at the same temperatures as the liquid, has then to be heated before being fed to the boiler burners, and heaters are provided for this purpose.

In the initial design of these dual-fired boilers careful consideration was given to

1. Safety.
2. The need to operate on oil alone or any combination of oil and gas.
3. Wide burner turn down to cope with manoeuvring conditions.
4. Boilers to be suitable for installation in an engine room.

The first pair of dual-fired boilers were of the ESD II type with front firing (see Figure 5.1). These boilers were designed for a normal output of 22 250 kg and maximum of 33 200 kg/h each, at 41 bar 454°C.

In common with most other dual fired boilers subsequently designed by this company, the furnaces were bounded by tangent

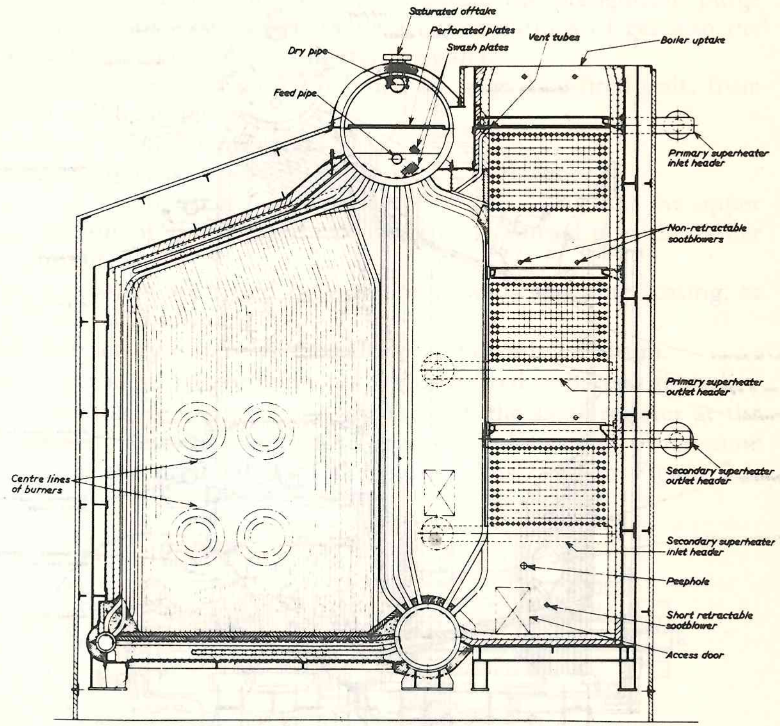


Figure 5.1 Foster Wheeler ESD front-fired oil/natural gas boiler

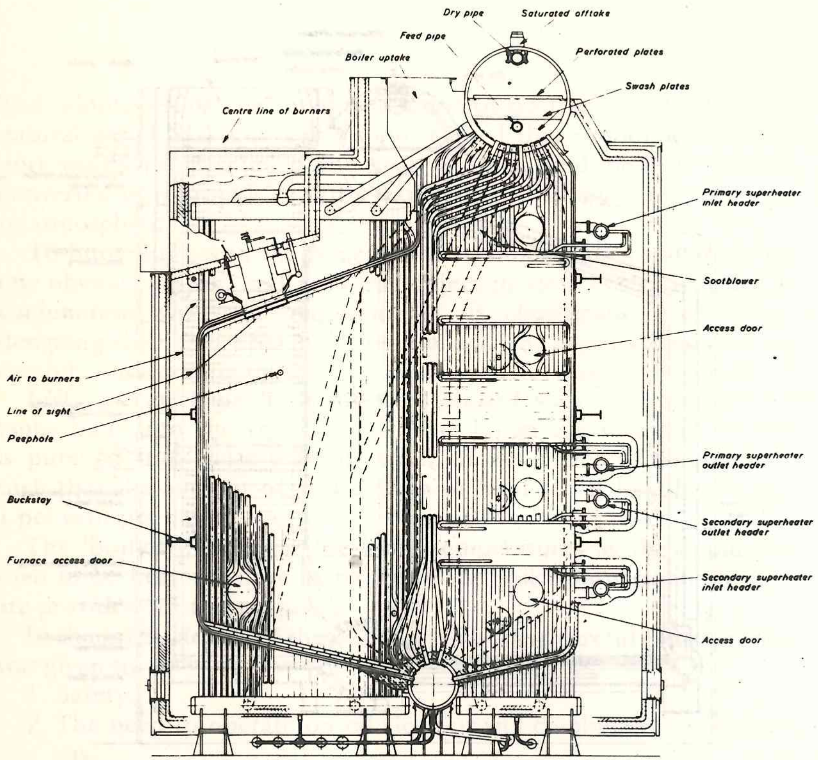


Figure 5.2 Foster Wheeler ESD roof-fired monowall oil/natural gas boiler

tubes, although at the present time preference is for monowall construction.

As a safety precaution, all dual-fired boilers designed by Foster Wheeler are entirely double cased, the air flow from the forced draught fans passing through the double casing. This ensures that any leakages through the actual furnace walls are only of air into the boiler furnace, and not gases outwards into the machinery space.

As a safeguard against furnace explosions an open vent is fitted at the top of the boiler furnace which during the pre-ignition purge effectively clears away any possible accummulations of gas into the boiler uptake (methane gas is lighter than air).

Figure 5.2 shows a modern design of large dual-fired unit, from which it will be noted that:

(a) Roof firing is employed.
(b) The boiler is monowall encased.
(c) The steam drum position has been altered so that the upper section of the furnace can be directly vented into the boiler uptake.
(d) Buckstays are fitted between monowalls and outer casing, as extra wall support.
(e) Refractory is only used on floors and over lower drum.

One of the initial requirements for dual-fired units was that they would be able to burn oil and gas through the same register at the same time. An extensive development and testing programme resulted in the production of the burner illustrated in Figure 5.3.

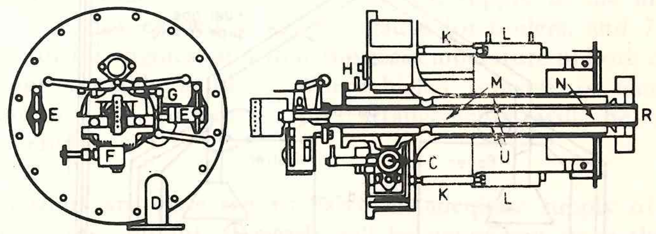


Figure 5.3 Arrangement of register and burner

A.	*Oil valve lever*	J.	*Inert gas jacket*
B.	*Steam valve lever*	K.	*Combustion air inlet*
C.	*Gas valve lever*	L.	*Air slide*
D.	*Gas inlet*	M.	*Oil and steam tube*
E.	*Air slide*	N.	*Gas nozzles*
F.	*Steam purging block*	O.	*Oil swirler*
G.	*Interlock mechanism*	Q.	*Gas tube*
H.	*Inert gas inlet*	R.	*Oil atomiser*
		T.	*Tip swirler*

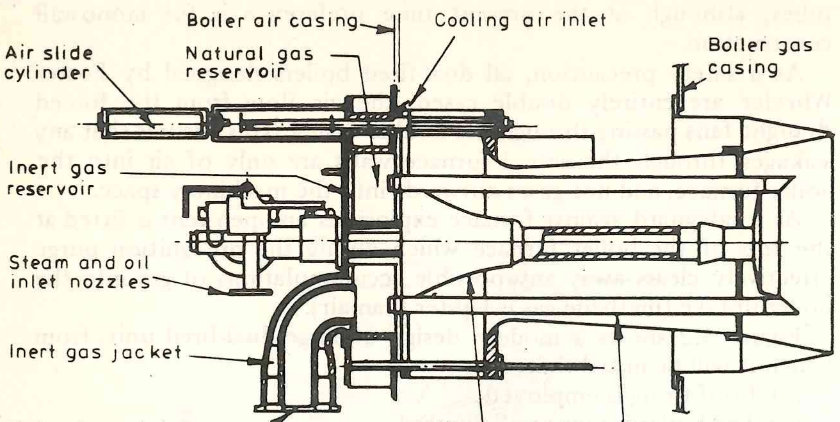


Figure 5.4 Combined natural gas and oil burner

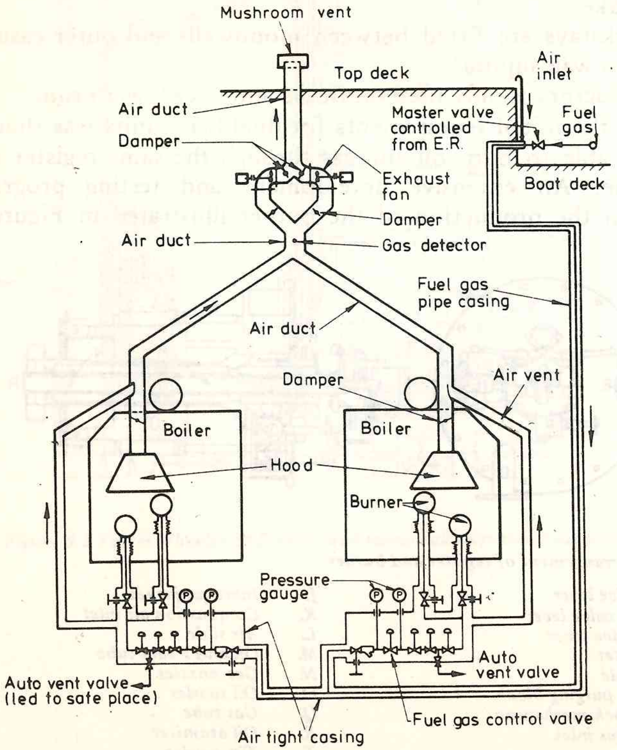


Figure 5.5 Typical gas supply and safety venting arrangement

This burner proved satisfactory in service and is still being fitted in some new installations, although for larger outputs the burner shown in Figure 5.4 has been developed. In this later type of burner the gas is introduced by means of 'spuds' or 'pokers', and the oil and atomising steam via the central gun. The registers are of the axial flow type with slides operated pneumatically and turn-downs of 15:1 on oil and 5:1 on gas are normal, the latter being dependent on the available gas pressure.

The foregoing is a brief summary of the boiler modifications necessary for burning LNG. For safe operation, however, there are many additional requirements and controls necessary to comply with the classification authorities (see Figure 5.5). These are listed below.

CLASSIFICATION REQUIREMENTS FOR 'USE OF CARGO AS FUEL'.

1. Methane (LNG) is the only cargo whose vapour or boil-off gas may be used in main propelling machinery rooms and boiler rooms. In these rooms, LNG may be utilised only in boilers, inert gas generators, and internal combustion engines.

2. Proposals for the use of methane (LNG) as fuel for other than main propulsion purposes, e.g. cargo reliquefaction and inert gas generation will be specially considered. The Rules are based on the assumption that the pressure of the gas supply to the machinery space will not exceed 1 kg/cm^2 gauge for boilers, and 7 kg/cm^2 gauge for oil engines, and that the gas temperature in both cases will be approximately ambient. Where higher pressure or temperature conditions are proposed, the arrangements will be specially considered.

3. All ships are expected to carry an adequate supply of oil fuel bunkers, the amount of which will be dependent upon the service in which the ship is engaged and the ship shall not be solely dependent on methane 'boil-off' for fuel requirements at any time in the voyage.

Main boilers

4. Oil fuel alone is to be used for starting up and, except under clearly prescribed special conditions, for manoeuvring and port operations. Each boiler is to have a separate uptake to the top of the funnel or a separate funnel.

5. The firing equipment is to be of combined gas and oil type and be capable of burning both fuels simultaneously. The gas nozzles are to be so disposed as to obtain ignition from the oil flame which is to be present under all conditions of firing. A mechanical interlocking device is to be provided to prevent the gas supply being opened until the oil and air controls are in the firing position. Each burner supply pipe is to be fitted with a gas shut-off cock and a flame arrester unless the latter is incorporated in the burner. An audible alarm is to be provided giving warning of loss of minimum effective pressure in the oil fuel discharge line or failure of the fuel pump.

6. In addition to the low water level fuel shut-off and alarm required for oil-fired boilers, similar arrangements are to be made for gas shut-off and alarm when the boilers are being gas fired.

7. An inert gas or steam purging connection is to be provided on the burner side of the shut-off arrangements so that the pipes to the gas nozzles can be purged immediately before and after methane gas is used for firing purposes.

8. A notice board is to be provided at the firing platform stating: 'If ignition is lost from both oil and gas burners, the combustion spaces are to be thoroughly purged of all combustible gases before re-lighting the oil burners'.

Gas fuel lines

9. Gas fuel lines should not pass through accommodation, service or control station spaces. Gas lines may pass through or extend into other spaces provided they fulfil one of the following:

(a) The gas fuel line should be a double wall piping system with the gas fuel contained in the inner pipe. The space between the concentric pipes should be pressurised with inert gas at a pressure greater than the fuel pressure. Suitable alarms should be provided to indicate a loss of pressure between the pipes.
(b) The gas fuel lines should be installed in a mechanically exhaust ventilated pipe or duct. The air space between the outer and inner walls of piping or ducts should be equipped with mechanical ventilation having a capacity of at least thirty air changes per hour. The ventilation system should be arranged to maintain a pressure less than the atmospheric pressure. The fan motors should be placed outside the ventilation pipe or duct. The ventilation outlet

should be placed in a position where no flammable gas-air mixture may be ignited. The ventilation inlet should be so arranged that gas or gas-air mixture will not be drawn into the system. The ventilation should always be in operation when there is gas in the supply pipeline. Continuous gas detection should be provided to indicate leaks, and to shut down the fuel gas supply to the machinery space in accordance with (19). The exhaust fan for this duct should be arranged so that the gas fuel supply to the machinery space will be cut off if the required air flow is not established and maintained.

10. The gas supply lines in the machinery space are to have all-welded joints so far as practicable, and are to be tested in place by hydraulic pressure to 7 kg/cm² or twice the working pressure, whichever is the greater. Subsequently, the lines are to be tested by air at the working pressure using soapy water, or equivalent, to verify that all joints are absolutely tight.

11. If a gas leak occurs, the gas fuel supply should not be operated until the leak has been found and repaired. Instructions to this effect should be placed in a prominent position in the machinery space.

12. The double wall piping system or the ventilation duct provided for the gas fuel lines should terminate at the ventilation hood or casing required by 13.

13. A ventilation hood or casing should be provided for the areas occupied by flanges, valves, etc, and for the gas fuel piping at the gas utilisation unit, such as boiler, diesel engine, gas turbine, which is not enclosed in the double wall piping system or ventilated duct. If this ventilation hood or casing is not served by the exhaust ventilation fan serving a duct as specified in 9(b), then it should be equipped with an exhaust ventilation system and continuous gas detection should be provided to indicate leaks and to shut down the gas fuel supply to the machinery space in accordance with (10). The exhaust fan should be arranged so that the gas fuel supply to the machinery space will be cut off if the exhaust ventilation is not functioning so as to produce the required air flow. The hood or casing should be installed or mounted to permit the ventilating air to sweep across the gas utilisation unit and be exhausted at the top of the hood or casing.

14. Each gas utilisation unit should be provided with a set of three automatic valves. Two of these valves should be in series in the gas fuel pipe to the consuming equipment. The other valve should be in a pipe that vents, to a safe location in the open air, that portion of the gas fuel piping that is between the two series valves. These valves should be arranged so that failure of necessary forced draft, loss of flame on boiler burners, abnormal pressure in the gas fuel supply line, or failure of the valve control actuating medium will cause the two gas fuel valves which are in series to close automatically and cause the vent valve to open automatically. Alternatively, the function of one of the series valves and the valve in the vent line can be incorporated into one valve body so arranged that when one of the above conditions occurs, flow to the gas utilisation unit will be blocked and the vent opened.

15. Local manually operated shut-off arrangements are also to be fitted in the gas supply to each utilisation unit.

16. A master gas fuel valve that can be closed from within the machinery space should be provided outside the machinery space. The valve should be arranged so as to close automatically if leakage of gas is detected, or loss of ventilation for the duct or casing or loss of pressurisation of the double wall gas fuel piping occurs.

17. Provision should be made for inerting and gas freeing that portion of the gas fuel piping system located in the machinery space.

18. Make-up air for the required ventilation air system and discharge of the air from the ventilation system should be respectively from and to a safe location.

19. Gas detection systems provided in accordance with the requirements of (9) and (13) should alarm at 30% of the lower flammable limit and shut down the gas fuel supply to the machinery space before the gas concentration reaches 60% of the lower flammable limit.

Plans

20. The following plans are to be submitted for consideration:
General arrangement of plant.
Gas piping system, together with details of interlocking and safety devices.

Gas heaters.
Gas compressors and to their prive movers.
Gas storage pressure vessels.
Gas and oil fuel burning arrangements.

Equipment for heating, compressing and storing methane gas

21. The methane gas is to be heated and compressed outside the machinery space. If the gas is stored in a pressure vessel, the latter is also to be located outside the machinery space.

22. Provision is to be made to enable the machinery and associated pipework used for preparing and supplying the gas boil-off to be purged of flammable gas prior to being opened up for maintenance or survey.

23. Gas heaters and compressors, of watertight construction, may be installed on the open deck provided they are suitably located and protected from mechanical damage. Alternatively, the heaters and compressors may be installed in a well ventilated compartment outside the machinery space. This compartment is to be treated as a dangerous space to which the special requirements for electrical equipment are applicable.

24. If steam is adopted as the heating medium, the steam supply to the heaters is to be automatically controlled by the discharge temperature of the methane from the heaters, and the steam drains are to be led to a vented drain tank outside the machinery space. The vents are to be led to a safe position.

25. The prime movers for the gas compressors are to be regulated to maintain a positive suction pressure and arranged to stop automatically if the pressure on the suction side of the compressors is lower than 0.035 kg/cm^2 gauge or other approved positive pressure appropriate to the cargo tank system. They are also to be capable of being stopped, in emergency, from suitable positions on deck and in the machinery space.

26. Gas compressors of the piston type are to be fitted with relief valves discharging to a safe position. The relief valves are to be so proportioned and adjusted that the accumulation with the outlet valves closed will not exceed 10% of the maximum working pressure.

27. The suction and discharge connections to the compressors are to be fitted with isolating valves.

28. Pressure vessels for storing methane gas are to be of approved design and fitted with pressure relief valves discharging to atmosphere in a safe position.

Ventilation of machinery spaces

29. Efficient arrangements are to be provided for the thorough ventilation of the machinery space under all climatic conditions, and are to include a monitoring system with visual and audible warnings to detect gas leaks.

Survey

30. The gas compressors, heaters, pressure vessels and piping are to be constructed under Special Survey, and the installation of the whole plant on board the ship is to be carried out under the supervision of the Classification Surveyors.

31. All details of the gas fuel system should be submitted for approval.

6 Composite boilers and exhaust-gas heat exchangers

In the quest for higher efficiency, the designers of marine machinery installations are constantly endeavouring to extract the maximum amount of energy from the fuel within the limits dictated by practical and economic considerations. In all forms of marine propulsion plant, a great deal of energy is wasted, principally by way of the exhaust gases to the atmosphere but also through the cooling water systems, to the sea. It is this waste-heat energy which is potentially recoverable. Continually rising fuel costs and the fact that world reserves of primary energy are not inexhaustable make efficient use of such waste energy increasingly attractive.

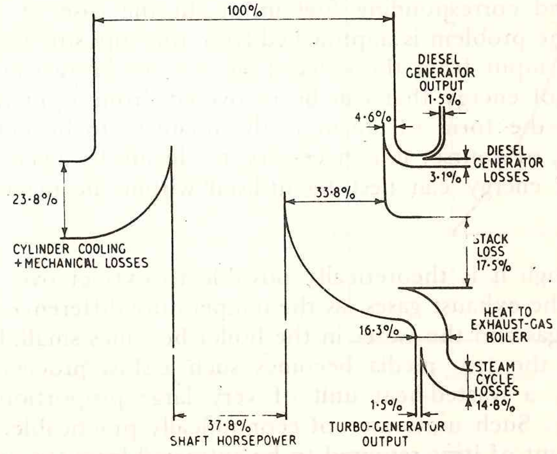


Figure 6.1 Diagram showing typical heat balance for large modern turbo-charged vessel

Figure 6.1 is a typical heat balance diagram for the main heavy oil engine of a large modern vessel. It will be noted that not more than 40% of the fuel consumed is converted into useful work through the main engine. Of the remaining energy liberated from the fuel, some

34%, the equivalent of about 90% of the mechanical power output, is contained in the exhaust gases. The temperatures of these exhaust gases range from 280°C. to 340°C. in the case of slow speed 2-stroke engines and from 370°C. to 410°C. for medium speed 4-stroke engines but it should be remembered that the volume of gas available from a 4-stroke engine is about half of that available from a similarly rated 2-stroke engine. Thus, the apparent increased amount of heat available from the 4-stroke engine is not as pronounced as appears from reference to the exhaust gas temperatures.

When consideration is given to the large volumes of exhaust gases available at these temperatures and when it is recalled that the corresponding temperature of steam at a pressure of 7 bar is 170°C, it readily becomes apparent that the conversion of waste-heat from the exhaust gases of large marine heavy oil engines into useful energy in the form of low pressure steam presents a very convenient method of increasing the machinery's overall efficiency.

There are a number of special factors that require to be considered in designing a waste-heat recovery system which are not common to a fired power plant. In the design of a fired boiler, the required output is known and the designer has to determine the size of the boiler and corresponding fuel input. In the case of a waste-heat boiler, the problem is approached from the opposite direction. Here, the heat input from the exhaust gases is the known factor and the amount of energy that can be recovered, from a practical point of view, in the form of steam is the quantity to be determined. In addition, of course, it is necessary to decide by what method the resultant energy can best be utilised within the machinery installation.

Although it is theoretically possible to extract over 50% of the heat in the exhaust gases, as the temperature difference between the exhaust gas and the water in the boiler becomes small, heat transfer between the two media becomes such a slow process that, to be effective, a wasted-heat unit of very large proportions would be necessary. Such units are not economically practicable. The greater the amount of heat required to be extracted from the exhaust gases, the smaller becomes the logarithmic mean temperature difference (LMTD) of the gas and contents of the boiler. Basically, the heating surface required to extract a given amount of heat from exhaust gases can be expressed as:

$$\frac{\text{Gas weight} \times \text{mean specific heat} \times \text{temperature drop}}{\text{Overall heat transfer rate} \times \text{LMTD}}$$

$$\text{or} \quad \text{Heating surface} \propto \frac{\text{Gas temperature drop}}{\text{LMTD}}$$

This is perhaps easier to understand by referring to Figure 6.2 which illustrates that any increase in heat recovery from a given amount of exhaust gas at constant inlet temperature requires a corresponding increase in the heating surface which varies logarithmically. Thus, in order to increase an evaporation rate by a multiple of two, an increase of heating surface of almost three times the original is required.

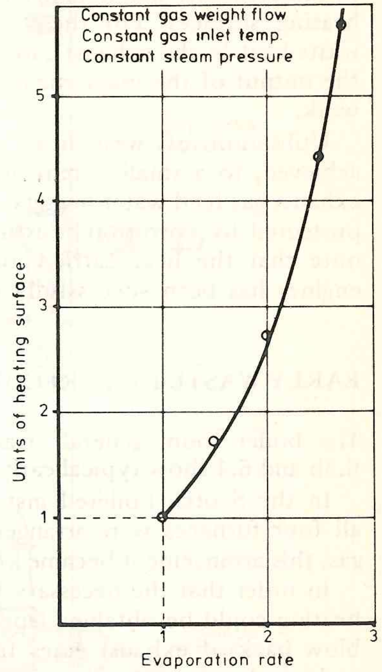


Figure 6.2 Curve showing variation of heating surface with evaporation rate for a given heat input

In order to limit the size of waste-heat units to practicable proportions, a terminal temperature difference of about 16°C. is normally considered to be a minimum figure.

In addition, the maximum utilisation of the energy in the exhaust gases is greatly restricted by the danger of low temperature corrosion on the gas side of waste-heat units. The exhaust gases from a heavy oil engine contain about 10% of water and when an engine is operating on fuels of high vanadium or sulphur content conditions are ideal for the formation of sulphuric acid on the gas side of the waste-heat unit if the temperature of the heating surfaces falls below the acidic dew point which, for practical purposes, may be taken as 140°C. To avoid this danger, a designed gas outlet temperature of not less than 180°C. is usually recommended.

It will be clear from the above therefore, that to arrange for waste-heat boilers to operate at pressures in excess of 7 bar may result in the available waste-heat energy not being used to the best advantage. On the other hand, generating steam at pressures below 5 bar with a view to extracting a maximum amount of waste-heat may lead to unacceptable maintenance costs due to rapid corrosion of gas side heating surfaces. For these reasons, only about one fifth of the waste-heat in the exhaust gases, representing between 5% and 10% of the output of the main engine is available for conversion into useful work.

Utilisation of waste-heat in the lower temperature ranges is achieved, to a small extent, in many modern systems, by means of exhaust gas feed water heaters or economisers having heating surfaces protected by corrosion resisting material. Similarly, it is worthy of note that the heat carried away in the cooling systems of main engines has been successfully used for feed water heating purposes.

EARLY WASTE-HEAT RECOVERY SYSTEMS

The boiler room general arrangements illustrated in Figures 6.3a, 6.3b and 6.4 show typical early waste heat recovery systems.

In the Scotch boilered installation shown in Figures 6.3a and b all four furnaces were arranged to operate using oil fuel or exhaust gas, this arrangement became known as 'alternately fired'.

In order that the necessary flexibility of oil firing and exhaust gas heating could be obtained, special arrangements were made to avoid blow back of exhaust gases from the smokebox via the tube bank and combustion chamber into any furnace being oil fired. In the case illustrated, separate uptakes were attached to the divided smoke-boxes and locking arrangements were provided to ensure that oil firing and exhaust gas heating could not take place simultaneously in any one furnace.

In other arrangements, only one of a pair of Scotch boilers was equipped for alternate firing. It will be seen that such systems required long, sinuous, large diameter exhaust pipes with heavy change-over valves which took up valuable space in an engine room and required to be heavily insulated if excessive heat losses were to

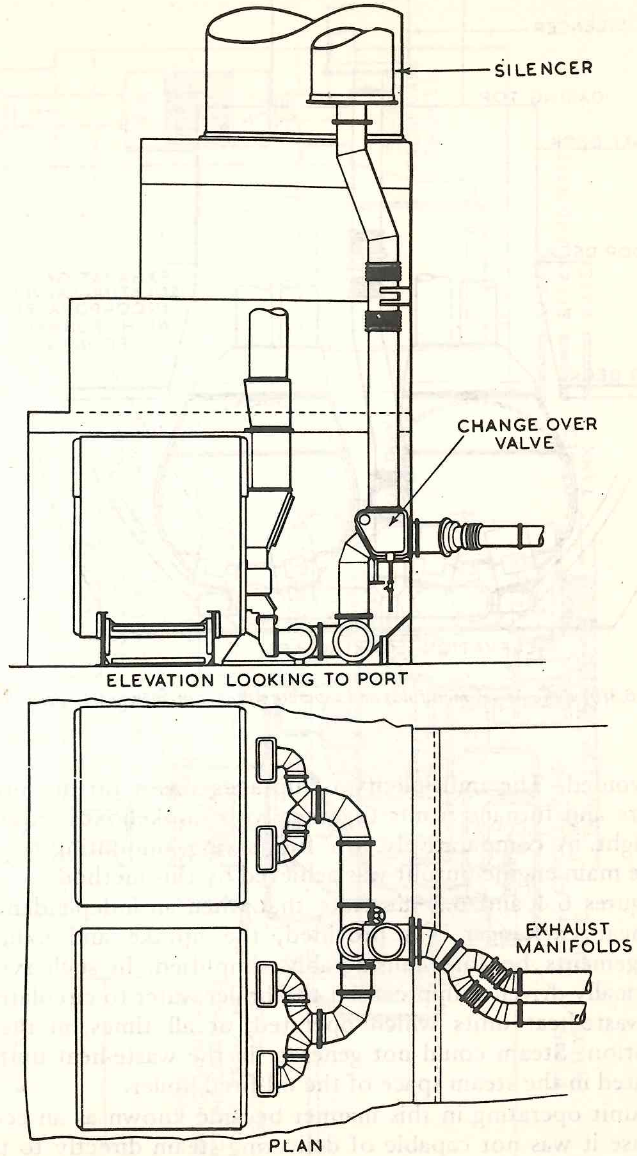


Figure 6.3(a) Arrangement showing main engine exhaust gas system passing through Scotch boilers – port elevation and plan

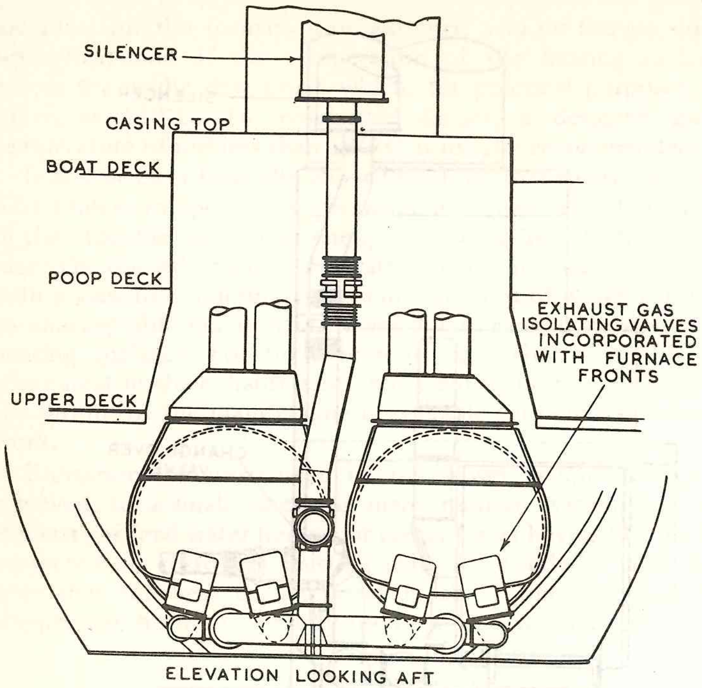


Figure 6.3(b) Exhaust gas manifolds and separate uptakes in 'alternately-fired' boiler

be avoided. The multiplicity of uptakes was a further undesirable feature and furnace fronts together with smokeboxes required to be gas tight. A comparatively low fuel saving amounting to about 2% of the main engine output was achieved by this method.

Figures 6.4 and 6.5 illustrate that when an independent exhaust gas heat exchanger was provided, the uptake and exhaust pipe arrangements became considerably simplified. In such systems, an electrically-driven pump caused the boiler water to circulate through the waste-heat units which operated, at all times, in the flooded condition. Steam could not generate in the waste-heat unit but was liberated in the steam space of the oil-fired boiler.

A unit operating in this manner became known as an economiser because it was not capable of delivering steam directly to the steam range. It can be seen that there was no difficulty in operating the waste-heat unit when a boiler was being oil fired. The additional space required to accommodate the exhaust gas unit and the initial

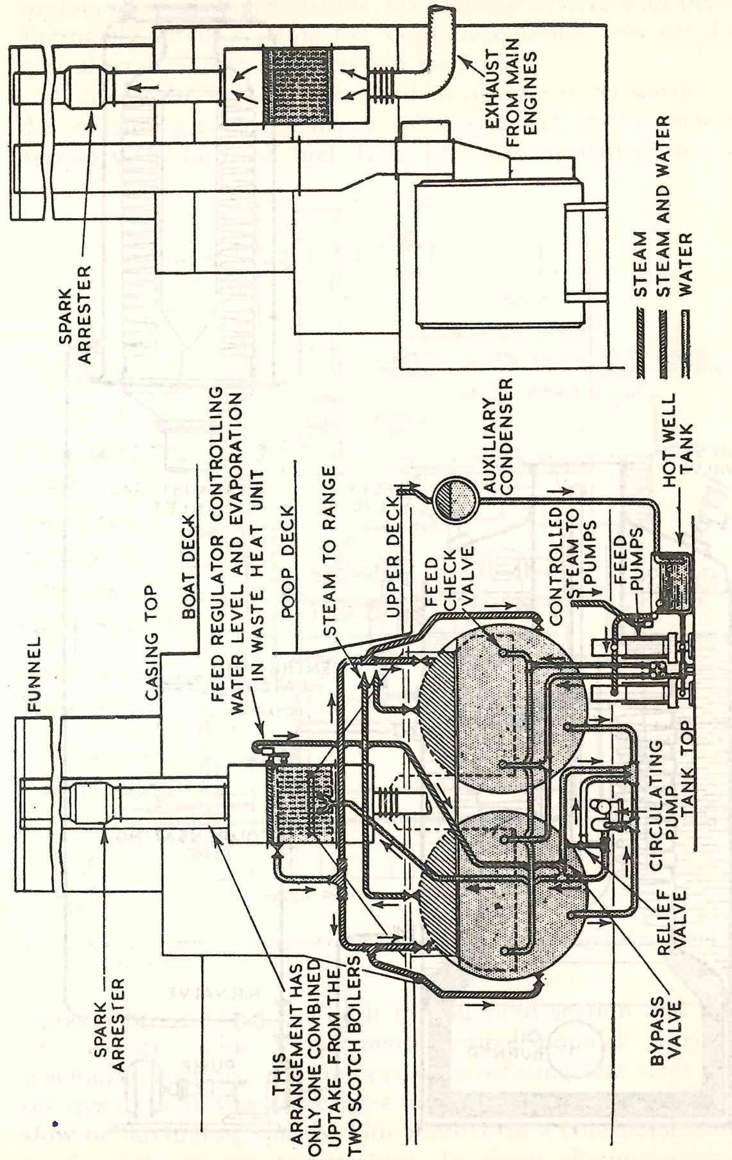


Figure 6.4 Arrangement of exhaust gas heat exchanger and Scotch boilers coupled by water-circulating pump

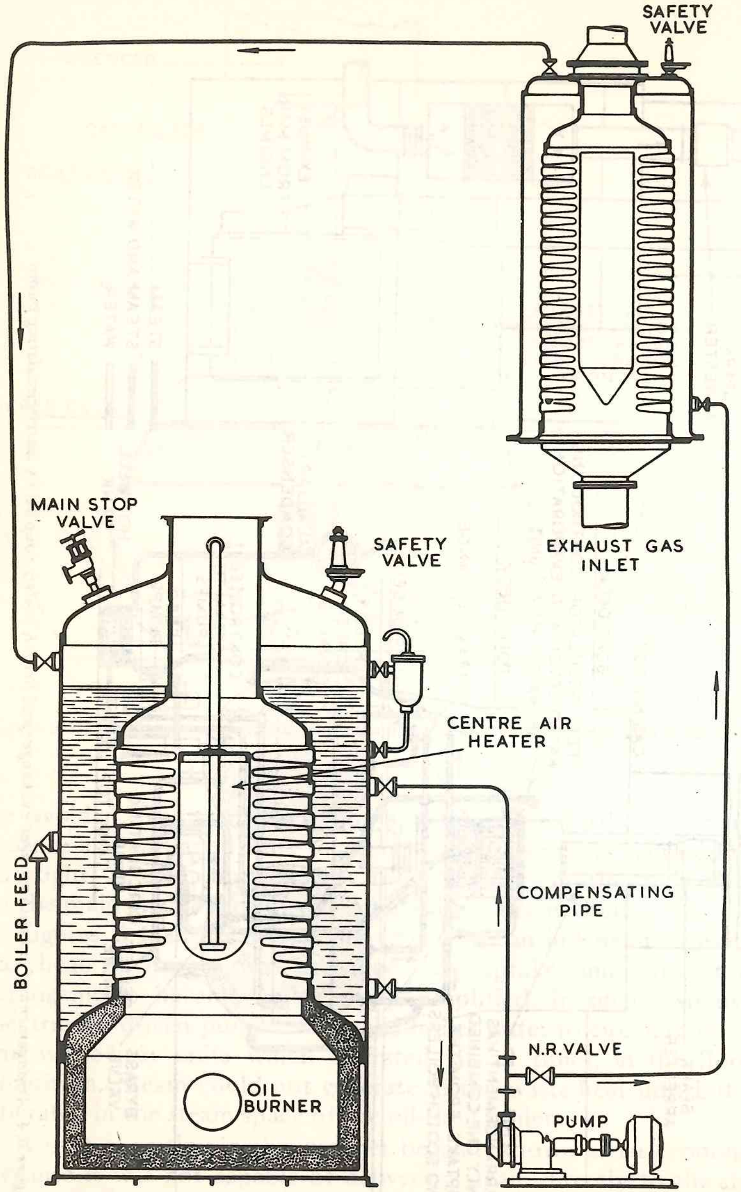


Figure 6.5 Clarkson forced-circulation system with oil fired boiler and silencer economiser to recover waste heat from diesel engines

cost were obvious disadvantages to be considered. In an effort to combine the advantages of the 'economiser' system with those of the alternately fired system, the composite boiler was developed. A typical arrangement is depicted in Figure 6.6.

A composite boiler is designed to operate using waste-heat from the exhaust gases of a heavy oil engine and at the same time, if necessary, to burn oil fuel. It is, of course, essential that separate

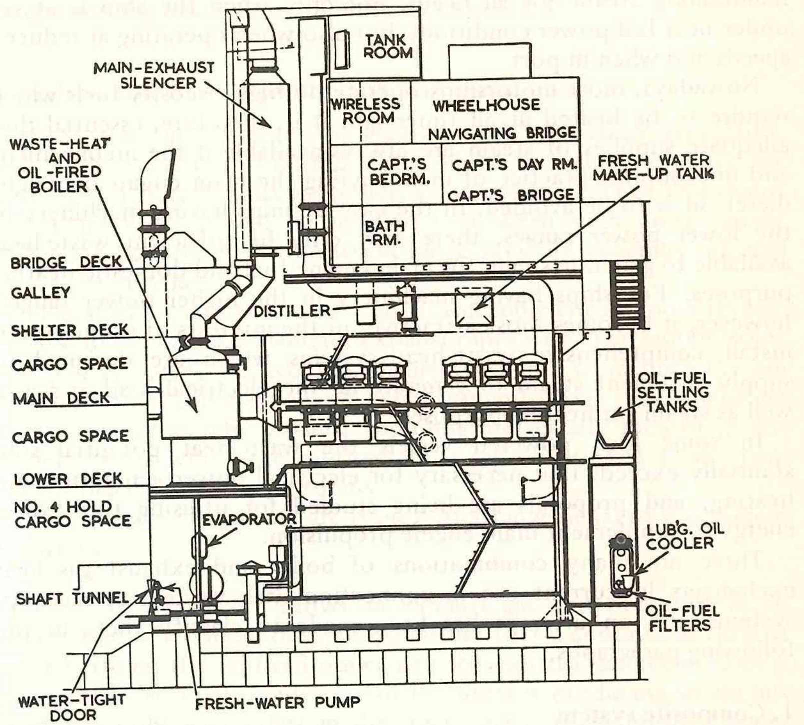


Figure 6.6 Arrangement of engine room with main engine exhaust led to composite boiler Note separate uptakes

uptakes be provided for both the oil fired section and that of the exhaust gas. This arrangement became popular when essential machinery such as steering gear or generating sets were dependent on steam, as it was sometimes necessary to run the main engine at slow or fluctuating speeds. This resulted in a considerable reduction in the exhaust gas temperature. In these circumstances, the oil burners were brought into use to augment the reduced heat available from the exhaust gases.

MODERN WASTE HEAT RECOVERY SYSTEMS

To make the most efficient use of the waste-heat contained in the exhaust gases of a heavy oil engine, a machinery installation should be so designed that there is a sufficient demand for steam when the ship is at sea so as to utilise most of the waste-heat available when the main engine is developing about 80% of full power. At the same time, a waste-heat system should incorporate means of raising and maintaining steam for all needs, not only when the ship is at sea under near full power conditions, but also when operating at reduced speeds and when in port.

Nowadays, most motorships operate on high viscosity fuels which require to be heated at all times and it is, therefore, essential that adequate supplies of steam are always available if the inconvenient and uneconomic practice of manoeuvring the main engine on a light diesel oil is to be avoided. In the case of ships having machinery in the lower power ranges, there may only be sufficient waste-heat available to generate steam for main engine fuel and domestic heating purposes. For ships having machinery in the higher power ranges, however, it becomes most attractive, in the interests of economy, to install comprehensive waste-heat systems which are designed to supply sufficient steam to generate all the electrical load at sea as well as steam for heating purposes.

In some high powered vessels the waste-heat potential substantially exceeds that necessary for electrical power generation and heating, and proposals are being studied for utilising this excess energy to supplement main engine propulsion.

There are many combinations of boiler and exhaust gas heat exchangers in current use in connection with waste-heat recovery systems and an attempt has been made to classify these in the following paragraphs.

1. Composite system

A simple form of waste-heat recovery system that fulfils the conditions required on board a modern small motorship is the provision of a composite boiler. The fitting of such a unit ensures that steam can be available when the ship is either at sea or in port. A composite boiler may be oil fired simultaneously with, or independently of, the main engine exhaust gas firing arrangements. The relative quantities of steam produced by the oil fired or exhaust gas sections can be adjusted to suit fluctuating requirements. Composite boilers are currently being fitted as the only means of steam generation in many slow speed dry-cargo motor ships.

Although not as efficient as some of the more sophisticated waste-heat recovery systems, composite boilers owe their popularity to their simplicity and low initial cost. There is no difficulty in arranging for these boilers to be automatically operated. A single composite boiler forms the steam raising plant in the very successful, standard 'SD 14', 'Freedom' and 'Fortune' type ships. Typically representative of such boilers are the Aalborg AQ5, Cochran Commodore, Cochran Vertical, Spanner Swirlyflo and A.G. Weser designs see Figures 6.32, 6.28, 6.26, 6.33 and 6.35.

2. Systems using two separate tank type units

These systems incorporate two separate tank type steam generators. One of the units is an oil-fired boiler whilst the other may take the form of either an exhaust gas boiler, a composite boiler or an exhaust gas economiser (it will be recalled that when such units cannot deliver steam directly to the steam range they are generally referred to as economisers).

Such systems contribute to a good accessible engine room layout, because long and large-diameter exhaust pipes with their cumbersome change-over valves are avoided. Straight uptakes from both the oil-fired boiler and the main engine exhaust manifold via the exhaust gas unit are possible. The exhaust gas units are usually located in the funnel casings whilst the oil-fired units can be situated at any convenient place in the engine rooms.

The following examples are typical of arrangements of this system in current use.

Example 1. Figure 6.7 shows an exhaust gas unit operating as an economiser. The circulating pumps ensure that a continuous flow of water between the oil-fired boiler and the exhaust gas economiser is maintained. Normally, only one of the units is producing steam but steam can only accumulate in the steam space of the oil-fired boiler which acts as a steam receiver for the economiser unit when the former is not being fired. Thus, both units are always held at the same pressure and both are, therefore, available to deliver steam whenever required. The exhaust gas unit, it should be noted, is operated in the fully flooded or 'drowned' condition at all times when exhaust gases are flowing through it. A steam and water mixture is returned to the oil fired boiler where the steam is liberated.

The steam range is connected to the oil-fired boiler and has no direct connection to the economiser. If the required amount of

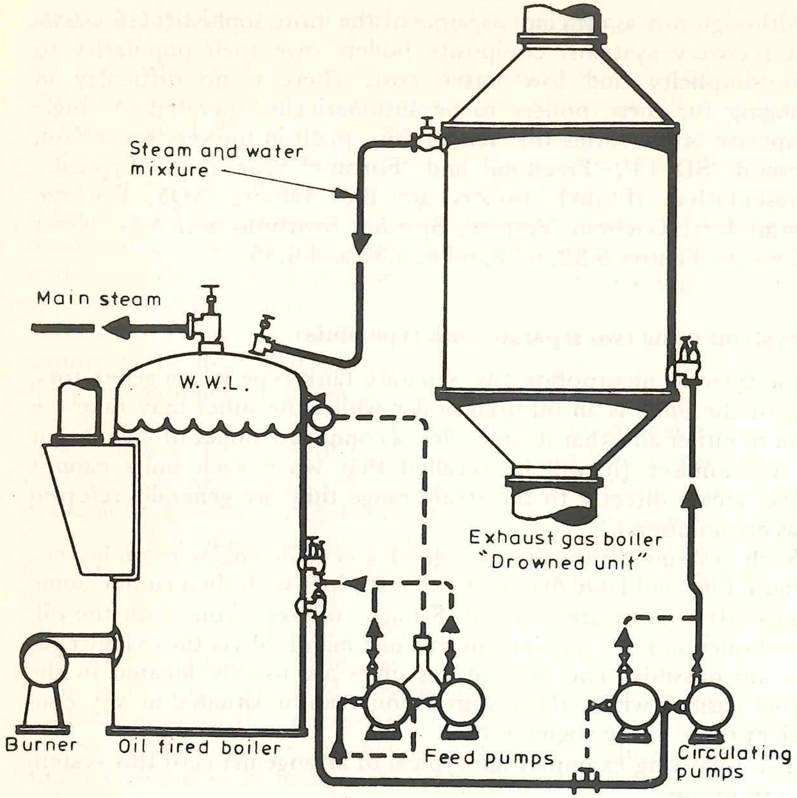


Figure 6.7 Exhaust gas system using oil-fired boiler with exhaust economiser

steam cannot be generated by the heat from the exhaust gases, for instance when the main engine is operating at low speed, the oil-fired unit can be fired to augment the steam generation of the exhaust gas unit and so maintain the required total steam output. All feed water is introduced into the system through the oil-fired boiler.

It will be readily seen that the exhaust gas unit cannot be operated independently and that the pumps are essential to maintain the forced circulation required for efficient steam generation. When the main engine is not operating and exhaust gases are therefore not available, all steam required must be produced by the oil-fired boiler. The circulating system, in these circumstances, can continue to operate or, alternatively, the exhaust gas unit can be isolated and the circulating pumps stopped.

Example 2. The system shown in Figure 6.8 incorporates two independent boilers, one being oil fired whilst the other is exhaust-gas-heated. The exhaust gas unit generates steam independently of the oil-fired unit and is fitted with an integral feed system. Steam may be delivered to the range by either, or both, units. It should be particularly noted that in this system, the exhaust gas heated unit functions as a boiler and is generally so designated.

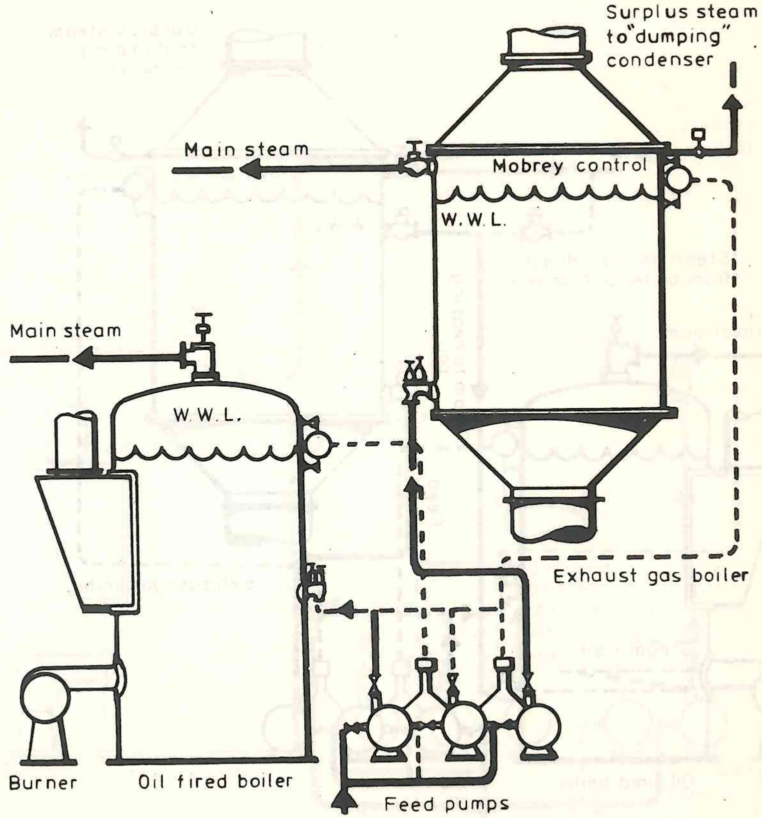


Figure 6.8 Exhaust gas boiler and oil-fired boiler

One disadvantage of this system is that prior notice must always be given if the main engine is to be stopped or operated at reduced speed in order that the oil-fired boiler can be prepared for steaming, a procedure that is not always convenient if the main engine has to be stopped in an emergency! One solution to this obvious disadvantage, is to arrange for the exhaust gas boiler to be of composite type and examples of this will be encountered in service.

Example 3. Figure 6.9 represents a similar arrangement to that shown in Figure 6.8 except that the oil-fired boiler is maintained in a steaming condition by means of a 'simmering' coil which continually receives steam from the main steam range or direct

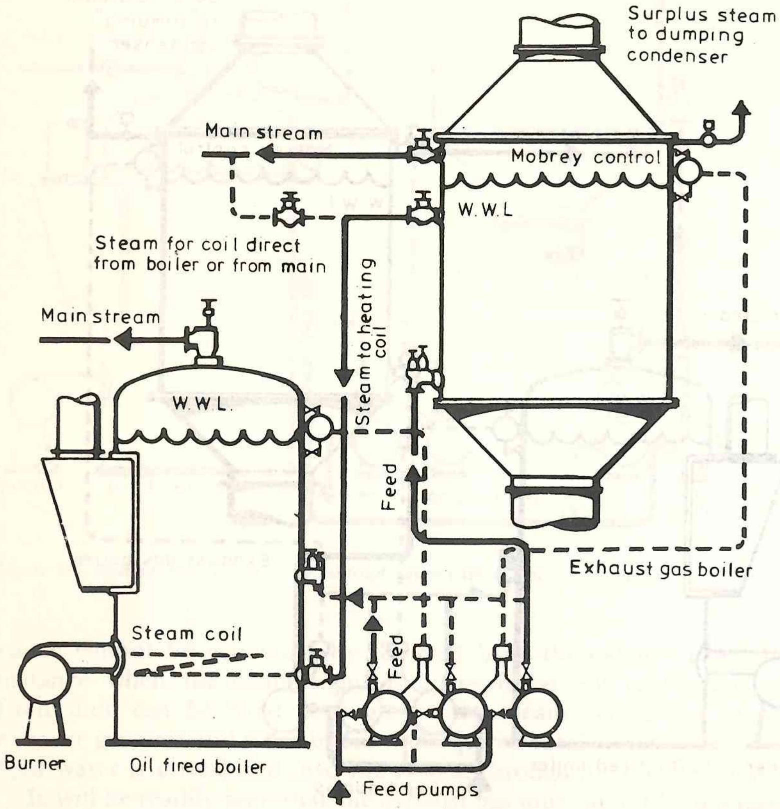


Figure 6.9 Exhaust gas boiler and oil-fired boiler fitted with "Simmering" coil

from the exhaust gas boiler when the latter is in service. With this arrangement, a quick change-over from the exhaust gas to the oil-fired boiler is possible. As in Figure 6.8 steam is supplied direct to the range by either, or both, boilers.

Example 4. It is sometimes necessary to have an arrangement so that the two units can operate together in series as in Figure 6.7 but with provision to enable the exhaust gas unit to operate independently as in Figure 6.8.

The layout shown in Figure 6.10 enables either system to be used as required but it should be noted, that because the whole of the designed heating surface of the exhaust gas unit is not in contact

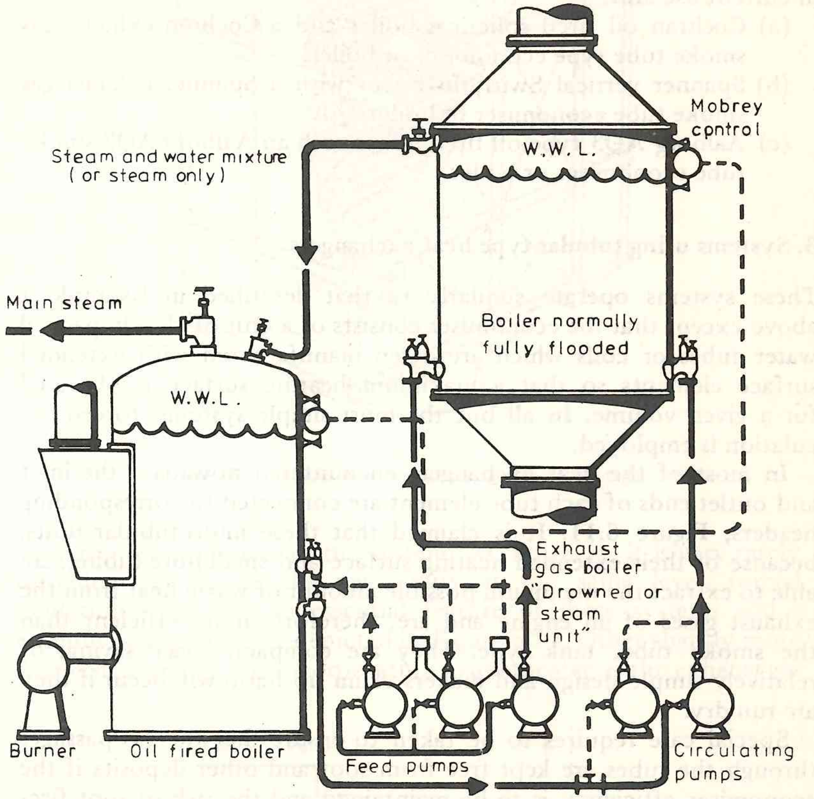


Figure 6.10 Exhaust gas unit operating as either economiser or boiler

with the water, the steam output of the exhaust gas unit will be reduced when it operates as a boiler. As the exhaust gas unit cannot deliver steam directly to the range it is generally referred to as an economiser when operating in either of these alternative conditions.

It has been shown that economisers are arranged to operate in the flooded condition. In order to ensure that the flooding is complete under all normal conditions, the safety valves of economisers are usually adjusted to a slightly higher pressure than the safety valves of the boiler or steam receiver to which they are connected. In this way evaporation cannot take place until the boiling water is released into the steam receiver.

Typical commercial examples of the combinations described above in current use are:

(a) Cochran oil fired spherical boiler and a Cochran exhaust gas smoke tube type economiser or boiler.
(b) Spanner vertical Swirlyflo boiler with a Spanner exhaust gas smoke tube economiser or boiler.
(c) Aalborg AQ3 type oil fired boiler with an Aalborg AQ2 smoke tube economiser or boiler.

3. Systems using tubular-type heat exchangers

These systems operate similarly to that described in Example 1 above except that the economiser consists of a unit of closely packed water tubes or coils which are often manufactured with extended surface elements so that a maximum heating surface is obtained for a given volume. In all but the most simple systems, forced circulation is employed.

In most of the heat exchangers encountered nowadays the inlet and outlet ends of each tube element are connected to corresponding headers, Figure 6.11. It is claimed that these multi-tubular units, because of their extended heating surface and small bore tubing, are able to extract the maximum possible amount of waste heat from the exhaust gases of an engine and are, therefore, more efficient than the smoke tube, tank type. They are compact, space saving, of relatively simple design and makers claim no harm will occur if they are run dry.

Special care requires to be taken to ensure that the gas passages through the tubes are kept free from soot and other deposits if the economiser efficiency is to be maintained and the risk of soot fires avoided. Special attention requires to be paid also to feed water treatment as the internal cleaning of the elements is a difficult operation and descaling, except by chemical means, is often impossible.

In basic form, a typical system is shown in Figure 6.12. Here, the oil-fired boiler requires to be installed at the same level, and adjacent to, the exhaust gas economiser in order to promote natural

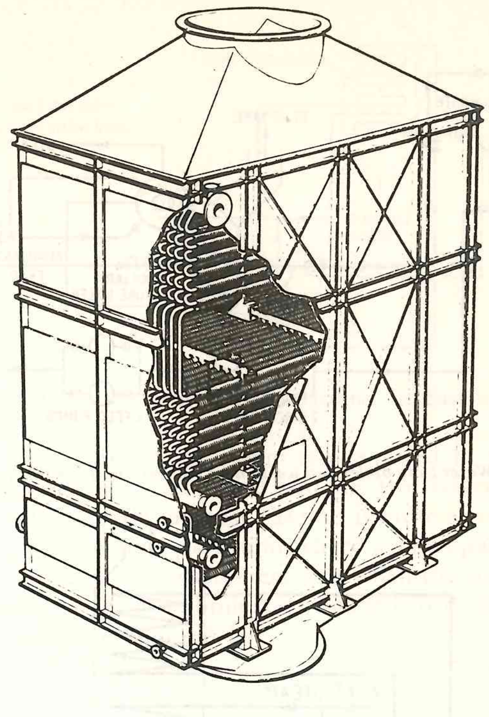


Figure 6.11 Foster Wheeler exhaust gas heat exchanger

circulation of the water in the system. As, however, it is very rarely convenient to install the two units at the same level, forced circulation is usually an essential feature of these systems and a common arrangement is depicted in Figure 6.13. Other slightly more advanced arrangements incorporating a superheater in the exhaust gas

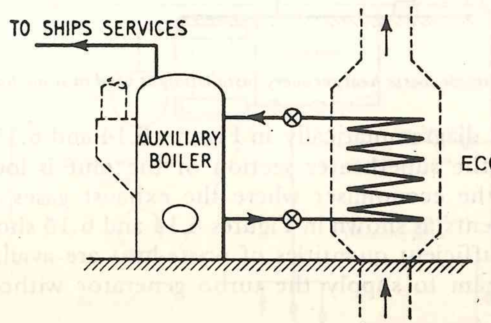


Figure 6.12 Simple form of waste-heat recovery system

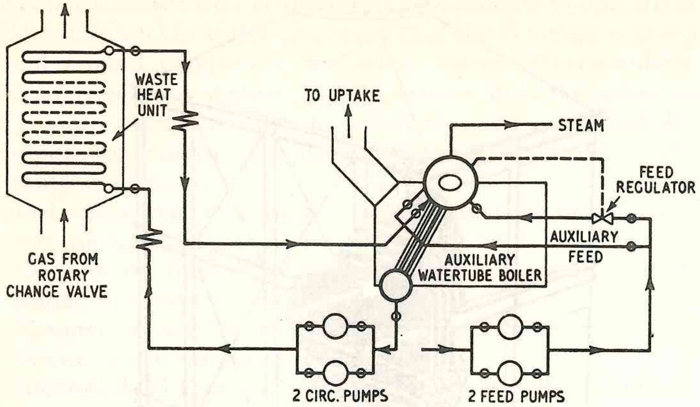


Figure 6.13 Water tube boiler and waste heat recovery unit for fast cargo liner

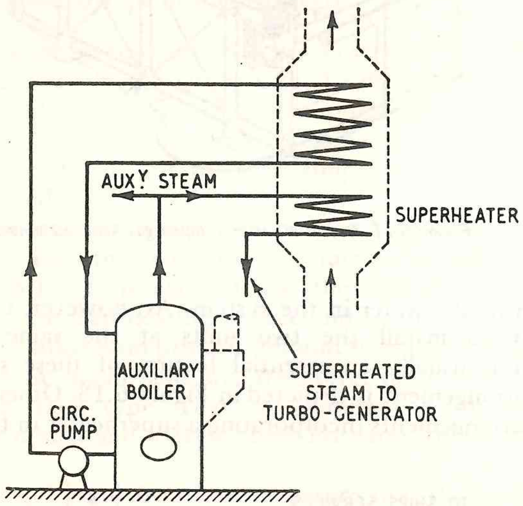
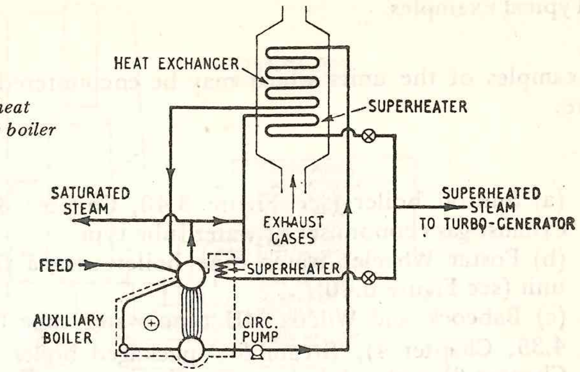


Figure 6.14 Simple waste heat recovery installation as used in some bulk carriers

unit are shown diagrammatically in Figures 6.14 and 6.15. Note that in these cases the superheater section of the unit is located at the lower end of the economiser where the exhaust gases are hottest. Such arrangements as shown in Figures 6.14 and 6.15 should only be fitted where sufficient quantities of waste-heat are available, at sea, to generate steam to supply the turbo generator without recourse

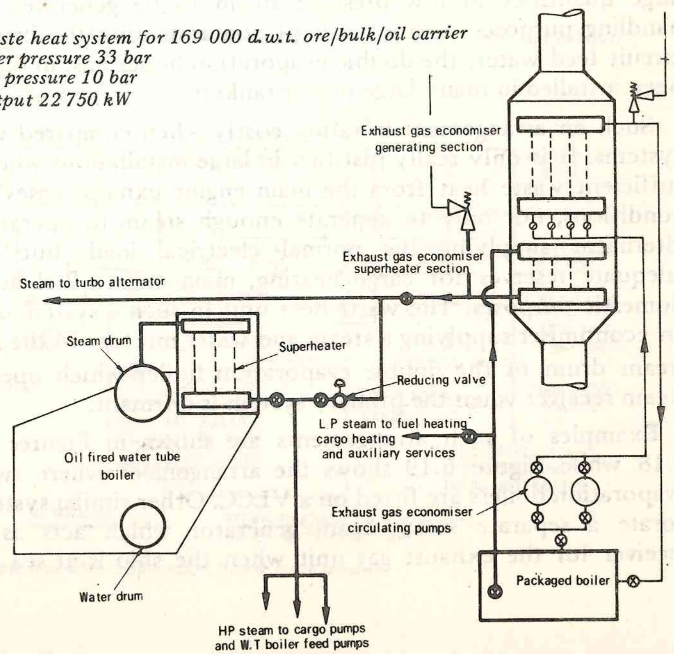
Figure 6.15 Exhaust gas heat exchanger and water tube boiler



to oil firing. Such systems may be found in fast cargo ships and passenger ships.

Where large quantities of steam are required in port, for cargo handling purposes, such as on oil tankers, two watertube boilers in association with a single exhaust gas unit is quite a common arrangement. Other systems may be found where a small packaged boiler is used in association with a waste-heat unit when the ship is at sea, and a medium sized water tube boiler is provided to deal with the cargo load when in port see Figure 6.16.

Figure 6.16 Waste heat system for 169 000 d.w.t. ore/bulk/oil carrier
Water tube boiler pressure 33 bar
Packaged boiler pressure 10 bar
Main engine output 22 750 kW



Typical examples

Examples of the units which may be encountered in these systems are:

(a) Sunrod boiler (see Figure 3.40, Chapter 3) with a Sunrod exhaust-gas economiser of water tube type.
(b) Foster Wheeler water tube boiler with a Green's 'Diesecon' unit (see Figure 6.40).
(c) Babcock and Wilcox MII type water tube boiler (see Figure 4.35, Chapter 4), 'Steambloc' packaged boiler (see Figure 3.18, Chapter 3) with a tubular type exhaust gas economiser. A recently introduced class of fast container ship is fitted with an Osaka Howden-Johnson boiler (see Figure 3.11, Chapter 3) and a Green's 'Diesecon' exhaust gas unit (Figure 6.40).

4. Systems incorporating double evaporation boilers or separate steam receivers

In the search to obtain some of the benefits associated with the modern high pressure water tube boiler, and at the same time enable large quantities of low pressure steam to be generated for cargo handling purposes without risk of contaminating the high pressure circuit feed water, the double evaporation boiler has, in recent years, been installed in many large motor tankers.

Such an arrangement is rather costly when compared with other systems. It is only really justified in large installations where there is sufficient waste heat from the main engine exhaust gases under sea conditions, not only to generate enough steam to operate a turbo-alternator supplying the normal electrical load, but also with adequate reserves for cargo heating, main engine fuel heating and domestic purposes. The waste-heat unit in such a system operates as an economiser supplying a steam and water mixture to the secondary steam drum of the double evaporation boiler which operates as a steam receiver when the primary system is dormant.

Examples of such arrangements are shown in Figures 6.17 and 6.18 while Figure 6.19 shows the arrangement where two double evaporation boilers are fitted on a VLCC. Other similar systems incorporate a separate steam/steam generator which acts as a steam receiver for the exhaust gas unit when the ship is at sea and these

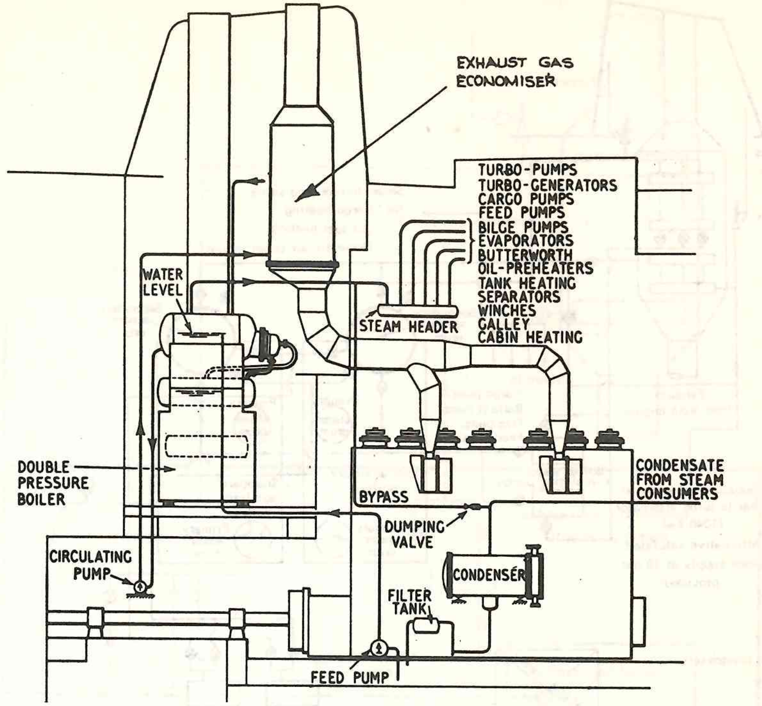


Figure 6.17 Auxiliary steam system embodying double evaporation boiler and exhaust gas heat exchanger

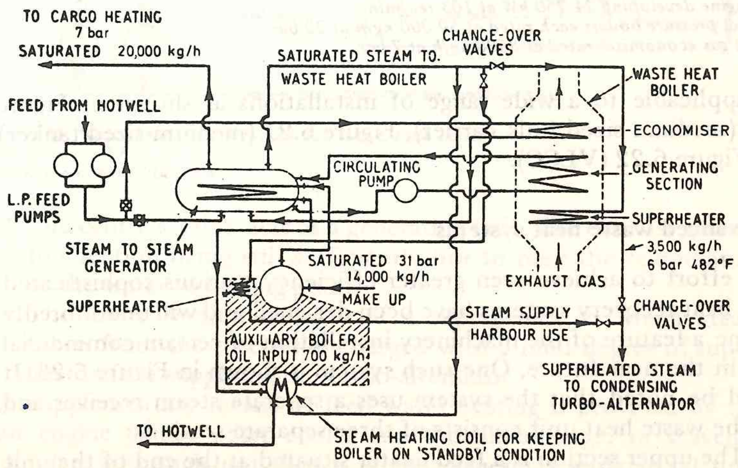


Figure 6.18 Typical double evaporation boiler arrangement

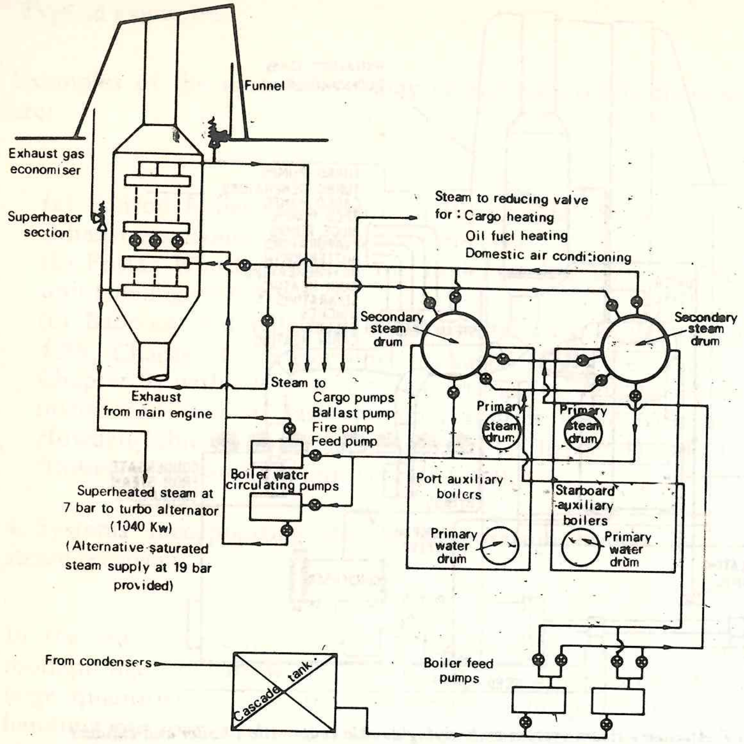


Figure 6.19 Waste heat recovery system for 250 000 d.w.t. oil tanker
Main engine developing 24 750 kW at 103 rev/min
Two dual pressure boilers each rated at 50 000 kg/h at 22 bar
Exhaust gas economiser rated at 8500 kg/h at 7 bar

are applicable to a wide range of installations as shown in Figure 6.20 (medium sized bulk carrier), Figure 6.21 (medium-sized tanker) and Figure 6.22 (VLCC).

5. Advanced waste heat systems

In an effort to achieve even greater efficiency, various sophisticated waste heat recovery systems have been designed and will undoubtedly become a feature of the machinery installation of certain commercial ships in the near future. One such system is shown in Figure 6.23. It should be noted that the system uses a separate steam receiver and that the waste heat unit consists of three separate sections:

1. The upper section is a feed heater situated at the end of the unit where the exhaust gases are coolest.

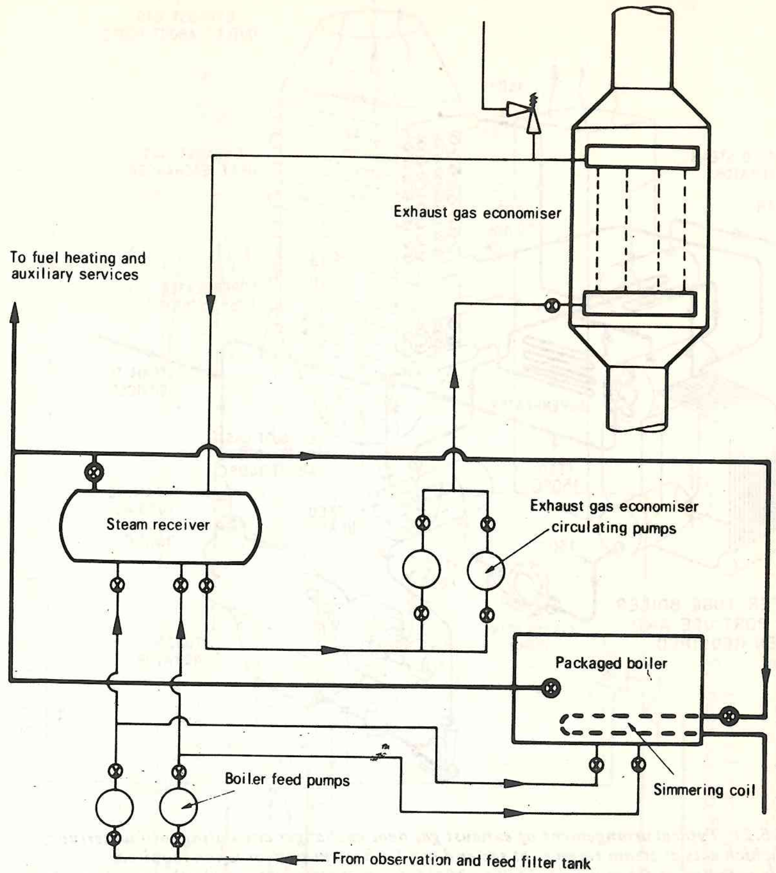


Figure 6.20 Waste heat system for 28 000 d.w.t. bulk carrier
Steam pressure 7 bar
Main engine output 9000 kW

2. The centre section acts as a generating unit. The exhaust gases in this section being still sufficiently hot to raise the temperature of the water to boiling point.
3. The lower section consists of a superheater in which steam taken from the receiver is charged with a mild degree of superheat before supplying the turbo-alternator.

A supplementary means of feed water heating is provided by the main engine jacket water cooler and the supercharger or scavenge air cooler. Although not shown in the diagram a separate oil fired boiler is provided for 'in port' conditions.

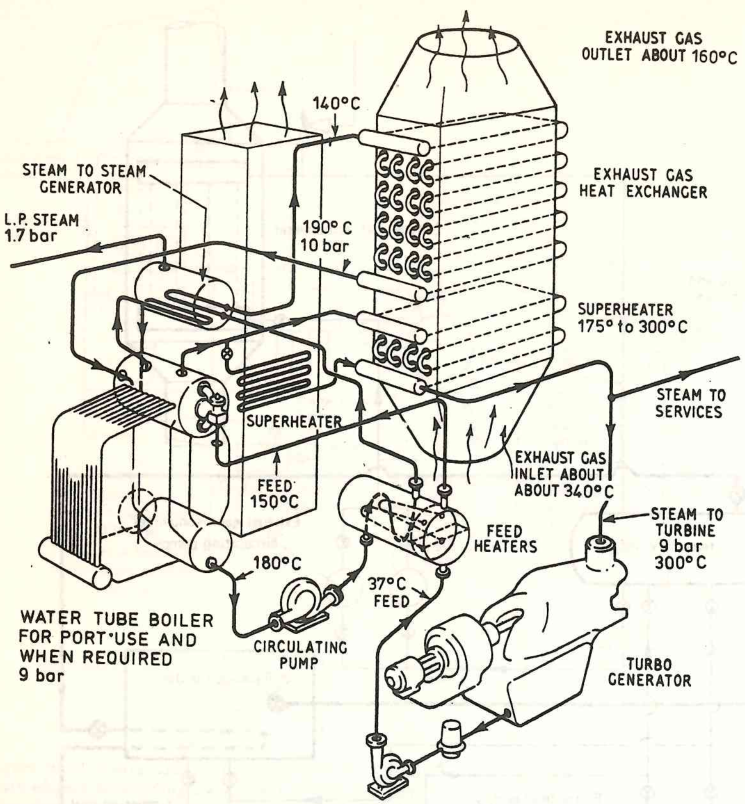


Figure 6.21 Typical arrangement of exhaust gas heat exchanger circulating into watertube boiler which acts as steam receiver at sea and can be fired in port or when required. Steam is supplied at 9 bar superheated to 304°C for turbo generator and other services, also steam at 1.7 bar for heating and domestic use.

COMPOSITE BOILERS

Scotch boilers

In early motorships the Scotch boiler was much used as a composite boiler, modifications being made which enabled it to be operated on either exhaust gas or oil, or both, when necessary. For motor vessels which required a large amount of steam in port for operating winches or cargo pumps, it was often modified as in Figure 6.24. It will be

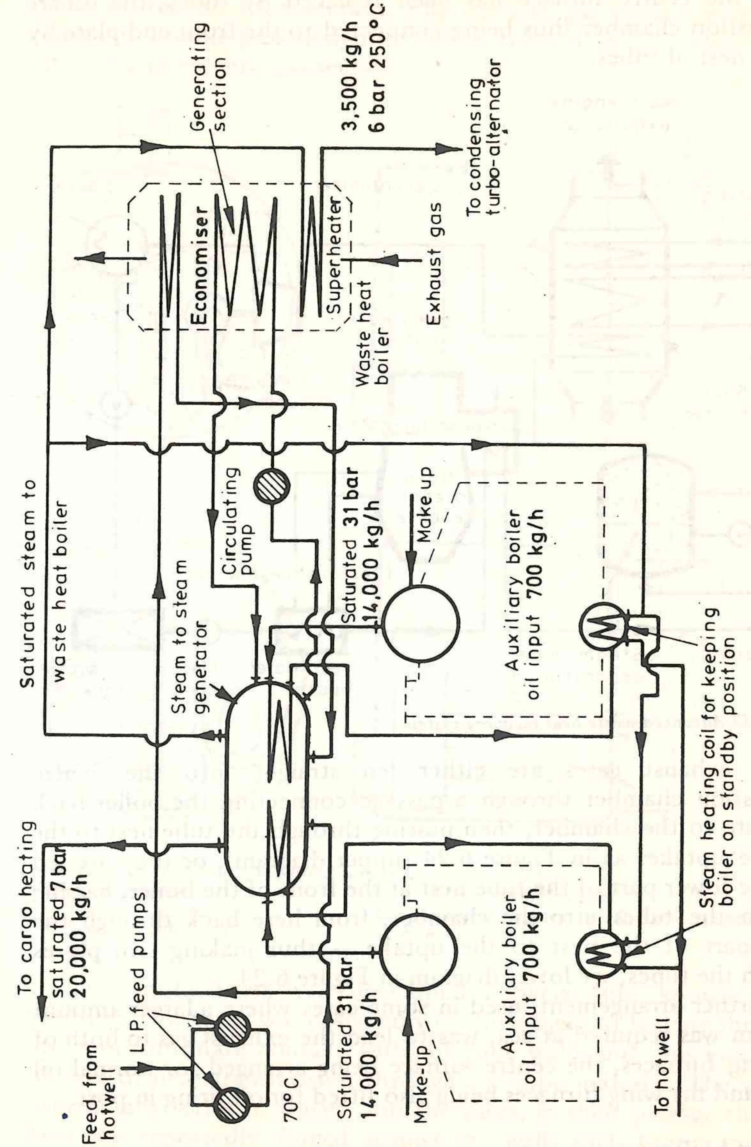


Figure 6.22 Auxiliary steam system for motor vessel embodying closed circuit w.t. auxiliary boilers, steam to steam generator, waste heat boiler and turbo alternator.

noted that this is essentially a normal three-furnace Scotch boiler in which the centre furnace has been replaced by tubes, the centre combustion chamber thus being connected to the front end-plate by a large nest of tubes.

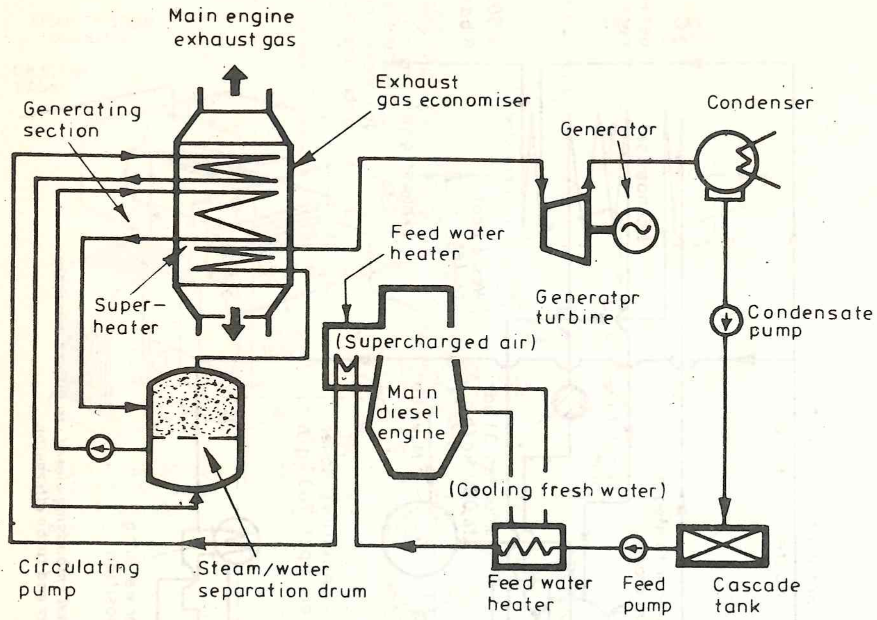


Figure 6.23 Advanced waste heat recovery system

The exhaust gases are either led straight into the centre combustion chamber through a passage connecting the boiler back end plate to the chamber, then passing through the tube nest to the separate uptake, as in Figure 6.24 (upper diagram), or they are led into the lower part of the tube nest at the front of the boiler, passing through the tubes into the chamber, from here back through the upper part of the nest to the uptake – thus making two passes through the tubes, see lower diagram in Figure 6.24.

A further arrangement, used in some cases where a larger amount of steam was required at sea, was to lead the exhaust gas to both of the wing furnaces, the centre furnace being arranged for normal oil firing, and the wing furnaces being also fitted for oil firing in port.

Cochran boilers

The conventional Cochran composite boiler is shown in Figures 6.25 and 6.26. In this boiler a separate nest of tubes is provided for the exhaust gases and this is located immediately above the return smoke tubes of the oil fired section. The exhaust gas section may be of single- or double pass design. Separate uptakes are provided for the oil-fired and exhaust gas sections.

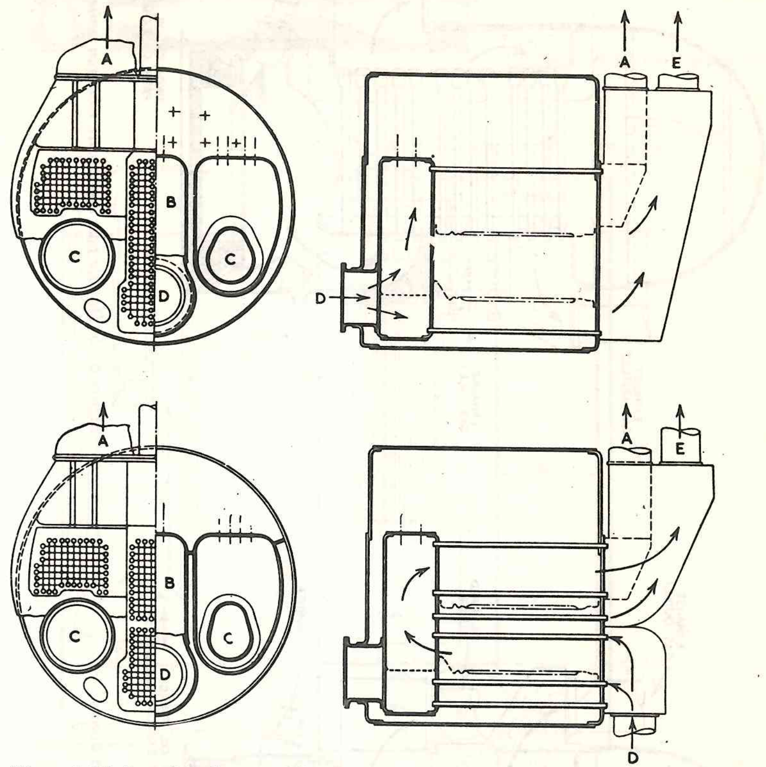


Figure 6.24 Scotch boiler, modified for use as a composite boiler
(Upper) Single pass *(Lower) Double pass*
A. Oil burning uptake *C. Oil burning furnaces* *E. Exhaust uptake*
B. Exhaust gas tube nest *D. Exhaust inlet*

The manufacturers have developed a special tube known as the 'Sinuflo'. This tube, was designed with the object of forcing the gases into more intimate contact with the tube walls and thus increasing the rate of heat transmission through the tube material. The tube is formed in a series of waves, and the gases, in their passage through them are repeatedly forced against the walls each time a curve is traversed. The wave formation of these tubes is only shallow (see Figure 6.27) and does not interfere with normal cleaning operations or their insertion in the tube plates. The tubes are expanded in the

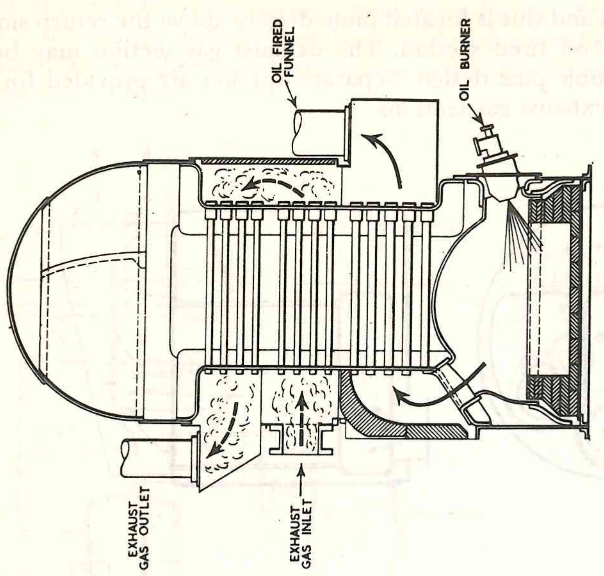


Figure 6.26 Double pass composite Cochran boiler

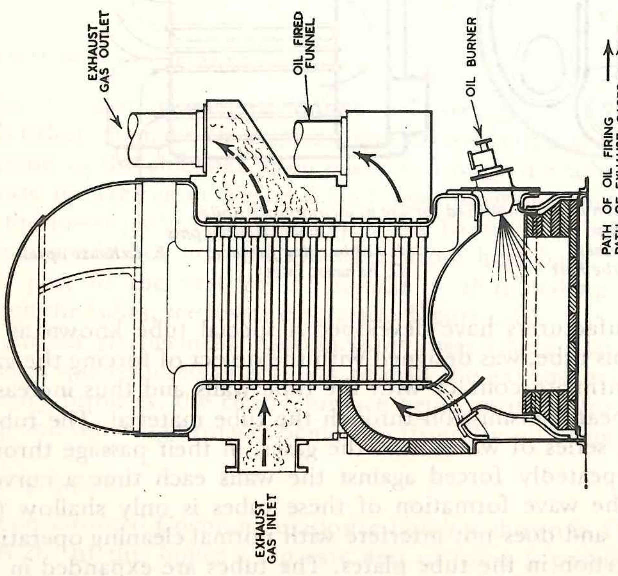


Figure 6.25 Single pass composite Cochran boiler

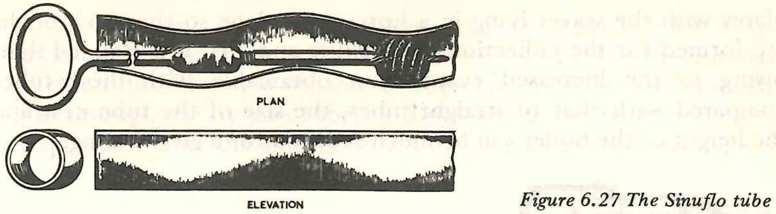


Figure 6.27 The Sinuflo tube

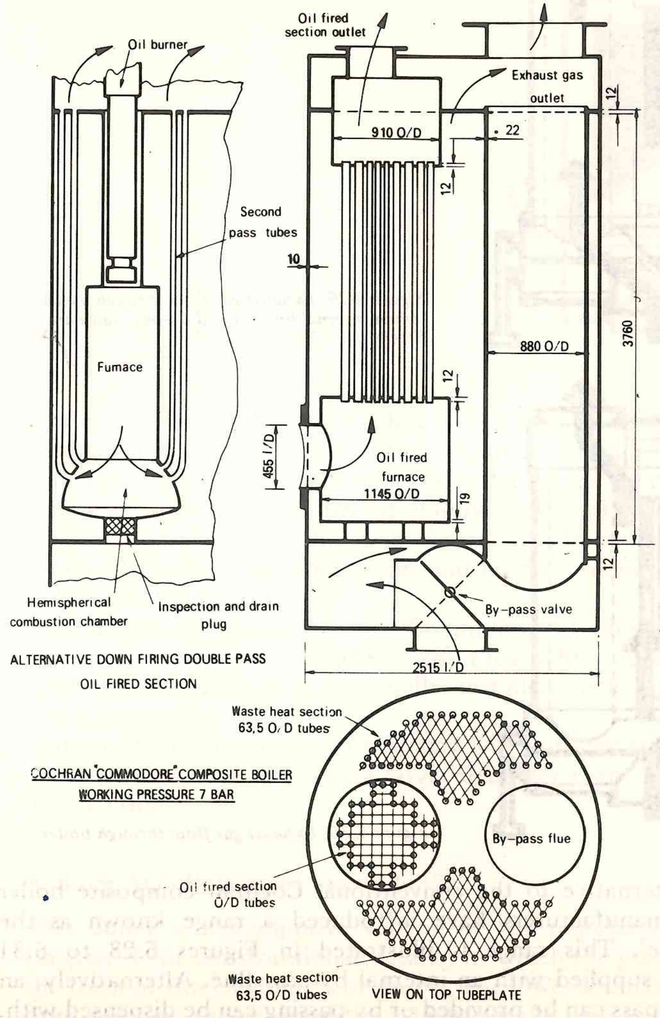


Figure 6.28 Cochran 'Commodore' composite boiler
Working pressure 7 bar

plates with the waves lying in a horizontal plane so that no troughs are formed for the collection of moisture and dirt. It is claimed that, owing to the increased evaporation obtainable with these tubes compared with that of straight tubes, the size of the tube nest and the height of the boiler can be much reduced for a given rating.

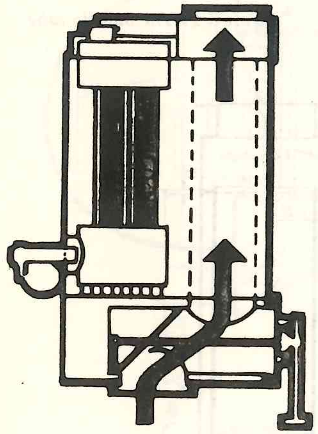


Figure 6.29 Exhaust gas flow through by-pass (when internal by-pass and by-pass valve are fitted)

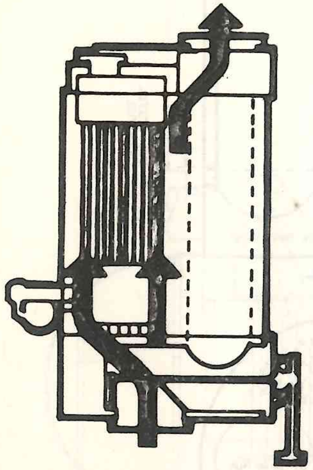


Figure 6.30 Exhaust gas flow through boiler

As an alternative to the conventional Cochran composite boiler the same manufacturers have introduced a range known as the 'Commodore'. This range is illustrated in Figures 6.28 to 6.31 and can be supplied with an internal by-pass flue. Alternatively, an external by-pass can be provided or by-passing can be dispensed with.

The by-pass valve arrangement can be regulated by a simple mechanical operation or by automatic controls. The by-pass valve in such an installation is capable of diverting up to 95% of the exhaust gas through the by-pass tube, thus regulating the steam output to the requirements of the ship at sea. A single pass of stay and plain tubes

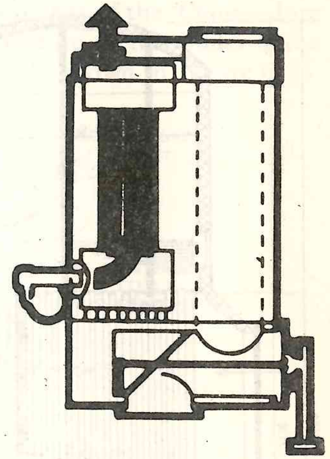


Figure 6.31 Gas flow when direct firing of boiler takes place

located between the tube plate of the cylindrical combustion chamber and the tube plate of the cylindrical furnace forms the tube nest for the oil fired section. The exhaust gas heating surface is composed of a large number of closely packed plain and stay tubes forming a single pass as shown in Figure 6.28. In common with other composite boilers the exhaust gas and oil fired sections are provided with separate uptakes.

A modified version of the 'Commodore' boiler incorporates a top fired furnace, see Figure 6.28, thus achieving a two pass oil fired section. This type is usually installed with an external by-pass arrangement.

In most of these types of boilers it will be found that the tubes of the exhaust gas section are of larger diameter than those of the oil-fired section.

Aalborg AQ5 boiler (see Figure 6.32)

This boiler is a composite version of the popular AQ3 type (see Chapter 3 for constructional details) in which the pressure shell is in the form of three cylinders or drums. The lower drum contains the oil-fired furnace, the centre drum which is made with two tube plates is essentially a water space whilst the upper drum is a steam and water space. The tube plate of the lower drum and lower tube plate of the centre drum form the boundaries of the smokebox for the oil-fired section whilst the upper tube plates of the centre drum and the tube plate of the upper drum form the boundaries of the exhaust gas

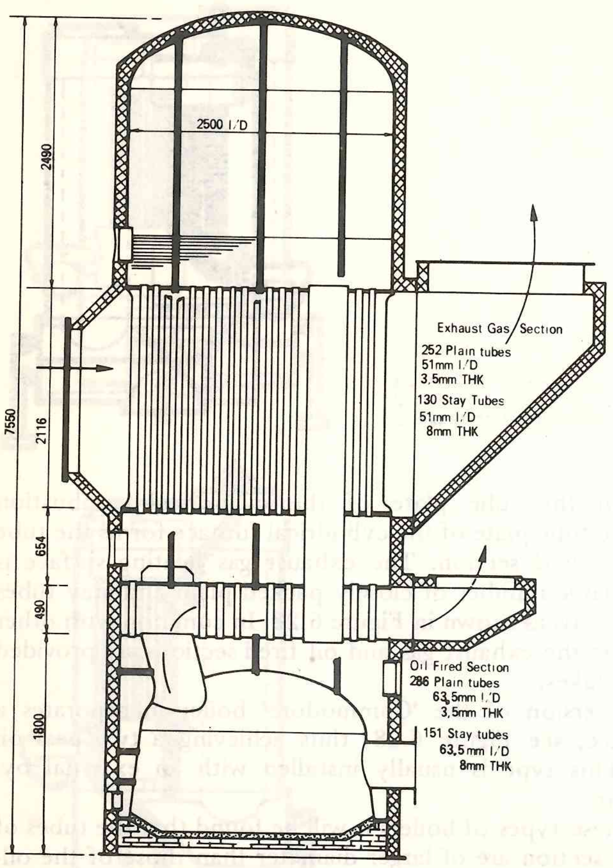


Figure 6.32 Aalborg AQ5 composite boiler
Working pressure 7 bar
Oil fired section heating surface 75m²
Exhaust gas section heating surface 200m²

section. The three sections are connected by straight plain and stay water tubes, and the two large downcomers which connect the upper and lower drums, to promote efficient circulation are a feature to be particularly noted.

In the design of this type of boiler careful attention requires to be paid to the staying arrangements between the shell sections.

Spanner 'Swirlyflo' boiler

This well-known boiler is similar to the 'Commodore' except that the cylindrical furnace is dry bottomed whereas that of the 'Commodore is completely water cooled. The special feature of this boiler is the form of the 'Swirlyflo' tube which is clearly shown in Figure 6.33.

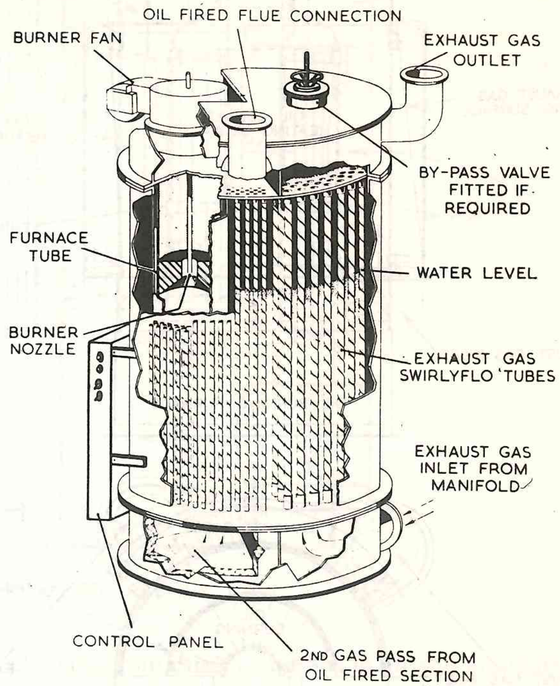


Figure 6.33 Cut-away view of Spanner composite boiler (see also Chapter 3)

Like all boilers of its type, both the shell of the boiler and the furnace are of all welded construction. Bolted joints at the top of the boiler secure separate uptakes from the gas and oil fired sections.

Thimble tube composite boilers

Thimble tube boilers in simple and composite forms were commonly fitted in small waste heat recovery installations. In simple form they

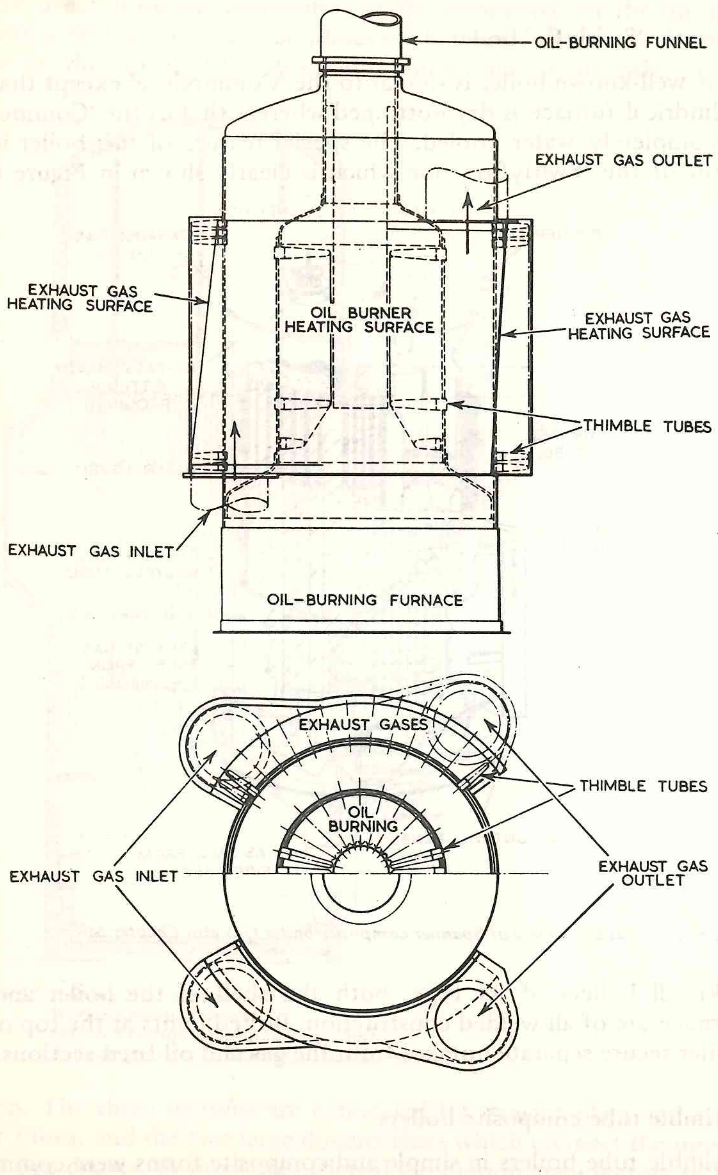


Figure 6.34 Composite thimble tube boiler

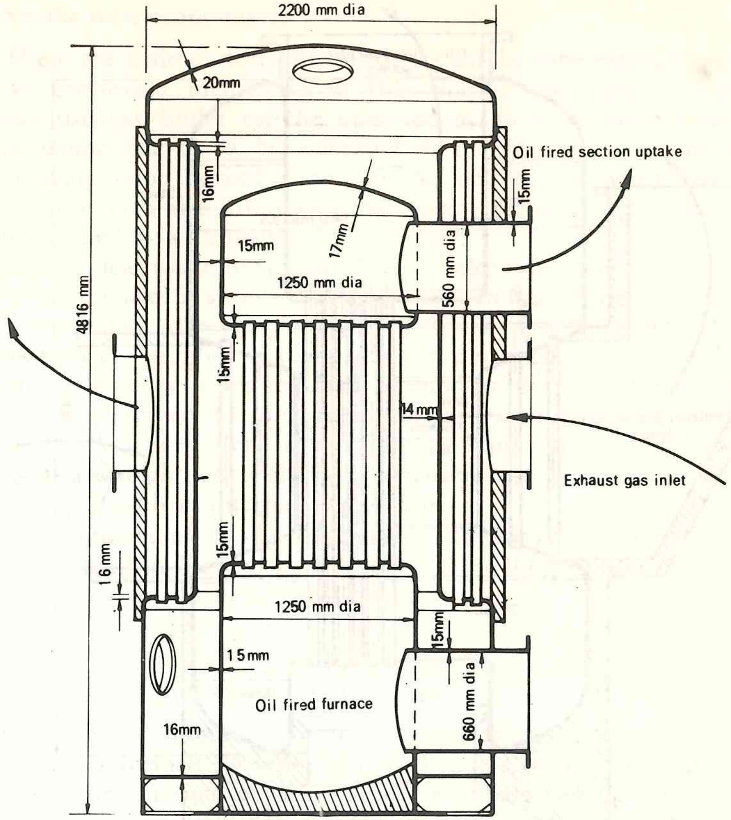


Figure 6.35 A.G. Weser composite boiler

were used as silencer economisers on both main and auxiliary engine exhausts, in a forced-circulation system coupled to an oil-fired auxiliary boiler (see Figure 6.5).

The larger composite form was often fitted in motor vessels where the amount of steam required did not warrant Scotch boilers. The exhaust gases pass around the outside of the boiler shell inside a casing into which thimble-tubes, expanded into the boiler shell, project. A normal firebox with internal projecting thimble-tubes is also fitted for oil firing, (Figure 6.34).

Two other composite boilers of rather unique design which may still be encountered in ships built in Northern Europe are shown in Figures 6.35 and 6.36.

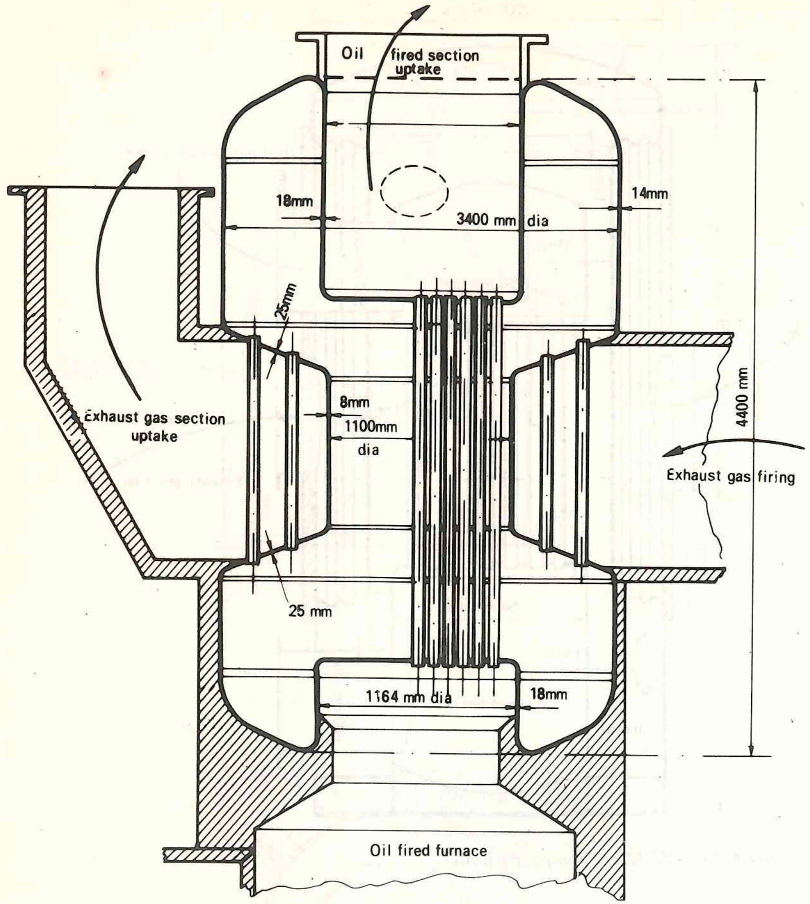


Figure 6.36 Howaldtswerke composite boiler

EXHAUST GAS ECONOMISERS

These heat exchangers can be conveniently divided into three categories, as follows:

1. Smoke tube type.
2. Coiled water tube type.
3. Straight water tube type.

Smoke tube economisers

These are a direct development of the smoke tube exhaust-gas boiler. As previously mentioned in this chapter, in many systems the exhaust gas boiler can be operated as an economiser merely by arranging for it to be operated in the 'drowned' condition and ensuring good forced circulation to deliver the water and steam mixture into the interconnected steam receiver, a function often performed by a dormant oil-fired boiler.

A typical waste heat unit of the smoke tube type that operates as an economiser is shown in Figure 6.37. In basic form it consists of a circular shell, the end plates of which are tube plates through which pass a large number of plain tubes. A percentage of these tubes are, of course, stay tubes required to support the flat tube plates. The unit is designed to operate in the dry condition and acts as an efficient silencer. Very little, if any, back pressure is built up because of the straight through tube arrangement. Such units are often equipped with an internal by-pass flue.

A similar tank type economiser makes use of thimble tubes and is represented in Figure 6.5 and, although no longer popular because of initial cost, may still be encountered at sea.

Coiled water tube type

Coil type economisers are erected on a framework and the heating surface is formed by series of coiled tube elements suspended in the framework in such a way that the elements can be withdrawn for repairs or renewal without disturbing adjacent coils. A La Mont economiser of coil type is shown in Figure 6.38. It will be seen that the inlet end of each coil is connected to a distribution header and the flow of water through each coil can be adjusted by means of apportioning orifices shown in Figure 6.39. The outlet end of each coil is attached to the collecting header.

It is quite common to find this type of economiser operating in conjunction with an oil fired water-tube boiler, the steam drum of which is arranged to act as a steam receiver for the La Mont unit when all steam is being generated by exhaust gas.

It will be noted from Figure 6.38 that a coil type economiser can be constructed with two or more sections so that feed heating, generating and superheating sections can be provided. Whereas there is a distinct advantage so far as the saving of weight and space is concerned with this type of unit, it has proved difficult to maintain in a clean condition both internally and externally. Consequently, if