Marine Steam Boilers

First Printing..............................1983

Published and Reprinted by
KEELUNG BOOK CO.,
Keelung, Taiwan
The Republic of China

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發行人：汪孝義
發行所：基隆圖書公司
基隆市忠一路3～2號
行政院新聞局局版台業字第1589號
印刷所：三揚印刷企業有限公司
板橋市三民路一段31巷89弄5號

Preface

The marine engineer today is faced with a subject of immense scope due to the wide variety of types of propelling machinery, both steam and oil. High speed passenger liners, for which steam power remained supreme for over sixty years, are no longer commonplace and the present day role of steam for propulsion is in vessels of very high power such as large tankers and fast container ships. The choice of steam for propulsion of tankers is favourably influenced, to some extent, by the fact that steam is additionally a convenient means of cargo heating and pumping.

Nowadays, very few oil-engined vessels are built without a steam boiler of some description being included in the machinery installation and, in the case of oil-engined tankers, it is quite usual to find a pair of large auxiliary water tube boilers — often of double evaporation type. The increase in the number of shipbuilding nations in recent years has brought about a similar increase in the types of main and auxiliary boilers available to the shipbuilder, and a corresponding need for marine engineers to keep abreast of all such developments.

Rules governing the construction of boilers and the testing of the materials used, based on many years of experience, are specified by the classification societies. These safeguards, coupled with good design and workmanship and adequate supervision, result in boilers which, when properly maintained and tended, are safe and reliable in service.

There are numerous publications dealing with boilers from the theoretical and design aspect but in this book the authors' have endeavoured to cover the subject in a practical manner for the marine engineer. When going to sea for the first time engineers may join a vessel fitted with boilers of a type not seen before. It may also happen that the engineer is faced with a boiler defect at sea when an emergency repair has to be carried out. In such cases it is considered that a book dealing with the various types of boilers at present in general use can be of considerable service.

This book, originally written in 1953, was an endeavour to meet these requirements and this edition has been thoroughly revised and, in some places rewritten, to bring it up to date and in line with recent developments. In an endeavour to make the contents more valuable to engineers studying for Department of Trade Certificates of Competency examinations, numerous additions and amendments have been made, many of them at the instigation of marine and technical school lecturers.

Four new chapters have been included in this fourth edition. As a result of recent developments in dual-fired watertube boilers using oil and gas, a separate chapter has been devoted to this subject. The authors, recognising the ever increasing importance of instrumentation and controls, have made this the subject matter of a further new chapter. Water treatment has been given more comprehensive treatment in a separate chapter and likewise, the section on boiler maintenance and repair has been enlarged to form its own chapter.

However, in order to keep this book to manageable proportions, it has been found necessary to omit the chapter, included in previous editions, dealing with classification society rules. Regulations covering the construction of marine boilers have been in existence for over one hundred years. Lloyd's Register was one of the first recognised authorities to introduce such regulations when their Boiler Rules were issued in 1877. Since that time various organisations and authorities have formed their own Rules for the construction of boilers and each of the leading classification societies as well as the government bodies of the major maritime nations have, independently, issued their own regulations.

In recent years, attempts have been made to unify all such Rules through the influence of ISO (the International Organisation for Standardisation). This is a worldwide federation representing thirty-eight national standards institutes and its function of developing and unifying international standards is carried out through technical committees on which each member body is represented. International organisations, both governmental and non-governmental in association with the permanent officers and staff of ISO, also participate in the work. ISO Standard No. R 831 is the current reference for boiler construction and was introduced in 1967. A number of government organisations and classification societies including Lloyd's Register of Shipping have adopted this standard as basis for their own Rules. These Rules are continually being amended, as required to take into account developments in technology.

The British engineering industry widely accepts the use of SI units the international system (Systems International d'Unites) based on the metre-kilogramme-second (MKS) system. Engineering calculations are greatly simplified when SI units are employed so that their introduction into engineering courses is understandable. SI units have, for example, been introduced gradually into the academic section of the Department of Trade engineers' examinations. However, in applied engineering, which is the concern of this book, the change to SI units will take place gradually. Engineers, in the main, continue to work and think in the units they have been accustomed to. Whether trained on imperial, metric or SI units, engineers will need to familiarise themselves with conversion to equivalent values in other units and, to enable them to convert as accurately as may be required, the necessary information and conversion factors relating to all quantities referred to in the book will be found conveniently available in the Appendix. Wherever possible in this book, SI units have been used with the view to encouraging the practical marine engineer to work and think in this comparatively new media.

It has been suggested that any difficulty arising from unfamiliarity with the SI units of pressure (newton per square metre) can be avoided by adopting the 'bar' as a pressure unit. Since 1 bar (= 10^5 N/m^2) is equivalent to 14.5 lbf/in^2, it is very nearly equivalent to 1 atmosphere and is therefore a conveniently sized unit for comparison with imperial units; incidentally, also 1 bar is very nearly 1 kgf/cm^2.

In this fourth edition James H. Milton enlisted the assistance of Roy M. Leach, a colleague from Lloyd's Register of Shipping as co-author. Regrettably, during the closing stages of the preparation of this work 'Jim' Milton died. It is sincerely hoped that this latest publication will prove to be a fitting epitaph to a man who was highly regarded throughout the marine engineering fraternity not only for his wide experience in the field of boilers but also for his flair for solving machinery problems covering a wide spectrum.

James H. Milton
Roy M. Leach

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Acknowledgements

The authors are indebted to the following manufacturers and designers who have generously provided information and illustrations, in particular:

Mr. J.B. Donnelly, C.Eng. M.I. Mar.E. (Foster Wheeler Power Products Ltd)
Mr. A.F. Hodgkin, C.Eng. M.I. Mar.E., M.I. Mech.E. (Babcock and Wilcox Ltd.)
N.E.I. John Thompson Ltd., and Thompson Pressure Vessels for the section on 'Welded Boiler Drums'.
Messrs: J.D. Skelly B.Sc. Chart. Chemist, M.R.I.C. and J.H. Lester, L.R.I.C., C.Eng. M.Inst.F., M.I.Mar.E. of Nalfloc I.C.I. for the section on 'Feed Water Treatment'.
The Committee of Lloyd's Register of Shipping.
Mr. A.W. Jones, B.Sc. Marine Engineering Dept., King's College, Newcastle-upon-Tyne.
Mr. F. Jarrett, Marine Engineering Dept., Poplar Technical College.
Mr. M.C.L. Oxley, M.Sc.
The authors' many colleagues at Lloyd's Register of Shipping.

The Institute of Marine Engineers.
Osaka Boiler Manufacturing Co. Ltd.
Clarke Chapman Limited.
Hitachi Shipbuilding and Engineering Co. Ltd.
A.B. Svenska Maskinverken.
Aalborg Vaerft A/S.
Blohm and Voss A.G.
M. & W. Grazebrook Ltd.
Kawasaki Heavy Engineering Ltd
E. Green and Son Ltd.
A.G. Weser.
A.G. Howaldswerke-Deutsch Werft.
Muira Co. Ltd.
Stone-Platt, Crawley, Ltd.
S.A. ETS. Wanson.
G.E.C. Diesels Ltd.
Hopkinsons Limited.
Clyde Blowers Limited.
Cockburns Ltd.
Gebr. Leser K.G.
Dewrance & Co. Ltd.
Richard Klinger Ltd.

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Historical development of the marine boiler

It is surprising to find that many centuries elapsed before it was realised that by heating water in a closed vessel and harnessing the steam thus produced under pressure, an inexhaustible source of mechanical power was available for the service of man. Until the middle of the eighteenth century the only mechanical aid used in industry was that obtained by sails on water borne vessels, and by wind and water wheels in land practice.

The pioneer inventors

The ever-increasing demand for assistance in removing water from deep-mining operations, principally tin-mining in Cornwall, and later, for increasing the production of fabrics in the cotton and wool factories which sprang into existence at that time, resulted in many practical pioneers—Savory, Newcomen, Trevethick, Watt and others—working on the problem of producing a steam engine which would be capable of continuous work with but little attention.

It may be noted here that Newcomen engines, which were first used in Cornish mines in 1756, had open top cylinders, depended on vacuum and atmospheric pressure for their power and were very inefficient. Trevethick appears to have been the first inventor to construct boilers to produce steam above atmospheric pressure, but his engine was not very successful either, and it was James Watt who, by improving the mechanism of the Newcomen engine, made an engine which was capable of really good service. This power unit was first used in mining operations and, later, in industrial factories.

Two major problems faced these early inventors—to design and manufacture, first, boilers capable of producing steam at a constant low pressure over a considerable period of time and with a minimum amount of attention, and, second, engines which by use of this steam could operate at a constant speed performing useful work. It is with the first of these problems, boilers, that this book is concerned.

Materials used for the first boilers

In those early days designers were confronted with the difficulty of obtaining suitable material of satisfactory size and thickness, but it was soon recognised that iron, which could be obtained in plates of reasonable size, would meet their requirements. The iron used in this country up to this time was produced by smelting ore, found in the northern counties, with charcoal. Concurrent with the introduction of steam machinery, coal-mining, which until then had been of low production, came to the fore, and coal quickly became the fuel for the manufacture of iron and for steam production.

The next step forward was the introduction of blast furnaces producing pig-iron which, being readily liquefied, could be moulded to any required shape. This cast iron was used in boiler work to some extent, but fatal accidents occurred, and its use to any degree was abandoned. A later advance was the introduction of rolling mills producing both sheets and angles of uniform thickness and good ductility, suitable for boiler construction.

Early designs

In these early days boilers were designed for low pressures and were often of very peculiar shape to meet various local conditions. It soon became apparent, however, that a circular form was the best for resisting internal pressure, and the ever-increasing demand for steam in factories led to the development of large tank boilers, fired externally, with the flue gases passing away to tall chimneys at high temperature.

This arrangement was naturally very uneconomical, and a great step forward in the saving of fuel was made by the addition of internal circular furnaces surrounded by the boiler water, thus increasing the heating surfaces and lowering the chimney temperatures. Some Lancashire and Cornish boilers embodying these features are still in industrial use.

The first locomotives

As these improvements in the design of engines and boilers for pumping and factory work were being brought into use, the early pioneers were faced with the difficulty of getting coal expeditiously and in quantity from the pits to the factories and towns. Their problem was to make an engine which could draw heavy loads at a reasonable speed along country roads. It was quickly recognised that special tracks with lines laid down were needed for this purpose, and for some years horses were employed to draw laden trucks along these lines. As time went on, however, these horses were replaced by steam engines and boilers fitted on a wheeled framework. The boilers were naturally cylindrical in shape with a water-cooled firebox at one end and a flue which took the products of combustion from the firebox through the barrel to the chimney at the other end.

Although these early locomotives were very inefficient, their development led to a complete railway line being laid down between Stockton and Darlington, which was opened to traffic in 1825 with a locomotive capable of drawing a heavy train with passengers at 12 miles per hour. Stephenson finally produced his famous engine, the *Rocket,* in 1829, winning a prize of £500 offered by the directors of the Liverpool and Manchester Railway. This locomotive was so successful that the future of railway engineering was assured. A boom in this form of transport followed, as it was quickly recognized that by this means journeys from town to town were made much quicker and more comfortable in every way.

It may be noted here that Stephenson's *Rocket* differed from its predecessors in that he arranged for the products of combustion, on leaving the firebox, to pass through a number of 76 mm diameter copper tubes fitted in the boiler barrel and expanded into tube plates at the barrel ends. By this means the heating surface was considerably increased, and the success of the boiler was principally due to this factor.

Early marine steam engines

Turning now to the early pioneers in marine engineering, it would appear that the honour of producing the first practical steam engine for the propulsion of a water-borne vessel was that of Symington, who in 1803 constructed a small paddle-wheeled vessel, the *Charlotte Dundas,* which was tried on the Firth of Clyde canal for towing barges. She was quickly put out of commission on account of the heavy wash made by her paddles, the canal proprietors complaining that the wash would damage their property. A few years later, in 1807, an American engineer, Robert Fulton, constructed the first passenger steamship, the *Clermont,* and in 1811 Henry Bell built the famous *Comet,* which worked very successfully on the River Clyde. The building of many other vessels in various UK ports soon followed.

The first safety regulations

At this time the designers appear to have been given a free hand, with the result that many boiler explosions occurred. This resulted in the setting up of a parliamentary committee convened in 1817, and regulations were issued which required compulsory registration of all steamships. It was particularly specified that the boilers were to be made of wrought iron or copper and subjected to inspection. Two safety valves were to be fitted to each boiler and the boilers tested to three times the working pressure, based by calculation on a factor of safety of 6. At this time the machinery employed for propulsion consisted of paddle-wheels driven by side-lever engines, supplied with steam from very low-pressure boilers, and the vessels were comparatively small.

Introduction of the screw propeller

The successful introduction of the screw propeller in 1837 gave a great impetus to the use of steam propulsion, and from this time onward considerable advance was made in engine design. In particular, the direct vertical compound engine made its appearance in 1854, and this required steam to be supplied at a higher pressure than that previously used. Improvements in boiler design permitted the pressure to be raised to about 1.7 bar. The boilers then in use were mostly of the box type made to economize space, naturally limited on board ship, and to provide as much grate area as possible. Figure 1.1 shows one of these boilers fitted in a vessel built by the Thames Iron Works Company.

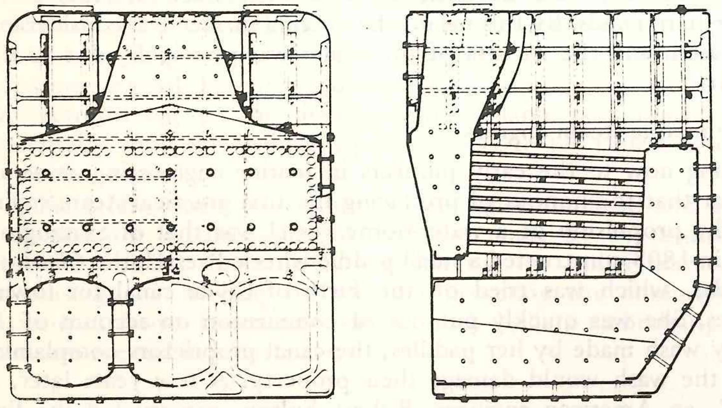


Figure 1.1 Box-type boilers fitted in vessel built by Thames Iron Works Co (1878) Working pressure 2 bar

Oval boilers

The introduction of triple-expansion engines in 1871, requiring the use of much higher steam pressure, resulted in boiler design being drastically altered, and oval-shaped boilers with the shell plating made semicircular in section at top and bottom, and flat sides well stayed, were common practice. These boilers gave considerable trouble owing to their shape and they were finally replaced by the completely cylindrical Scotch boiler, which became standard practice. A sketch of an oval boiler made in 1878 is shown in Figure 1.2.

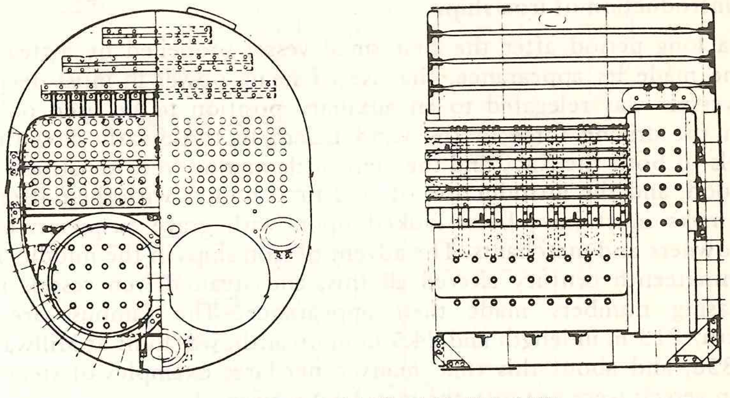


Figure 1.2 Oval boiler for SS 'State of California' built in 1878 Working pressure 4.8 bar, heating surface 105 m^2

Lloyd's Rules and factor of safety

Up to 1877 government regulations on boiler construction dealt largely with workmanship, materials and method of manufacture, and no definite factor of safety was insisted upon. In that year J.T. Milton, who was, for many years the Chief Engineer Surveyor to Lloyd's Register of Shipping, presented a paper to the Institute of Naval Architects in Glasgow, dealing with the strength of boilers. In this he stressed the need for a factor of safety to be definitely agreed upon. An interesting remark he made is that up to this time, all the inventions for generating high-pressure steam in water tube boilers had failed when set to work on ocean steaming, and that the ordinary cylindrical boiler, with all its defects, was the only one which could be said to be reliable.

Later in the same year, Lloyd's Register of Shipping, after a series of exhaustive tests and from an unrivalled knowledge of the troubles experienced in boilers when in service, formulated rules on a sound theoretical basis for the strength of cylindrical boilers. These rules, added to and amended where found necessary to meet changing conditions as time advanced, formed the basis on which the cylindrical boilers of the mercantile marine industry of this country, and indeed of the whole world, depended for their safe construction and maintenance.

The introduction of iron ships

For a long period after the first small vessel propelled by a steam engine made its appearance, the use of steam power in most deep-sea vessels was relegated to an auxiliary position to be used only when the driving force of the wind failed. In those early days the vessels of both the Navy and the mercantile marine were constructed of wood, and the introduction of coal fired boilers with their attendant risks must have been looked upon with grave suspicion by ship-owners and merchants. The advent of iron ships in the middle of the nineteenth century altered all this, and steam-driven vessels in increasing numbers made their appearance. The famous *Great Eastern,* 213 m in length and 24.5 m in breadth, was built at Millwall in 1858, and about this time many other large examples of steam-driven vessels were put into the merchant service.

At this time also great strides had been made in the design of sailing-ships, and practically the whole of the overseas trading, particularly to the Far East, was carried out by them. It was many years before the purely steam-driven deep-sea vessel, independent of wind, came into its proper place as a time-saver, particularly where perishable goods were to be carried. Even so, sailing-vessels of large size were still in active service in considerable numbers till the end of the nineteenth century. It is interesting to note that almost exactly 100 years elapsed from the time when Symington produced his steam driven *Charlotte Dundas* before sailing-vessels were entirely replaced by steamers.

Water tube boilers

Towards the end of the nineteenth century the British Admiralty came to the decision that, owing to the thickness of shell plating required in the tank boilers fitted in the larger warships, they had reached the limit of pressure at 10.7 bar. The need for quick raising of steam, increased power and decreased weight focused their attention on watertube boilers for steam production. This led to the installation of a French-designed boiler the 'Belleville', into several

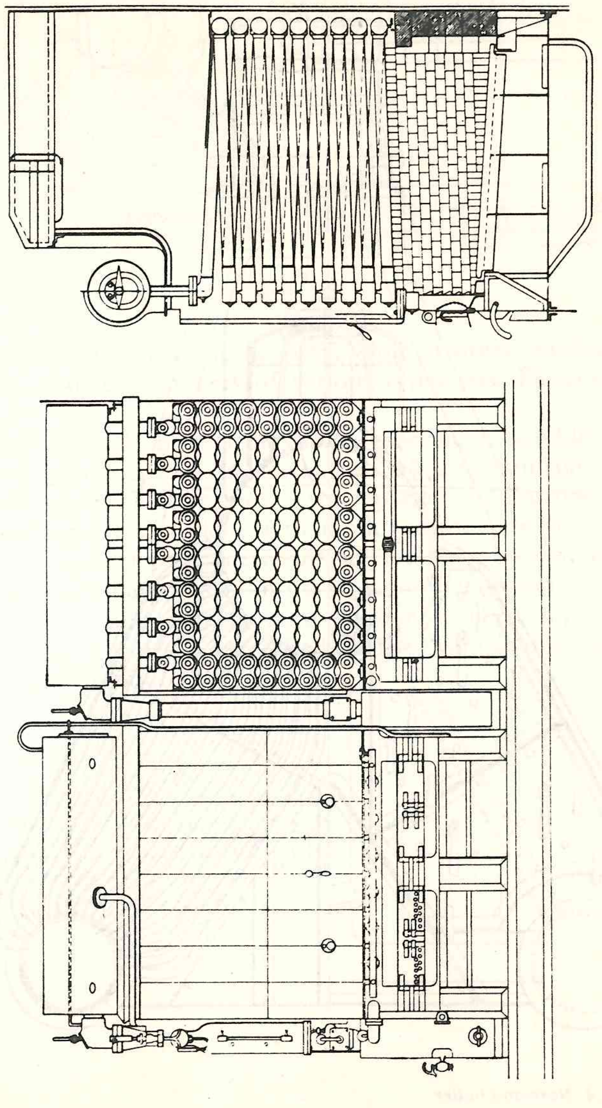


Figure 1.3 Belleville boiler

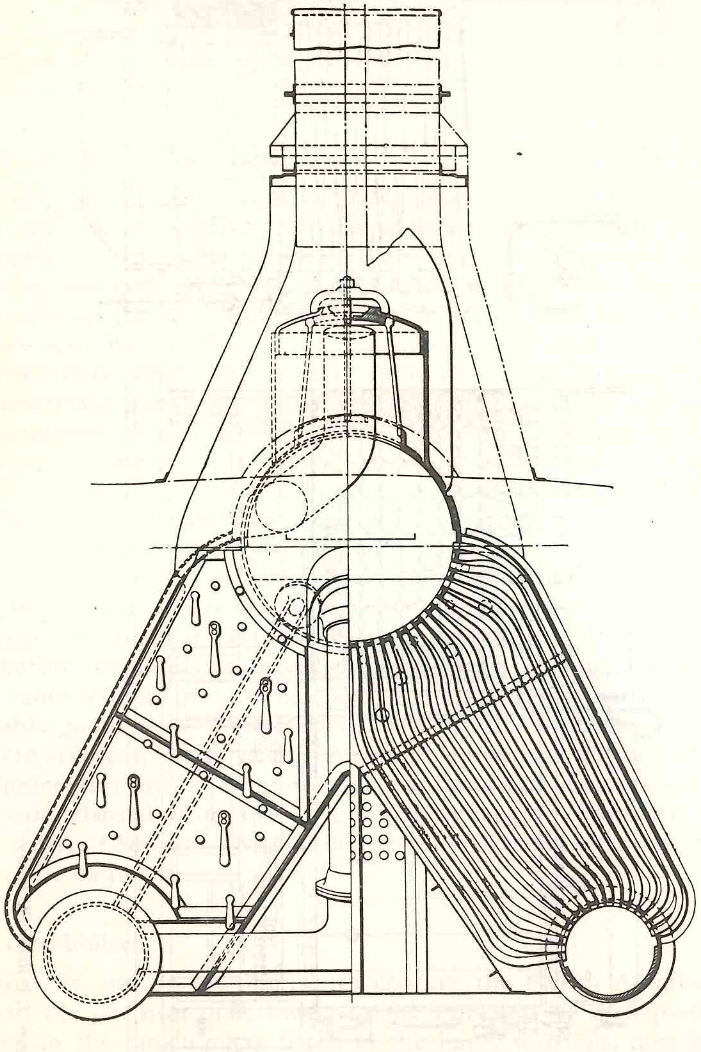


Figure 1.4 Normand boiler

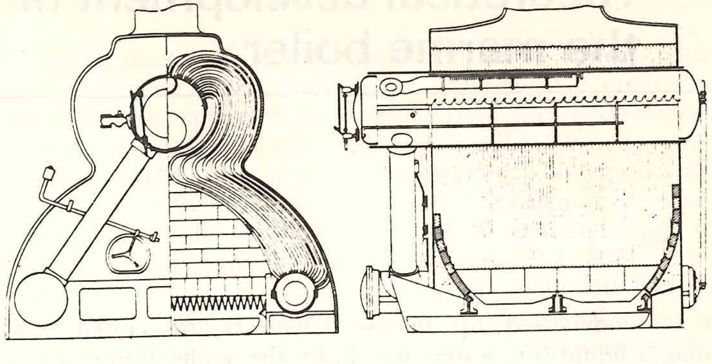


Figure 1.5 Thornycroft water tube boiler

of their battleships and cruisers, while in other smaller vessels they fitted small tube boilers of various types (see Figures 1.3, 1.4 and 1.5).

The Belleville boilers, however, gave much trouble through tube leakages, and after exhaustive trials by a Committee appointed to advise on the matter they were replaced by Yarrow and Babcock designed boilers, which, with modifications, are still in use at the present time. In the merchant service tank boilers, with pressures up to 17.25 bar are still in use, but on high-powered passenger and cargo liners and tankers these have now been superseded by oil-fired, high-pressure, water tube boilers of various designs.

2 Theoretical development of the marine boiler

Boilers as understood by marine engineers are closed vessels containing a liquid (i.e. water) which, by the application of heat, is converted into steam at any designed pressure. This steam, via suitable machinery, is then used for the production of useful work. All material substances contain heat in varying amounts which modern science connects with vibratory motion of their individual molecules, the amplitude and velocity of this motion increasing with any rise in temperature. At the lower limit of this temperature range, which theory places at minus 273°C, these molecules would cease to move and the body contain no heat. At the upper end of this scale there would appear to be no limit to the temperature which may conceivably be reached.

Many substances can assume different forms under varying conditions of pressure and temperature. Water is a familiar example of this, being liquid under ordinary atmospheric conditions, solid ice when very cold and totally gaseous when sufficiently heated. The gaseous state depends on the addition of heat, for as the boiling temperature of the water rises, so the pressure increases.

In the solid state the molecules are packed very close together, each exerting an attractive force on its neighbours sufficient to prevent any movement. With rising temperature the molecules are driven further apart, their mutual attraction is lessened and the liquid condition reached. Beyond this point, at constant pressure and with the liquid temperature increasing, the attraction between the molecules is still further lessened, and the condition reached where individual molecules are freed, each carrying its own store of kinetic energy, and in a closed vessel these free gaseous molecules exert pressure on the containing walls. As more and more molecules are freed from the water by heat the pressure rises, and finally what is termed the boiling point is reached. At this point the temperature of the water and the produced steam remains constant, dependent on the pressure maintained in the boiler.

THE PROPERTIES OF STEAM

The properties of this gaseous vapour, or steam appear to have been first thoroughly investigated by a distinguished French scientist Regnault, who, acting on instructions from the government, carried out many carefully planned experiments and published the results he obtained in 1847. His apparatus comprised a boiler, partially filled with about 150 dm^3 (litre) of water, a condenser to liquefy the steam as fast as it was formed and an air chamber larger than the boiler, provided with force pumps by means of which any desired pressure up to an absolute pressure of about 30 bar could be maintained. Pressures were measured by the use of a long mercury column and temperatures ascertained by air thermometer, to ensure great accuracy.

Steam pressure and temperature

The experiments showed that the pressure of saturated steam increases with its temperature, the relation between the two remaining constant so long as the steam is in contact with the water from which it has been produced. They further showed that each degree rise in temperature of the steam is accompanied by greater and rapidly increasing rises in pressure.

At 100°C the pressure is that of the atmosphere 1.0132 bar, and this pressure is increased by 0.0368 bar for a further rise of 1°C in the temperature. At 150°C the pressure rises to 4.76 bar, and the increase in pressure for 1°C rise is 0.129 bar, while at 275°C the pressure rises to 59.496 bar with an increase of 0.919 bar for a further rise of 1°C.

Table 2.1 Steam pressures and temperatures (*Extract from UK Steam Tables in SI units, 1970*)

Temp. °C.	*Absolute pressure* bar	*Specific enthalpy* kJ/kg			*Specific volume* dm^3/kg	
ts	ps	hf	hfg	hg	vf	vg
50	0.12335	209.3	2382.9	2492.2	1.0121	12046.0
100	1.01325	419.1	2256.9	2676.0	1.0437	1673.0
150	4.7600	632.1	2113.2	2745.4	1.0908	392.45
200	15.549	852.4	1938.6	2790.9	1.1565	127.16
235	30.632	1013.8	1788.5	2802.3	1.2187	65.245
250	39.776	1085.8	1714.7	2800.4	1.2513	50.037
300	85.927	1345.1	1406.0	2715.0	1.4041	21.649

Enthalpy of saturated vapour

Regnault was one of the earliest to explore experimentally the way in which the enthalpy (i.e. total heat) increment of evaporation (hfg) varies with pressure. He demonstrated that its value falls with increasing pressure. However, its rate of fall is initially lower than the rate of increase of the enthalpy of the corresponding saturated liquid (hf), so that the overall effect yields a rise in enthalpy of the saturated vapour (hg) with rise in saturation pressure to about 30 bar, beyond which it gradually falls.

First law of thermodynamics

Experiments have shown that provided the atoms of the working fluid remain unchanged (being neither subjected to fission or fusion) energy can be changed from one form to another, but can be neither created nor destroyed. This law of energy conservation is associated with the concept of energy transfer between systems to give the first law of thermodynamics:

> 'For a system operating with a closed cycle (i.e. initial and final states identical), the net transfer of work is equal to the net transfer of heat'

Joule was the first experimenter to demonstrate the equivalence of heat and work, and, using the British Imperial Units he showed that, 778 ft. lbf. of work were equivalent to 1 British thermal unit (Btu) of heat.

By using SI units, both heat and work have the same units, namely joules or kilojoules (J or kJ) and thus in this system the mechanical equivalent of heat is unity. i.e. 1 J = 1 Nm.

Useful conversions are as follows:

1 hph is equivalent to 0.7457 kwh is equivalent to 2684.5 kJ.

1 kWh is equivalent to 3.6 MJ is equivalent to 3600 kJ is equivalent to 1341 hph.

Boyle's and Charles' laws

These laws are only strictly applicable to perfect gases so that steam has to be in a highly superheated state before they can be even approximately used. Boyle's Law states that the product PV of the pressure and volume of a given mass of gas is constant provided the temperature remains constant (i.e. PV = constant). Charles' Law states that the ratio of volume and absolute temperature of a given mass of gas is constant provided the pressure remains constant (i.e. V/T = constant). Together they yield the familiar equation:

$$PV = m\,RT$$

where P is pressure (N/m^2), V is volume (m^3), m is the mass of gas (kg), T is absolute temperature (K), R is the appropriate gas constant (Nm/kg.K).

If steam behaved as a perfect gas, the value of R is given by:

$$\frac{\text{Universal gas constant (Nm/kg mol K)}}{\text{Molecular mass of steam}} = \frac{8314}{18} = 462 \text{ Nm/kg K}$$

Taking sample figures from the steam tables and calculating the value of PV/T (remembering 1 bar = 10^5 N/m^2) we get the following results:

Pressure bar (abs)	*Temperature* °C	K	*Specific volume* dm^2/kg.	$\frac{PV}{T}$
50	450	723	63.25	437
50	550	823	73.6	447

This demonstrates that these formulae are not strictly applicable to superheated steam at the temperatures usual in marine boilers.

For example, from Steam Tables:

At 50 bar, satn. temp. = 264°C, sp. vol. ≠ 39.37 dm^3/kg.

Steam temp. (°C)	300	350	400	450	500
Sp. volume (dm^3/kg)	45.310	51.941	57.791	63.250	68.494

Value of Kp is variable, from 2.9 kJ/kg K close to Saturation line → 2.3 kJ/kg K well into superheat region.

Second law of thermodynamics

We come now to the second law of thermodynamics – heat cannot pass from a cold body to a hot one by a purely self-acting process. In other words, mechanical energy cannot be obtained from heat by cooling a body below the temperature of surrounding objects. The working fluid in a steam engine, for instance, must be finally rejected at a temperature above that of the cooling medium – seawater. Steam is an elastic fluid, and through its changes in volume under the action of heat is capable of exerting energy on external bodies.

These changes in volume may proceed isothermally, in which case the temperature T remains constant, or the expansion may be adiabatic, with no heat added or subtracted.

The Carnot cycle

In a steam engine the working fluid goes through a cycle of operations in which the first period is the evaporation of the water in the boiler, the second is that of steam expansion, the third that of condensation in the condenser and the fourth that of forcing the water back into the boiler. A very important law due to Carnot states that 'efficiency of all reversible engines working between given limits of temperature is the same'. This efficiency is the maximum possible, and if U is the work done during a cycle of operation and Q the amount of heat added in the boiler, then

$$\frac{U}{Q} = \frac{Q - R}{Q} = \frac{T_1 - T_2}{T_1}$$

where T_1 and T_2 are the absolute temperatures of the hot and cold bodies and R is the heat rejected.

These expressions show that the power and efficiency of any reversible cycle are related to the upper and lower temperature difference between which the gas operates doing useful work, the efficiency increasing with any increase in the range of temperatures employed. As an example, if the upper limit were 260°C and lower limit 0°C, the efficiency using temperature absolute would be (533–273) ÷ 533 = 0.48, and ideally it would be possible to transform 48% of the heat expended into useful work, while by suitably increasing the upper limit and thus increasing the range, the efficiency might be further improved.

The development of high temperatures and pressures

In practice, the steam engine heat cycle is not ideally reversible. Its efficiency cannot in any circumstances, be as great as the Carnot ideally perfect reversible engine working between the same limits of temperature. However, the aforementioned considerations point the way to improvements in economy and power and hence, we find boiler pressures and temperatures of saturated steam have greatly increased during the past years.

This is one of the reasons for the replacement of the large and heavy tank boiler by the water tube boiler in high-powered vessels. The insistent demand for an increasing amount of power in a limited machinery space and for reduction in weight of boilers and their contents can only be met by the use of water tube boilers. These boilers in general have much smaller steam space in proportion to the amount of steam generated than is the case with tank boilers, and the steam produced is therefore more liable to contain suspended moisture. The addition of superheaters ensures dry steam and at the same time increases the steam temperature, and thus the heat energy of the steam. The volume also increases, the pressure in the superheater remaining constant.

Tank boilers also are often fitted with superheaters for the same reasons. The dry superheated steam reduces cylinder condensation in reciprocating machinery and lessens erosion by moisture in turbine installations.

The amount of additional heat put into the steam by superheating from say T_1 to T_2 is given by the expressions $Kp(T_2 - T_1)$, where Kp varies from 2.0 to 2.3 kJ/kg K depending on the degree of superheat.

COAL AND OIL

Having briefly dealt with the steam properties leading to the adoption of high pressures, a few words on the subject of the heating agents which are employed – coal and oil – may be of interest. The production of steam being dependent on heat derived from the combustion of either coal or oil prompts the question, 'what is heat?'

Radiant heat

We know, of course, that the original source of the heat which we experience and use is the sun, 100 times larger than our earth, and around which the earth revolves. Physicists tell us that the sun is composed of an immense whirling mass of gaseous atoms at extremely high temperature and of varying weights. Each of these atoms is a storehouse of potential energy of enormous power, and under the whirling heated conditions in which they exist many of them are continually broken, and their store of heat energy, now kinetic, escapes into space in every direction. Those atoms which arrive on this earth form what we term 'radiation'. This is the heat which we experience and enjoy daily.

The laws governing the action of radiant heat have, however, been known for many years. Radiant heat travels at\the same speed as light, 300 000 km/s approx, and in fact, both are forms of the same kinetic energy and are transmitted by transverse vibratory motion through space.

Heat from chemical action

Many chemical reactions, in which elements combine chemically to form a compound, are accompanied by an emission or absorption of heat. The reaction in which heat is absorbed is known as *endothermic* and that in which heat is given out as *exothermic*. The reaction of carbon and hydrogen, the main constituents of boiler fuel (coal, oil or gas), with oxygen is an exothermic reaction and the heat thus evolved during the oxidation (i.e. during burning) of fuel is utilised in a boiler to raise steam. (For further discussion, see chapter 16).

The origin of coal and oil

Coal and oil deposits are very dissimiliar in physical characteristics. The former are solid, whilst the latter are liquid, but both are derived from vegetable matter of the chemical formula $C_6H_{10}O_5$. In the formation of coal part of the carbon content remains free, the proportion varying with different coals, while the remainder is united with the hydrogen, forming readily ignitable hydrocarbons. The oxygen is largely eliminated.

In the case of oil fuel, the carbon and hydrogen contents under the pressure conditions of its formation, unite to form gaseous and liquid hydrocarbons of varying formulae – chiefly CH_4, methane gas. This gas occurs as the chief constituent of the natural gases found in all oil wells. In the liquid condensate the molecules contain more combined atoms than are to be found in the gas.

The liquid after being obtained from the well is a mixture of many compounds, and this has to be refined and distilled at varying temperatures to separate from it the oils for which there is the greatest demand. In general, the crude oil from the wells is dealt with in refining works situated in the neighbourhood of the wells themselves, and the product is then transported all over the world in specially designed tankers. At its destination it is again refined and cracked at varying temperatures to produce the petrol, paraffin, lubricating and fuel oils of commerce.

The available heat contained in fuel oil is greater than that contained in coal of equal weight, average approximate values per kg being about 43 MJ in the case of oil and 33 MJ in that of coal.

The use of coal and oil

Coal was the fuel used in all steam-propelled sea-going vessels, both naval and mercantile, until the beginning of the present century, but the many advantages appertaining to the use of oil gradually became recognized with an ever increasing percentage of the total world tonnage of steamships using oil fuel instead of coal. In 1939 the relative figures for coal and oil were 60% and 40%; in 1961 these figures were approximately 7% coal and 93% oil fuel; by 1967 oil was almost exclusively used. Both steam and diesel high-powered ocean liners, both passenger and cargo, now use oil fuel exclusively.

The various methods in which these fuels are employed for the economic production of steam in modern boilers, and the necessary precautions which have to be taken from a safety point of view, are dealt with in detail in later chapters.

3 Tank type boilers

The most common boilers in use today for general purpose medium pressure steam production are the capacity, or tank types – these boilers are of moderate steaming rate and have been evolved to work with feed water of medium quality. Such boilers are suitable for relatively simple installations and although, in their larger sizes, may still be encountered in use for main propulsion purposes, are now most commonly used for auxiliary or domestic services.

An auxiliary boiler is generally accepted as one which does not directly supply steam for main propulsion purposes, but does provide steam for auxiliary services essential to the ship when at sea. Examples of such services are: cooling, lubricating oil, fuel transfer and fuel service pumps, steering machinery, manoeuvring air compressors and heavy oil fuel heating systems.

A domestic boiler, on the other hand, does not supply steam for main propulsion purposes or for services of an essential nature -- in other words, it takes care of the 'hotel' and port service load.

Obviously, it is possible, and is often the case, that an auxiliary boiler performs the dual role of an auxiliary at sea and a domestic in port. In the case of a composite boiler in a motorship, the boiler will be exhaust gas fired at sea and oil fired when the ship is in port.

Currently, there are more than fifty different designs of tank type boilers to be found in use on board ships. These may be classified under two group headings – horizontal boilers and vertical boilers. The first part of this chapter is devoted to horizontal boilers, (i.e. Scotch boilers, Howden-Johnson and Capus boilers; dry-back multi-tubular boilers, Cochran 'Chieftain' and 'Wee Chieftain' boilers; Steambloc boilers), and the second section covers vertical boilers.

HORIZONTAL BOILERS

Scotch boilers

The best known boiler of the horizontal type is the Scotch or multi-tubular cylindrical boiler. The fundamental design of this boiler has

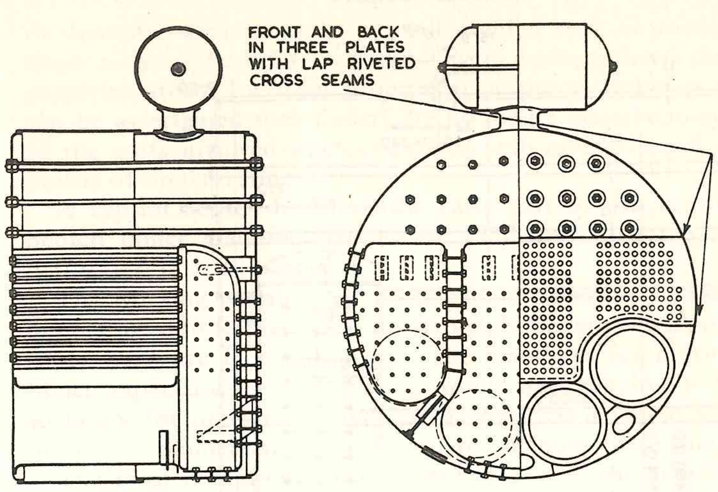


Figure 3.1(a) Early Scotch boiler (about 1900)
Working pressure 6 bar

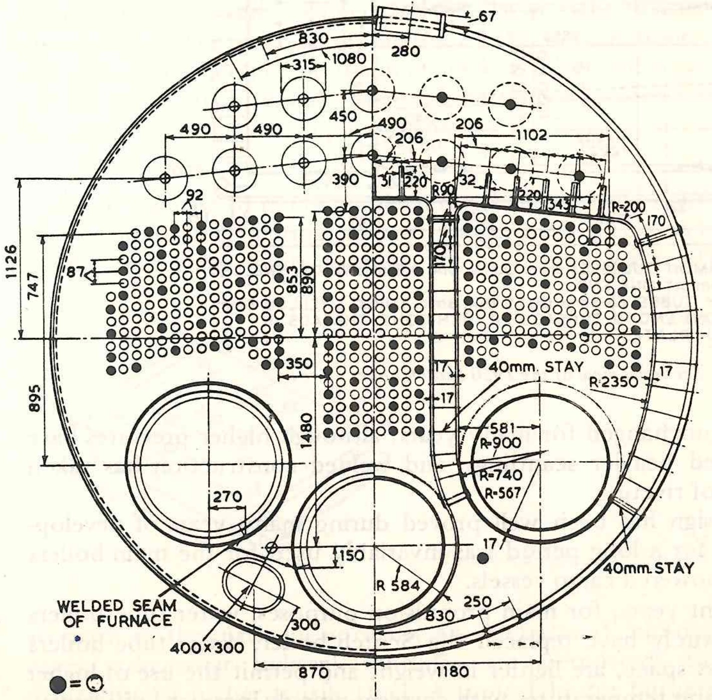
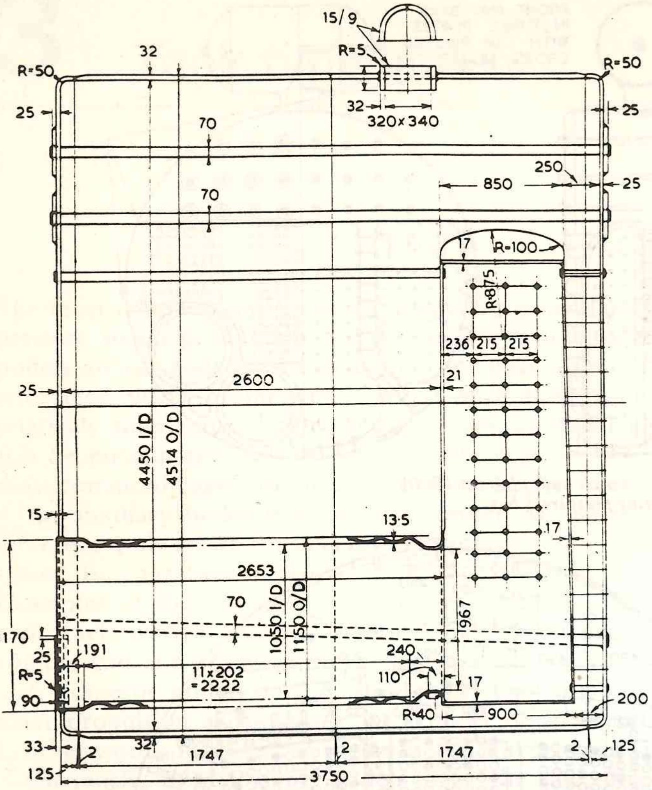


Figure 3.1(b) End view of Scotch boiler made about 1950 with a working pressure of 11 bar



358 COMMON TUBES 63·5mm. OUTS DIA. 3·65mm THICK. SWELLED 1·5mm. AT ONE END

106 STAY TUBES 63·5mm OUTS. DIA. 8mm. THICK. SWELLED 6mm. AT ONE END. 9 THREADS PR. INCH CONT. THREADS IN BOTH PLATES

Figure 3.1(c) Sectional view of the 1950 Scotch boiler

remained unchanged for many years, although higher pressures have necessitated heavier scantlings, and welded construction has taken the place of riveting.

The design has been well proved during many years of development and for a long period was invariably used for the main boilers of steam-powered cargo vessels.

In recent years, for main propulsion purposes, water tube boilers almost entirely have replaced the Scotch boiler. Water tube boilers occupy less space, are lighter in weight and permit the use of higher pressures and temperatures with correspondingly increased efficiency. Many Scotch boilers are still in service supplying steam for auxiliary or domestic services whilst a small number may be found in older ships such as harbour craft and even medium sized cargo ships supplying steam for main propulsion purposes. However, so far as can be ascertained such boilers are no longer manufactured because of the costs involved when compared with modern small tank type boilers of similar rating.

A typical Scotch boiler of the early part of this century and a Scotch boiler manufactured about 1950 are illustrated in Figures 3.1(a) to (c).

The working pressures of Scotch boilers steadily increased from 5.5 bar in 1880 to the end of the Scotch boiler era when pressures up to 17 bar were in common use. The scantlings for a normal sized boiler, especially the shell plating, would have required to have been so heavy for pressures above, say 21 bar that it would hardly have been a commercial proposition to manufacture such boilers.

The most commonly encountered version of the Scotch boiler is undoubtedly the three-furnace, single-ended type, although it is not many years since high-powered turbine and reciprocating engined passenger liners were steamed by the six or eight furnaced, double ended type. The main components of the Scotch boiler are shell, end plates, furnaces, combustion chambers, tubes and stays.

The main features of each of these components are briefly discussed in the following paragraphs.

Shell. In the case of riveted boilers, the shell normally consists of one ring of mild steel plating, in two plates, having two treble riveted double butt strap joints forming the horizontal seams. The tensile strength of the plating is normally 44—50 kg/mm², although in some cases, somewhat lighter scantlings are permitted through the utilization of higher tensile steel. A typical double butt strap joint is illustrated in Figure 3.2.

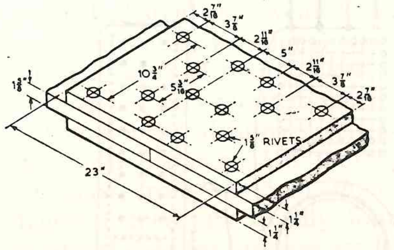


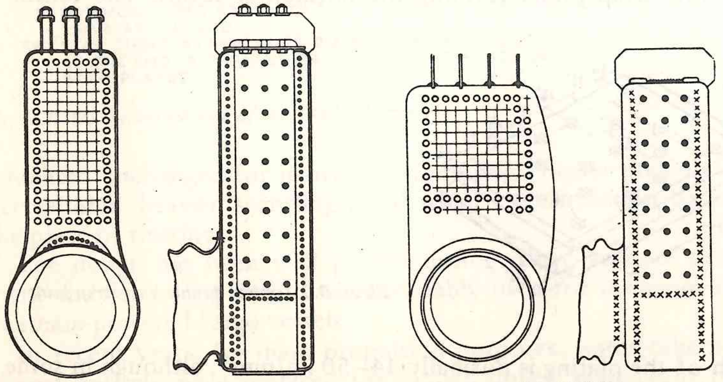
Figure 3.2 Typical double butt strap joint

Formerly, because of the small sizes of boiler plates produced, it was necessary to form the shell from two or more rings of plating as shown in Figure 3.1(a) and this was always the case where double ended boilers were concerned. The centre circumferential seams in such cases were invariably treble riveted and a number of single ended boilers built in this manner are still in service.

In recent years however, welding has largely replaced riveting for the boiler shells, except, perhaps, in cases where the boiler makers are not approved for Class 1 welding. A typical all welded Scotch boiler is shown in Figures 3.1(b) and (c).

End plates. The front and back end plates may be made of individual steel plates, or they may be built up from several plates of varying thicknesses with lap riveted or welded cross seams. Both front and back end plates are flanged to fit inside the shell for riveted boilers, and to butt against the shell for welding in the case of welded boilers.

It should be observed here that the plate thicknesses required depend on the working pressure, amount of support given by stays and flanging, etc. It is therefore quite usual to find end plates built up from two or three different thicknesses of plate, each plate thickness meeting the requirements of its individual loading. In riveted boilers, the end plates are usually riveted into the shell with the flanging outside of the circumferential seam, although in some cases when hydraulic riveting was utilised for the closing seam, the end plate was flanged inwards.



RIVETED CENTRE CHAMBER

ALL WELDED WING CHAMBER

Figure 3.3(a) Constructional details of various types of combustion chamber

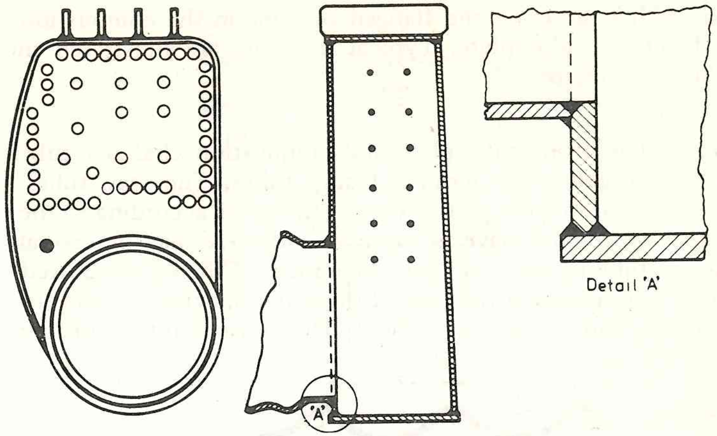


Figure 3.3(b) Alternative method of construction for all welded combustion chamber with detail of furnace attachment

Combustion chambers. As the name implies, these are chambers in which combustion, apart from that which has already occurred in the furnaces, takes place. These chambers, surrounded by the water content of the boiler are, in addition, heating surfaces, and it is from them that the products of combustion return to the uptakes via the plain and stay tubes. The combustion chamber, being at all times under compression, lends itself admirably to that modern method of fabrication, electric welding. Constructional details of several types are illustrated in Figures 3.3(a) and (b).

Furnaces. Scotch boilers furnaces are today generally made of corrugated steel with welded seams, the corrugation providing, for a given thickness, additional strength and longitudinal flexibility. In the early days of these boilers, they were of plain cylindrical section with lap riveted or butt strapped seams.

The number of furnaces in each boiler is usually dependent upon the boiler diameter. For those up to 3.5 m diameter, two furnaces are usual; from 3.5–5 m, three are used, while in boilers over 5 m diameter there are usually four furnaces. The usual types of corrugations used for furnaces are shown in Figure 3.4.

Scotch boiler furnaces are always withdrawable. In the case of furnaces riveted to their combustion chambers, this is accomplished by terminating the inner end of the furnace in a neck and flange (goose-neck), the flange being of such a shape as to be withdrawable through the front end-plate opening. In welded construction the furnace is welded direct to the flanged opening in the combustion chamber front or tube plate. Typical methods are illustrated in Figure 3.3(b) and Figure 3.5.

Boiler tubes. The front tube plate and combustion chamber tube plate are tied together by means of stay tubes. The stay tubes, screwed through both tube plates, vary in thickness according to the area of plate which they have to support, and there may be several thicknesses of tube in one tube nest, the minimum thickness allowed for such tubes, measured at the base of the threads, being 6.5 mm for marginal tubes and 5 mm for others. The normal pitch for the threads of these tubes is 9 per 25 mm, the smoke-box end of the tubes being enlarged and the thread being continuous, so that when inserted they can be screwed simultaneously through both tube plates. In some cases, the ends of the stay tubes are attached to the tube plates by welding, the weld execution being as shown in Figure 3.6. This method ensures pressure tightness under working conditions, but present difficulties when renewals are called for. The material used for stay tubes is, normally, steel. Plain tubes form the major part of the heating surface of the Scotch boiler and are generally made of either lap-welded steel, seamless steel or electric resistance welded steel.

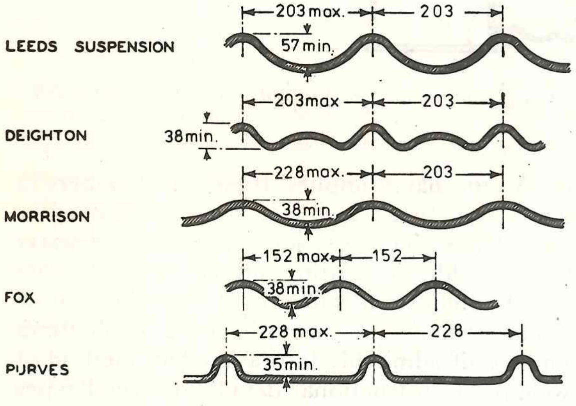


Figure 3.4 Various types of furnace corrugation

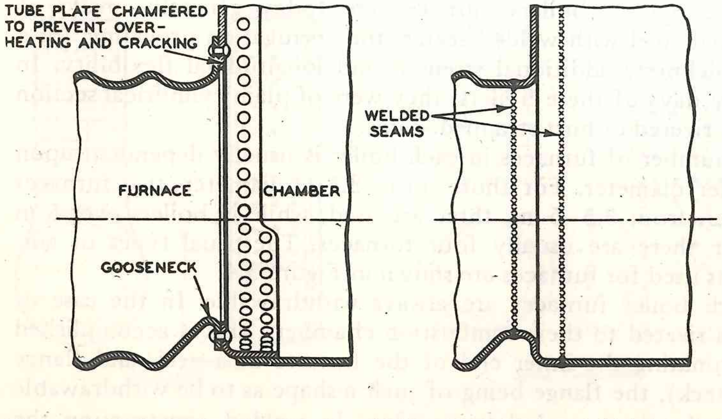


Figure 3.5 Methods of making furnaces withdrawable (left) riveted; (right) welded

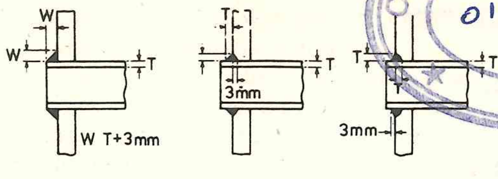


Figure 3.6 Welded stay tubes

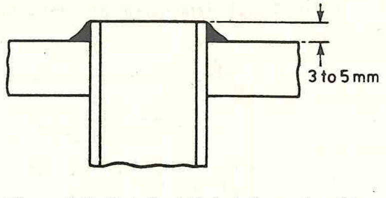


Figure 3.7 Detail of plain tube seal weld

The inner tubes in a nest are very inaccessible on the water side and unless considerable care and attention is paid to their cleanliness, on both this and the fire side, their heating-surface value rapidly decreases.

The normal sizes of plain tubes vary from about 60–90 mm o.d. with thicknesses of 3–4.5 mm, and they are made tight in the tube plates by means of expanding, supplemented in some cases by seal welding (see Figure 3.7).

Stays. Scotch boilers used to be fitted with stays of the screwed type, but most boilers encountered nowadays are fitted with plain bar stays, welded at both ends. Details of the method of attachment of welded combustion-chamber stays and longitudinal stays are shown in Figure 3.8(a) and (b).

As mentioned in the opening paragraph of this section, large multi-furnace Scotch boilers are no longer manufactured. However,

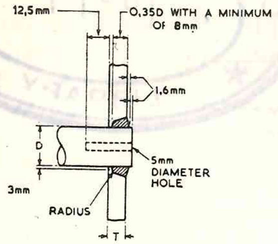


Figure 3.8(a) *Attachment of combustion chamber*

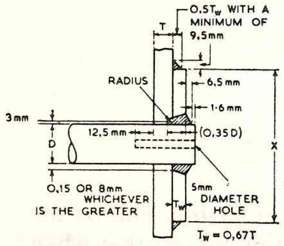


Figure 3.8(b) *Showing two methods of attachment of longitudinal stays*

a new generation of small, compact, packaged boilers has emerged in recent years. Many of these undoubtedly betray their 'Scotch' ancestry (see Figures 3.11, 3.12 and 3.23).

Howden-Johnson and Capus boilers

Two other designs of tank type boiler, which until recently were occasionally encountered aboard ship as main propulsion units were the Howden-Johnson and Capus. In both of these the furnaces passed from end plate to end plate. The combustion chamber, common in the case of the Howden-Johnson and divided in the Capus, was at the back, being bounded by circulating tubes and brickwork (see Figures 3.9 and 3.10).

These boilers were commonly stated as having 'dry back' combustion chambers, and the separation of their combustion chamber, from the cylindrical shell, greatly simplified construction and enabled this type to be designed for higher pressures than was practicable with Scotch boilers.

The Howden-Johnson and Capus boilers may be said to have possessed some of the advantages of both watertube and Scotch types, the watertubes helping to produce very rapid and effective circulation. In view of the number and small bore of the tubes enclosing the combustion chambers and the fact that they were all of bent form and therefore could not be sighted, it was very important that special care and attention was given to ensure that the purity of the feed water was of a reasonable standard.

Superheaters, positioned in the combustion chambers were fitted to both these types. In the Howden-Johnson boiler, the headers were placed above the chambers with the superheater elements hanging downwards whilst in the Capus boiler, the headers were situated low down into the back of the boiler and the elements protruded upwards in the combustion chamber forming the back wall of the respective chambers.

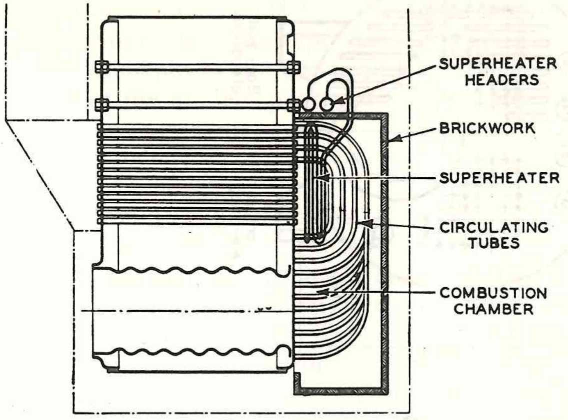


Figure 3.9 *Howden-Johnson boiler*

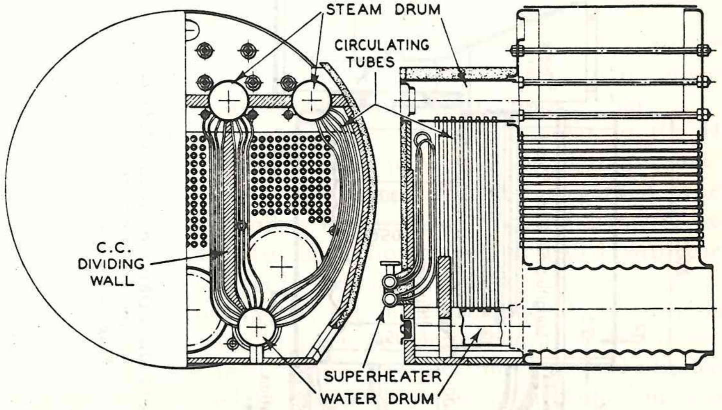


Figure 3.10 *Capus boiler*

Howden-Johnson type boilers, without superheaters, are currently being produced by one Japanese manufacturer. These are of all

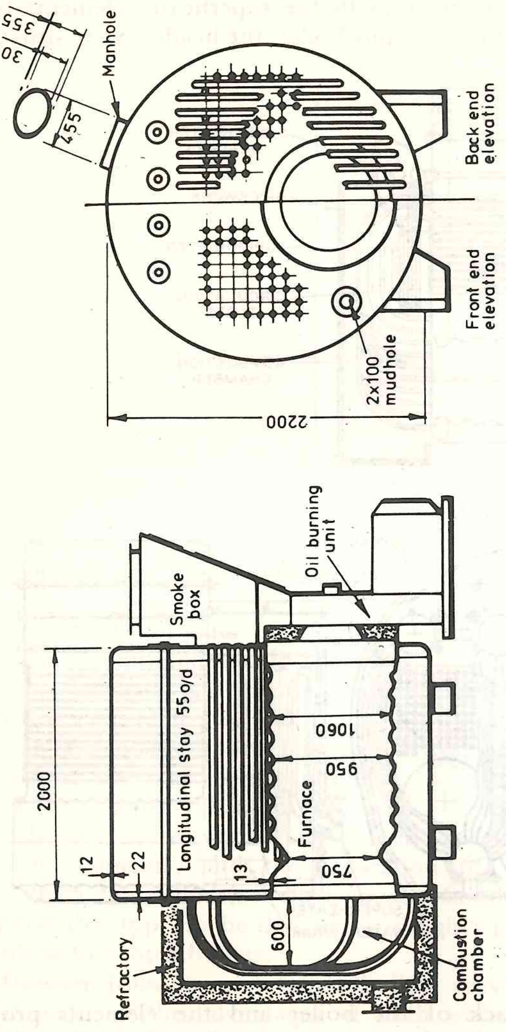


Figure 3.11 Osaka OEH type Howden-Johnson boiler
Working pressure 8 bar
Evaporation 1700 kg/h

welded construction and are available in a wide range of sizes varying in capacity from 1700 kg/h to 15 000 kg/h with corresponding shell diameters of 2200 mm to 4600 mm and pressures up to 10.5 bar. Single furnaces are incorporated in the design of the boilers at the lower end of the range and double furnaces are fitted to the larger boilers. The smallest model has been fitted in a series of fast refrigerated cargo ships built recently and supplies steam for all auxiliary purposes. This type of boiler is shown in Figure 3.11.

The principle of the Capus boiler has been adopted in the design of one of the modern packaged boilers of the 'Steambloc' range and this is shown in Figure 3.21.

Dry back multi-tubular boilers

A large number of dry back multi-tubular or 'Economic' boilers, having two or three corrugated furnaces connecting with a single common combustion chamber of brickwork enclosed in a mild steel casing, have been constructed during the last fifty years. Because of their simplified construction they have proved popular for supplying steam for auxiliary and non-essential services aboard medium sized tankers of the older type and also on cargo motorships, where steam winches are fitted for cargo handling purposes. These boilers are designed to have evaporation rates comparable with similar sized Scotch boilers but are not fitted with superheaters, working pressures are usually restricted to about 12 bar.

In appearance, these boilers are very similar to the Howden-Johnson boiler if the superheaters and circulating tubes in the combustion chamber of the latter type are disregarded. Whereas, in the case of Scotch boilers it is usual to find the diameter exceeding the overall length, dry back boilers are designed with the length exceeding the diameter in the ratio of about 3:2.

So far, in this chapter, the boilers described and reviewed have been of large capacity tank type where lengths of 6 m or more with corresponding diameters are not uncommon. Such boilers, until recently, were used for generating steam for both main propulsion and auxiliary purposes. Since about 1950, however, the tendency has been for most ships to be propelled by heavy oil engines with electrically driven auxiliaries, as a result of which large quantities of low pressure steam are no longer required, except perhaps on tankers where cargo heating remains a fundamental requisite.

However, now that high viscosity heavy oil has been established as the most economic fuel for marine internal combustion engines, a limited amount of low pressure steam has become an essential requirement on practically all motor ships — not only for heating the fuel, but also for domestic and ancillary services. Thus, the large capacity tank type boiler has become almost obsolete, being replaced in tankers by water tube boilers, often of the double evaporation type where quantities of low pressure steam are required.

For cargo motor ships, the manufacturers have introduced a new generation of small horizontal boilers and to some extent, such boilers appear to be replacing the more conventional vertical type of auxiliary boiler. The most recent development in the field of small horizontal boilers has been the adoption of the 'Packaged' boiler for marine use, this has proved to be particularly suitable where a high degree of automation has been required.

A 'Packaged' boiler is a complete steam generating unit comprising boiler and all items of ancillary equipment, all selectively chosen, fitted and assembled, mounted on a common base and works tested before despatch. The important factor is that each component is incorporated by the manufacturer into an overall design, thus, each is of proper and adequate capacity and quality for its specific function, thereby eliminating the 'hit and miss' arrangements which have, unfortunately, predominated in a great many smaller to medium sized boiler installations over the years.

'Packaged' boilers are available for immediate use once they are fastened down to the ship's structure and connected to the various services such as fuel, water, compressed air and electric power supplies and also, of course, to their flue gas vents and the ship's steam range. They are obtainable in capacities up to about 15 000 kg/h and are designed for pressures up to 17.2 bar.

The following boilers of the horizontal return tube tank type are typical of those found at sea today in use for supplying auxiliary and domestic services. Most of these boilers may be obtained 'Packaged'.

Cochran 'Chieftain' and 'Wee Chieftain' range

A cut-away view of the Cochran 'Chieftain' boiler is shown in Figure 3.12. This is a three pass semi-wet back design of packaged boiler which has a large heating surface in relationship to its volume. It is claimed that the boiler is exceptionally efficient.

This boiler is made in a wide range of sizes varying in output from about 2000 kg/h to about 15 000 kg/h with working presures up to 17.2 bar. In the larger sizes the boiler is equipped with twin furnaces. Overall dimensions of these packaged units extend from 1753 mm

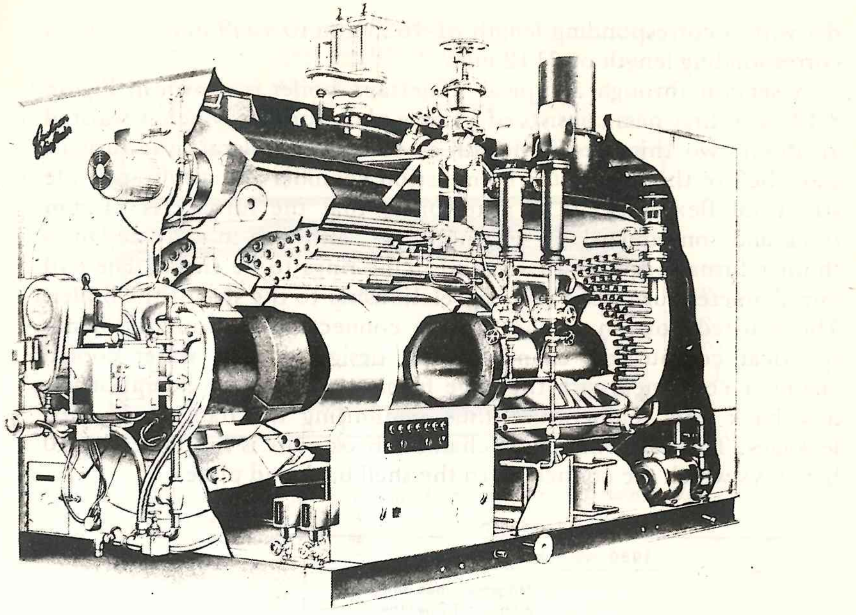


Figure 3.12 Cochran Chieftain boiler

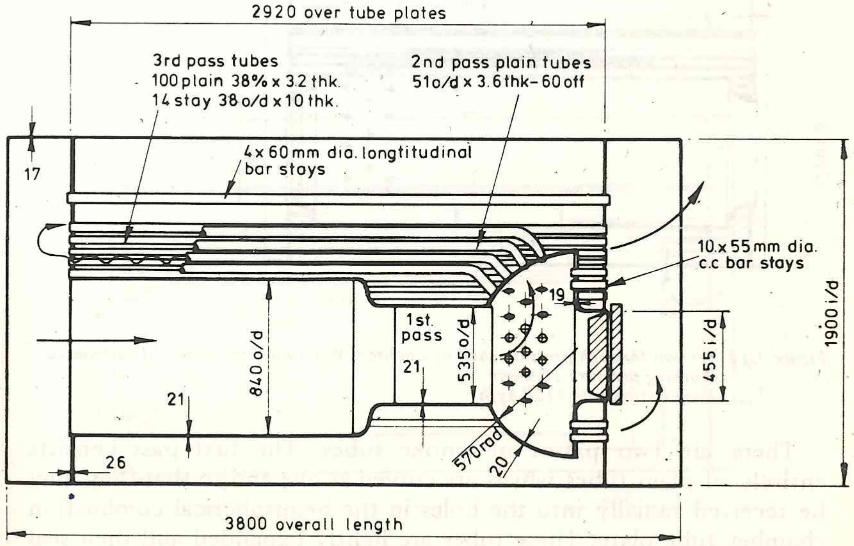


Figure 3.13 Section through pressure shell of Cochran 'Chieftain' boiler.
Working pressure 17.2 bar
Evaporation 3068 kg/h

dia with a corresponding length of 4623 mm to 4039 mm dia with a corresponding length of 7112 mm.

A section through a typical 'Chieftain' boiler is shown in Figure 3.13. The first pass consists of a single plain furnace which is waisted at about two thirds of its length in order to accelerate the furnace gases before they enter the combustion chamber and also to provide structural flexibility. It is noteworthy that the furnace is 21 mm thick and consequently is self supporting although in early designs a thinner furnace required two reinforcing rings to be fitted. The 840 mm diameter furnace is large in relationship to the size of the boiler. The waisted portion of the furnace connects with a unique hemispherical combustion chamber. The design of this water cooled chamber combined with the large furnace achieves an exceptionally low back end temperature thus minimising the dangers of tube leakages. The flat combustion chamber back plate is supported by 10 bar stays which are connected to the shell back end plate.

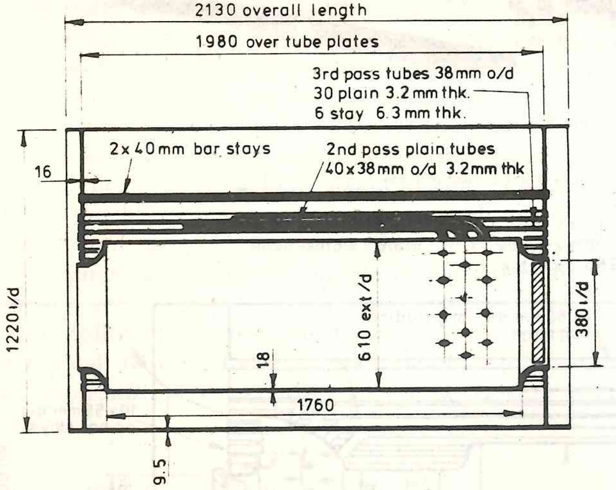


Figure 3.14 Section through pressure shell of Cochran 'Wee Chieftain' boiler (1220mm i.d.)
Working pressure 10.4 bar
Evaporation rate 1120 kg/h

There are two passes of smoke tubes. The first pass consists entirely of plain tubes which are curved at one end so that they may be received radially into the holes in the hemispherical combustion chamber tube plate. These tubes are lightly expanded and then seal welded at their combustion chamber ends whilst at the front tube plate they are attached by expanding only.

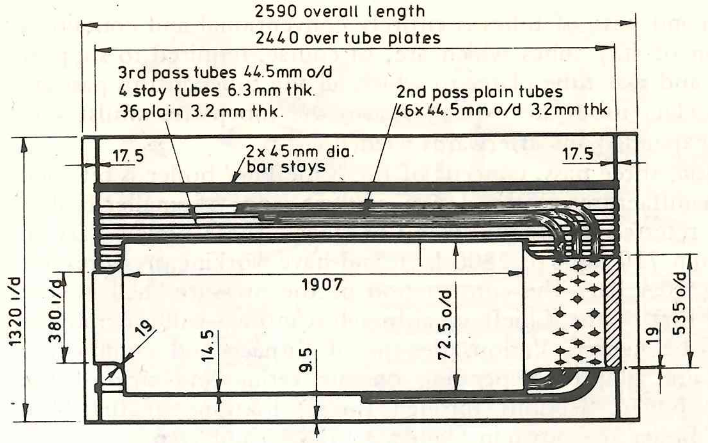


Figure 3.15 Section through pressure shell of Cochran 'Wee Chieftain' boiler (1320mm i.d.)
Working pressure 10.4 bar
Evaporation rate 2000 kg/h

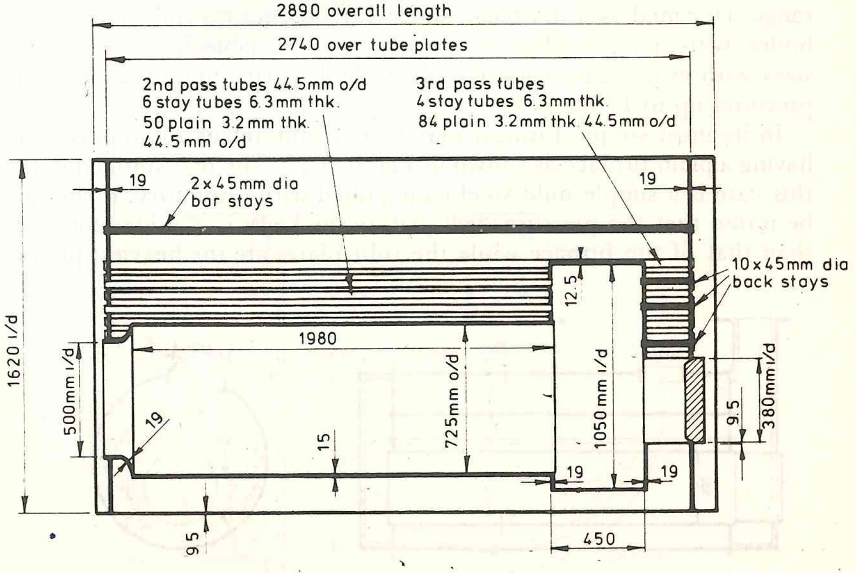


Figure 3.16 Section through pressure shell of Cochran 'Wee Chieftain' boiler (1620mm i.d.)
Working pressure 10.4 bar
Evaporation rate 2800 kg/h

The second pass of tubes is entirely conventional and contains a proportion of stay tubes which are, of course, required to support the front and rear tube plates to which all the tubes in this pass are attached. Plain tubes are expanded into the tubeplates whilst stay tubes are expanded and afterwards welded.

The basic, three pass, concept of the 'Chieftain' boiler is retained by the manufacturer in the design of their range of smaller boilers generally referred to as the 'Wee Chieftain'. These boilers vary in output from 710 kg/h to 2800 kg/h and have working pressures not exceeding 10.4 bar. The construction of the pressure shell is very similar to that of the 'Chieftain' although scantlings will generally be found to be lighter. Various designs of furnace and combustion chamber are adopted depending on the rating and size of the particular boiler. Sections through three variations of the 'Wee Chieftain' boiler are shown in Figures 3.14, 3.15 and 3.16.

The 'Steambloc' boiler

Another well known type of 'Packaged' boiler is the 'Steambloc' range. Designed as a dry-back, single furnace, return tube horizontal boiler with a high efficiency rating, it is available in a variety of sizes with evaporative capacities from 590 to 10 000 kg/h and steam pressures up to 17 bar.

In its most simple form, it may be encountered as a two-pass unit having a plain furnace as shown in Figure 3.17. The rear smokebox in this case is a simple mild steel casing lined with refractory. It should be noted that the pressure shell plating thickness is considerably less than that of the furnace while the tube plates are the heaviest plates

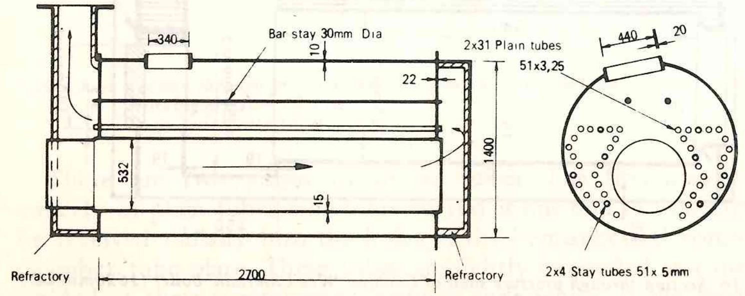


Figure 3.17 *'Steambloc' 200 boiler*
Working pressure 7.8 bar

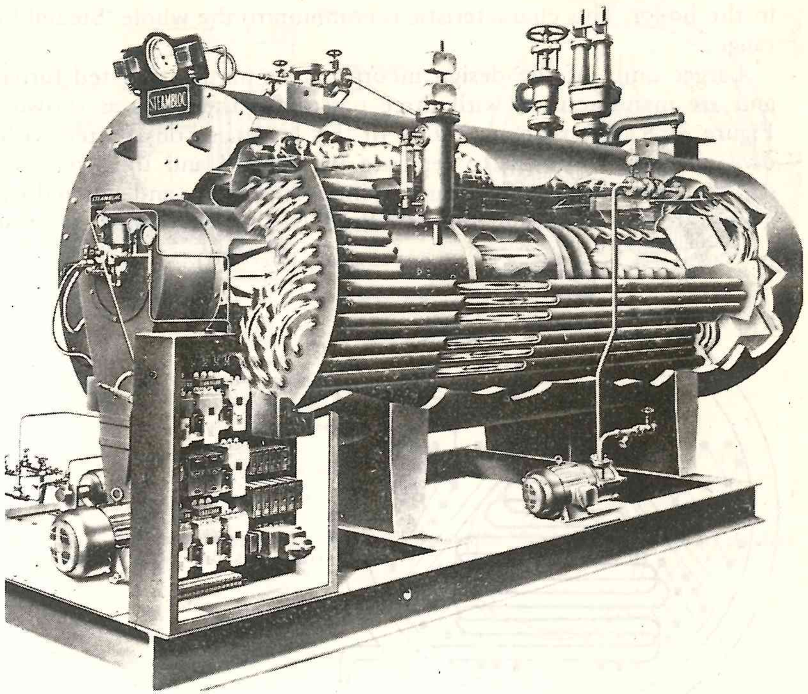


Figure 3.18 *'Steambloc' packaged boiler*
This is the land version which forms the basis of the marine unit (Babcock & Wilcox (Ltd)

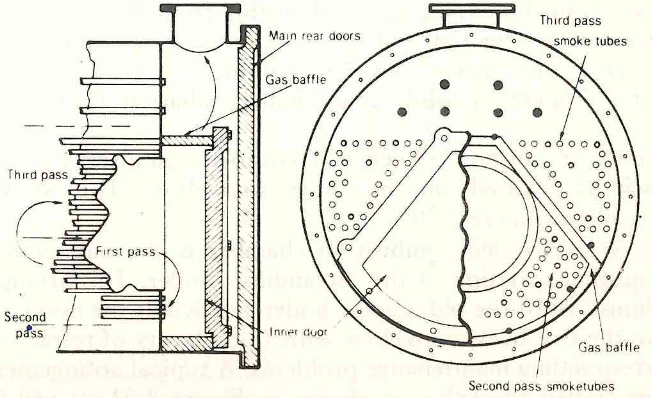


Figure 3.19 *Rear smokebox of 'Steambloc' 3-pass boiler showing patent twin rear doors*

in the boiler. This characteristic is common to the whole 'Steambloc' range.

Larger units of the design incorporate a part corrugated furnace and are manufactured with three passes for the gases as shown in Figure 3.18. The rear smokebox of this boiler is constructed with a division wall or baffle to separate the second and third passes of smoke tubes. This baffle forms an inner smokebox and is fitted with a separate door to completely seal the flue gases which have traversed the first pass, from the cooler gases exhausting from the third pass. The arrangement is depicted in Figure 3.19 which also shows the outer main door. This patent 'Twin rear door' is heavily insulated and facilitates inspection while maintaining radiation losses at a minimum.

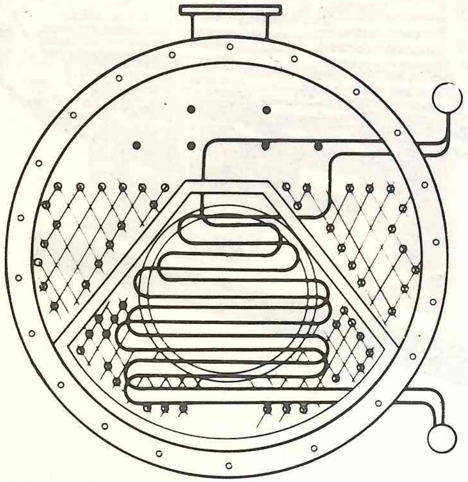
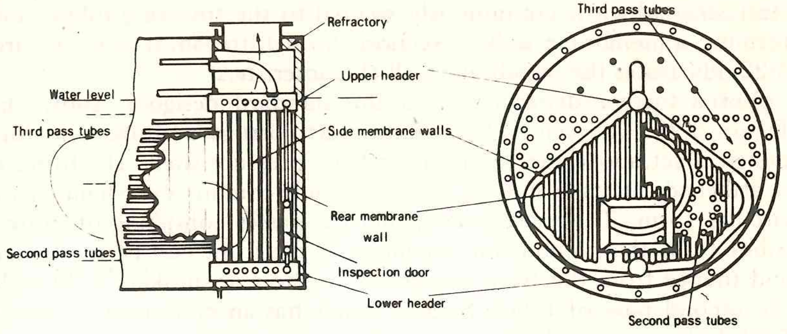


Figure 3.20 'Steambloc' boiler showing arrangement of integral superheater at end of first pass

The 'Steambloc' can be designed to incorporate an integral superheater which is located in the inner smokebox. This shown diagrammatically in Figure 3.20.

A unique water cooled combustion chamber is the outstanding feature of another variation of the 'Steambloc' boiler. This arrangement is reminiscent of the old 'Capus' boiler and avoids the necessity of insulating the dry back smokebox with thick layers of refractory with its corresponding maintenance problems. A typical arrangement of the water cooled smokebox is shown in Figure 3.21. It will be noted that the space between each water tube is fitted with a mild



Working pressure	9.8 bar
Length over tubeplates	3400 mm
Thickness of tubeplates	23 mm
Outside diameter of shell	2300 mm
Thickness of shell	14 mm
Outside diameter of furnace	1000 mm
Thickness of furnace	12 mm

Figure 3.21 Section through rear smokebox of 'Steambloc' Senior Type 700 boiler showing arrangement of water walls and heaters

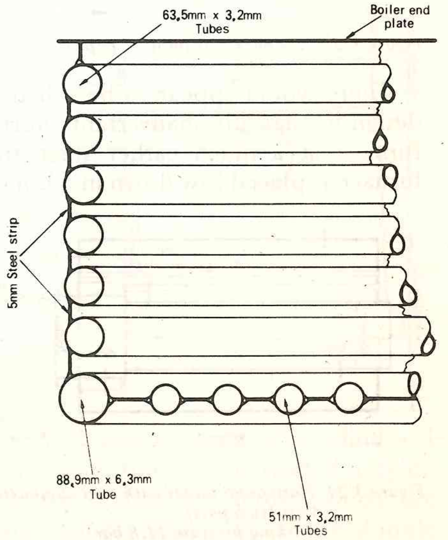


Figure 3.22 Details of 'Steambloc' water walls showing attachment of steel strip to tubes to form membrane wall

steel strip which is continuously welded to the touching tubes thus forming a membrane wall. A section through the smokebox, Figure 3.22, illustrates the membrane wall characteristics.

Yet a further departure from the standard design is shown in Figure 3.23. The centre line of the part corrugated furnace in this design is set above the centre line of the pressure shell. The furnace is attached, at its rear end, to a wet-back combustion chamber of circular form. There are two further gas passes consisting of smoke tubes from the combustion chamber to the front end of the boiler and thence from the front smokebox to the rear smokebox through the second pass of tubes. Such a boiler has an evaporation rate of 5000 kg/h and a working pressure of 10 bar.

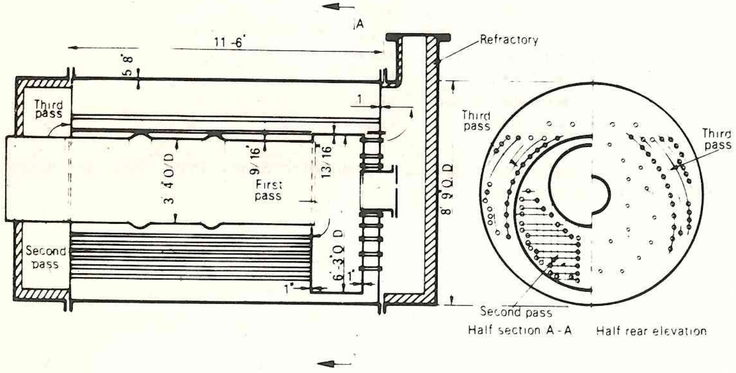


Figure 3.23 Wet back 'Steambloc' Type 480 boiler

There would appear to be a distinct disadvantage in this particular design in that any inadvertant shortage of water would lay bare the furnace at a much earlier stage than would be the case where a furnace is placed low down in a boiler.

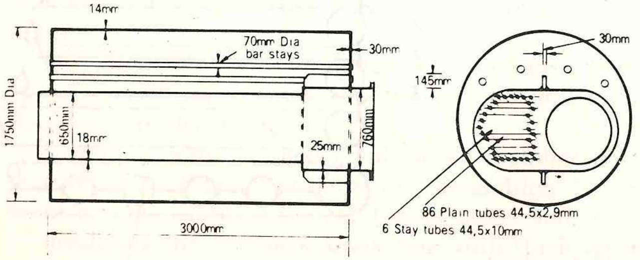


Figure 3.24 Horizontal boiler with oval combustion chamber manufactured by Blohm and Voss (two pass)
Working pressure 11.8 bar

Most of the other small to medium sized horizontal boilers likely to be found aboard ships today are of similar designs to those described above. One unusual boiler of continental manufacture has an offset plain furnace incorporating an oval shaped combustion chamber and is shown in Figure 3.24.

VERTICAL BOILERS

Cross-tube boiler

This boiler which is commonly used ashore for almost any purpose where a small boiler is required was, up to about thirty years ago often encountered aboard ship. It was the forerunner of the more efficient types now manufactured and was of relatively simple riveted construction.

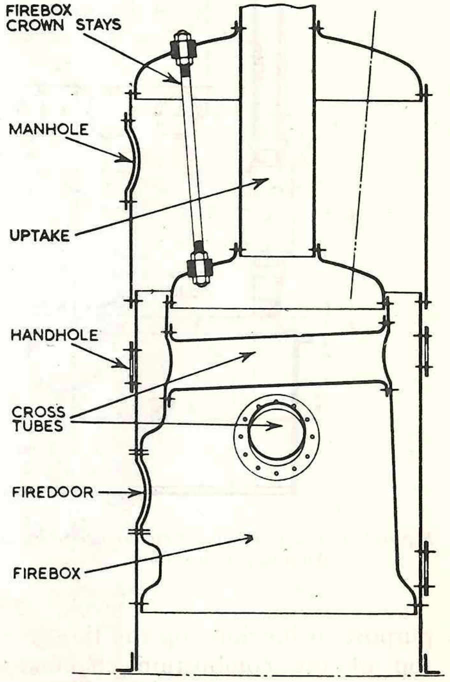


Figure 3.25 Vertical cross tube boiler

The boiler is shown in Figure 3.25 and consists of a cylindrical shell placed with its axis vertical. Inside this shell is riveted a cylindrical or slightly conical combustion chamber across which are placed two or three large water tubes. These serve the double

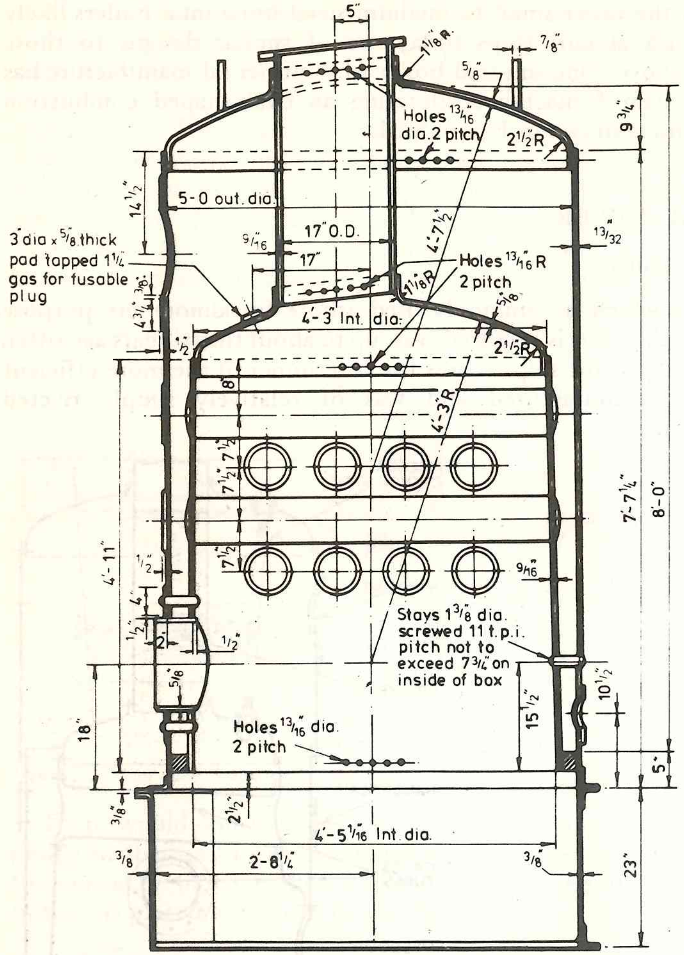


Figure 3.26 Cross-tube boiler manufactured by Charles D. Holmes & Co. Ltd Working pressure 7 bar

purpose of breaking up the flue gases and absorbing their heat. The top of the combustion chamber is flat or slightly dished and therefore requires to be stayed to the top of the outer shell. Rigidity is given to the bottom of the boiler by the double thickness of metal formed by the junction of the combustion chamber and shell and just below this, by the provision of an angle ring on which the boiler sits.

A more recent development of the vertical cross-tube boiler is shown in Figure 3.26 and incorporates up to sixteen cross tubes. This boiler may still be found in such ships as diesel engined trawlers and has a working pressure of 7 bar.

Cochran boiler

Originally, this boiler had a hemispherical furnace chamber attached at its circumference by means of an ogee ring to the shell bottom (see Figures 3.27a and b). The products of combustion passed from this chamber, through a throat, into a brick-lined combustion

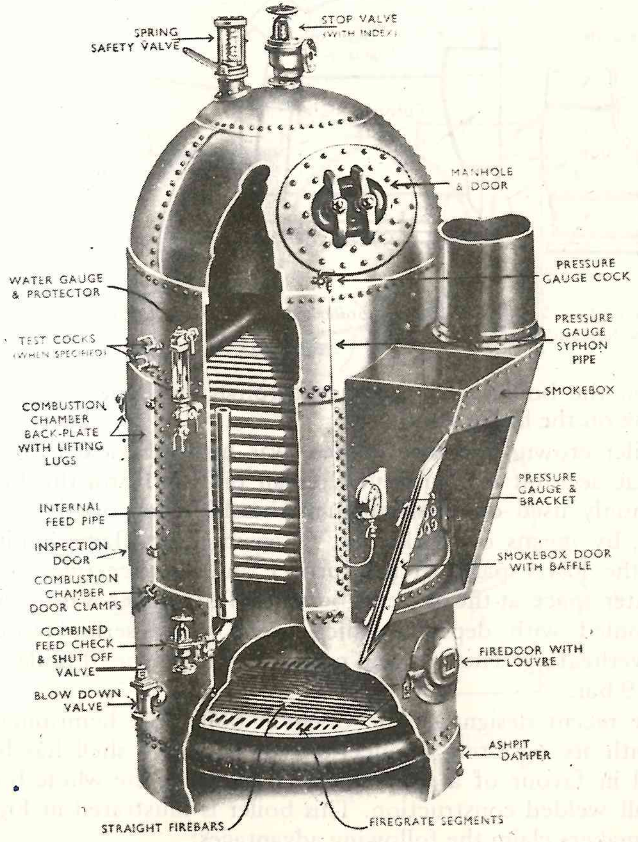


Figure 3.27(a) Sectional view of a Cochran vertical boiler

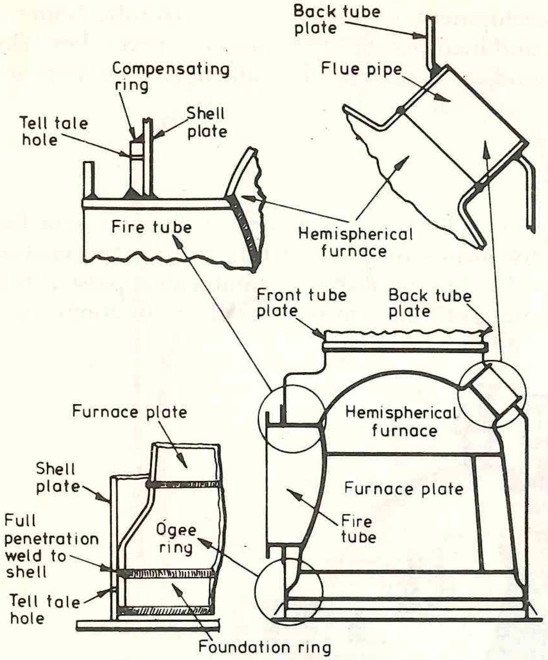


Figure 3.27(b) Part of Cochran vertical type boiler with hemispherical furnace showing welded construction and attachment to shell.

chamber on the boiler back and then through the boiler tubes into a smokebox on the boiler front.

The boiler crown, like the furnace, was hemispherical in shape, and on that account was unstayed. In an oil-fired form this boiler was commonly used on diesel-engined vessels. When oil fired, care was taken, by means of brickwork, to avoid direct flame impingement on the lower parts of the furnace and its ogee ring, as the narrow water space at the extreme bottom of the boiler was liable to become fouled with deposits which could cause serious trouble through overheating. The working pressure of this type of boiler was usually 7–9 bar.

In more recent designs of the Cochran boiler the hemispherical furnace with its ogee-ring connection to the lower shell has been abandoned in favour of a fully spherical furnace, the whole boiler being of all welded construction. This boiler is illustrated in Figure 3.28. The makers claim the following advantages:

1. Complete internal accessibility for cleaning and examination.

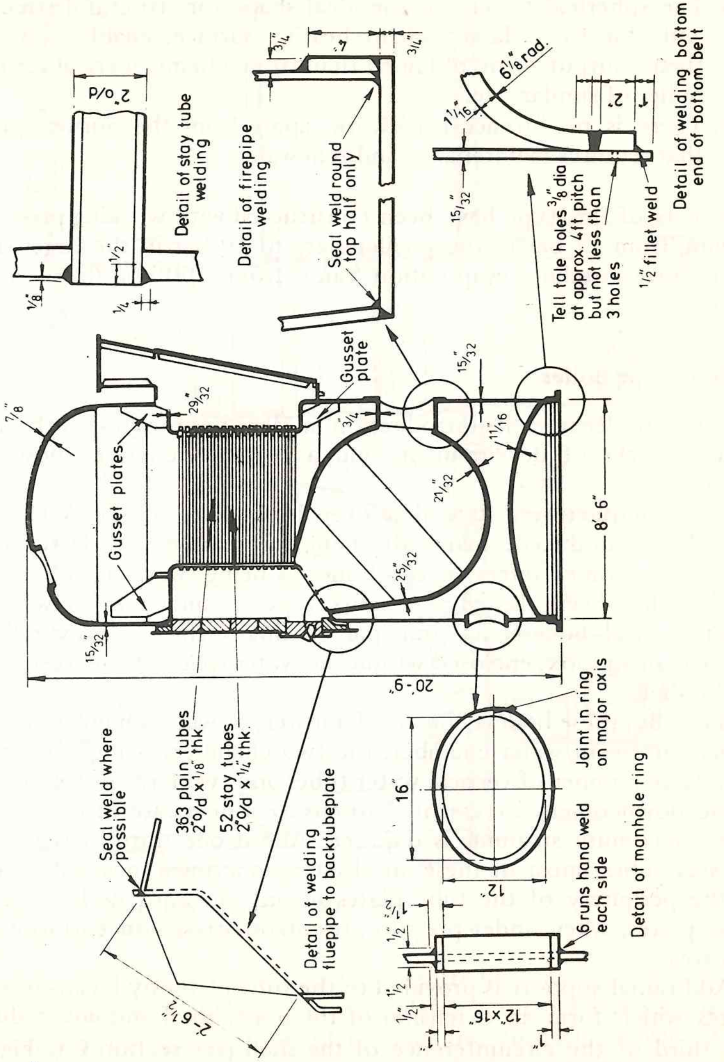


Figure 3.28 A recent type of Cochran spheroid boiler

2. Tube cleaning and external maintenance are simple.
3. No surfaces within the boiler, above water level, are exposed to hot gas temperature.
4. The spherical furnace is the ideal shape for structural strength and, due to its large radiant heating surface, enables a higher steam output to be obtained than from a hemispherical furnace boiler of similar size.
5. There is no furnace brickwork, apart from the burner quarls that requires maintenance and renewal.

Boilers of this type have been constructed with working pressures varying from 17 bar in the smaller sizes to 10 bar in the larger sizes with corresponding evaporation rates from 1000 kg/h to 4550 kg/h.

Aalborg type boiler

The AQ3 boiler since its introduction in 1947 has progressed through various stages of development, and a current design is shown in Figure 3.29.

The manufacturers state that over 1200 units of the AQ3 type have been produced, many of them for marine use. Descriptive matter sometimes refers to this boiler as being 'water tube', in this book it has been classed as a 'tank type' as, in common with all other vertical boilers, its principal heating surface is a cylindrical furnace, or firebox, enclosed within the water space of the lower part of the shell.

Basically, these boilers consist of a lower, or water chamber and an upper, or steam/water chamber, the two chambers being connected by a large number of vertical water tubes and two large downcomers. These downcomers are essential to ensure a high rate of circulation when maximum steaming is required. About one third of the tubes are stay tubes, most of these are situated in a ring as near as possible to the periphery of the tube plates as any outward deflections of these plates, when under pressure, results in stress concentrations in this area.

Additional support is provided to the tube plates by means of stay plates which form an extension of the boiler shell and cover about one third of the circumference of the shell (see section C-C Figure 3.30).

The flue gases ascend through the elliptical flue pipe into the smokebox where, by means of baffle plates attached to the first row of tubes they are dispersed evenly throughout the smokebox before escaping to atmosphere by means of the usual uptake.

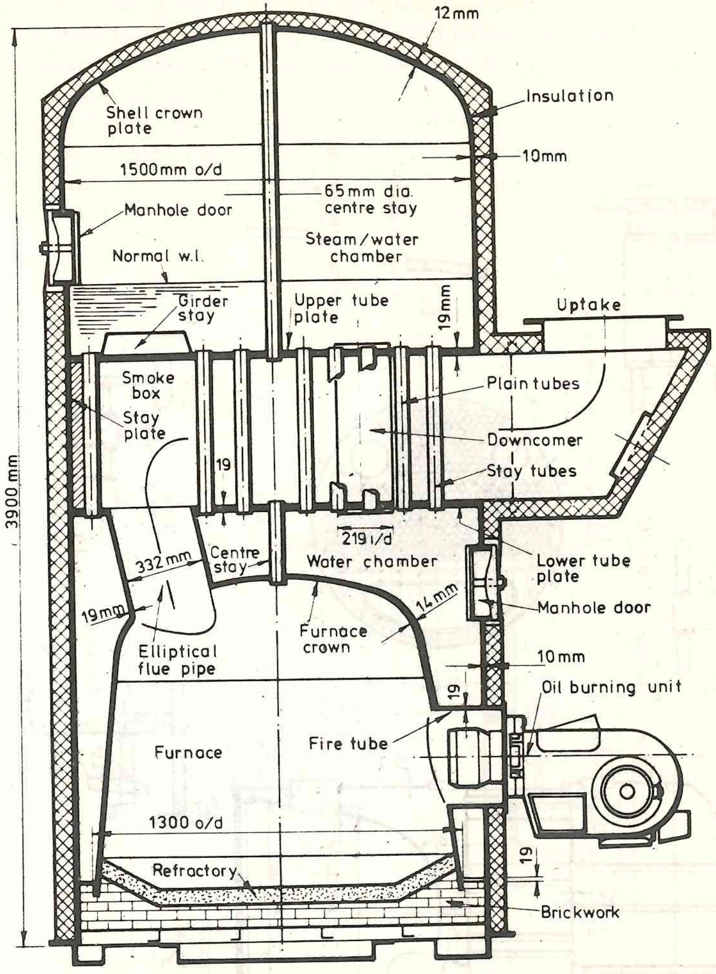


Figure 3.29 Type AQ3 Aalborg vertical boiler Working pressure 7 bar

The boiler is fitted with a large centre bar stay between the upper tube plate and the shell crown plate, a further bar stay is fitted between the lower tube plate and the furnace crown. It is of relatively simple construction and with the introduction in recent years of unflanged tube plates (see Figure 3.29), only the shell crown plate and the furnace crown plate require to be formed. As both these plates can now be formed cold, this operation presents no difficulty.

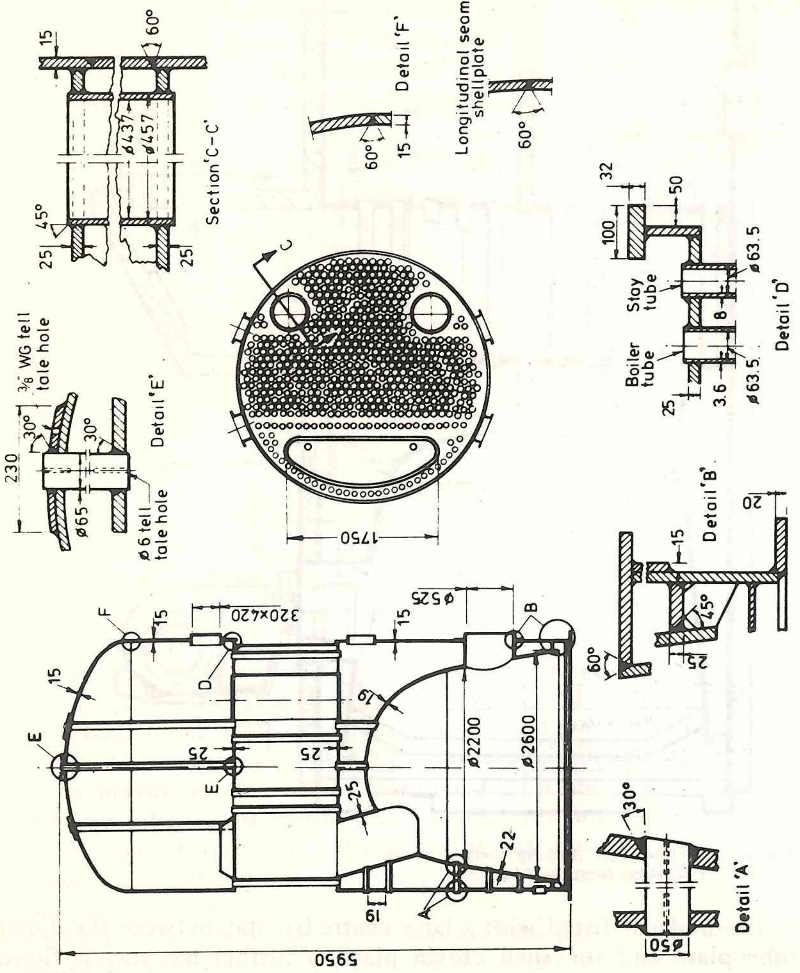


Figure 3.30 Plan and section veins of the Aalborg AQ3 boiler

The boiler is of all welded construction and, as the shell seams are subjected to 100% radiographic examination and as the shell plate thickness is below 20 mm, no final heat treatment of the complete structure is required.

AQ3 boilers are manufactured in a range of sizes varying from 800 kg/h to 12 500 kg/h in output with working pressures of about 7.5 bar being in general use. However, the manufacturers advertise this model for pressures up to 25 bar dependent on the boiler size. In

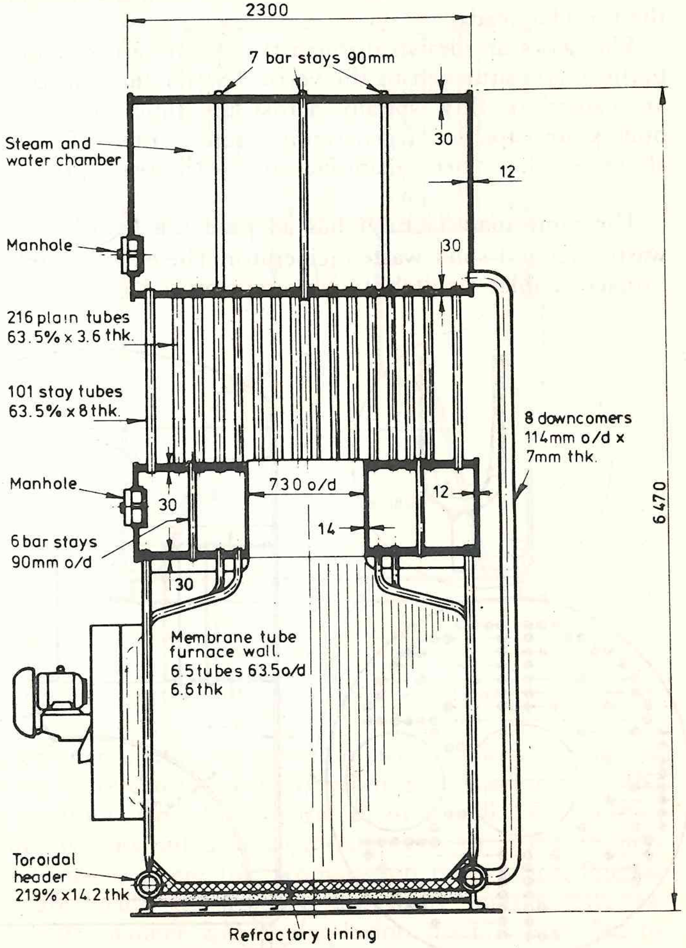


Figure 3.31 Type AQ9 Aalborg vertical boiler
Working pressure 9 bar

the larger sizes, the conical section of the furnace, together with the outer plating of the flue pipe are stayed to the boiler shell for support (see Figure 3.30).

The most recent development of this type of boiler is the AQ9 (Figure 3.31). In this boiler the furnace is surrounded by a closely placed row of membrane wall tubes which are connected at their lower ends to a toroidal header. In order to achieve adequate circulation and thus avoid overheating of the furnace tubes, large bore downcomer tubes are provided between the steam chamber and the toroidal header.

Flue gases are drawn through the centre uptake and, by means of baffle plates attached to the vertical water tubes in the smoke box, are caused to flow spirally across the tubes to the uptake. Such boilers are capable of generating steam at rates of 15 000 kg/h and above and have been manufactured with steam pressures up to 16 bar.

The same manufacturer has adapted the AQ3 boiler for use as a waste fuel and solid waste incinerator. The enlarged, refractory lined furnace enables a suitably high temperature to be maintained for the combustion of waste matter and sludge with a oil/water mixture up to 50% water.

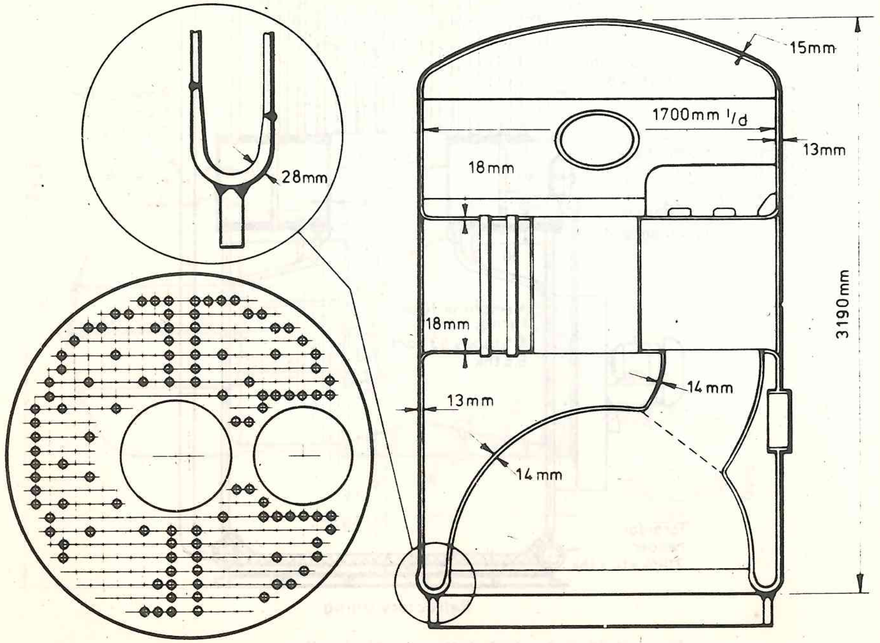


Figure 3.32 Hitachi Zosen Type HV boiler
Working pressure 7 bar

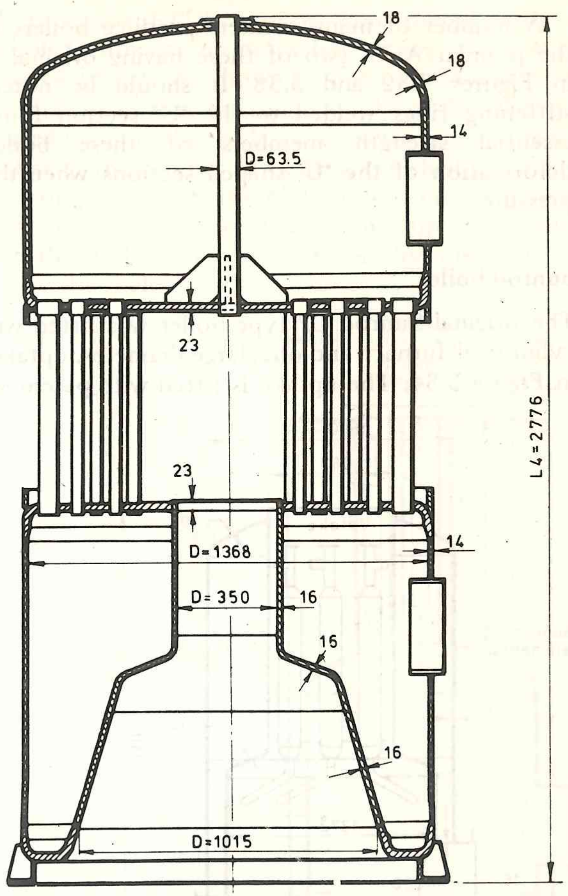


Figure 3.33 Helsingorskibs vertical boiler
Working pressure 7 bar

A special chamber is attached to the furnace in which solid matter such as kitchen waste can be gasified by hot gases passing from the furnace through the bottom holes in the division wall. The resulting gases subsequently pass out through the upper holes in the division wall into the furnace, where final combustion takes place. Special arrangements are made for feeding the waste matter into the chamber in a safe manner and an explosion door is provided to prevent damage to the boiler in the event of a gas explosion in the chamber. Arrangements can also be made for burning sewage.

A number of manufacturers produce boilers of similar design to the popular AQ3, two of these having original features, are shown in Figures 3.32 and 3.33. It should be noted that the vertical stiffening rings welded to the 'U' section foundation rings form essential strength members of these boilers by restricting deformation of the 'U' shaped sections when the boilers are under pressure.

Sunrod boiler

The original Sunrod CP type boiler was fitted with a dry bottomed cylindrical furnace and one, large diameter, uptake. This is illustrated in Figure 3.34. The uptake is fitted with patent water tube elements which are claimed by the manufacturer to increase the efficiency of the boiler and at the same time enable a compact design to be achieved.

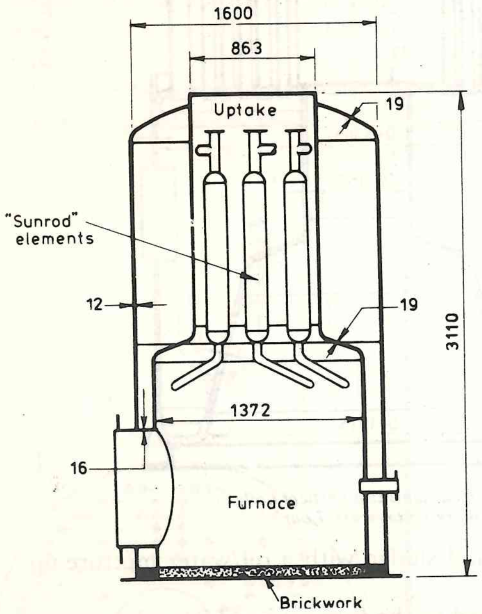


Figure 3.34 The early Sunrod Type CP15 boiler
Working pressure 7 bar
Evaporation 1500 kg/h

The CPD type and the CPDB type of boiler are further developments of the CP type. Whereas the CPD retains the dry bottomed furnace of the CP type, the CPDB type is constructed with a completely water cooled furnace, no refractory lining whatsoever being required. These two types are shown in Figure 3.35 and 3.36 respectively and it will be seen that the single uptake of the CP type boiler has been replaced by a number of large diameter uptake tubes. It should be noted that in these types of boilers, the shell plating is relatively thin when compared with the furnace and crown plates. Such boiler shells are sometimes referred to as pressure envelopes, the total weight of the full boiler being taken by the furnace structure rather than by the shell.

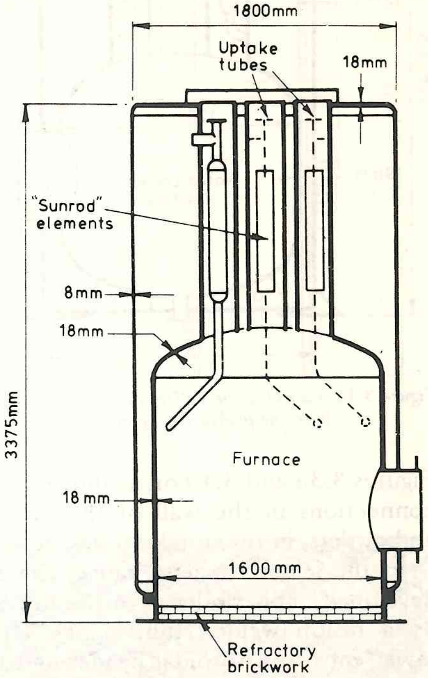


Figure 3.35 Sunrod Type CPD25 boiler
Working pressure 7 bar
Evaporation 2500 kg/h

The unique Sunrod patent element is shown in Figures 3.37, 3.38 and 3.39 and consists of a sturdy 168 mm diameter tube the outside surface of which is covered with a very large number of steel pins or rods. These pins are welded on to the tube by a special automatic welding machine to obtain perfect fusion between them and the surface of the tube, thus ensuring maximum heat conduction.

These tubes are fitted within the uptake tubes either, with both inlets and outlets situated in the walls of the uptake tubes as in

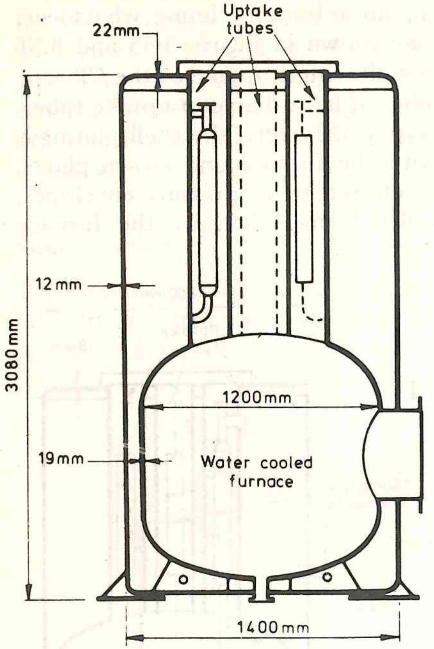


Figure 3.36 Sunrod Type CPDB 12 boiler Working pressure 8 kg/cm²

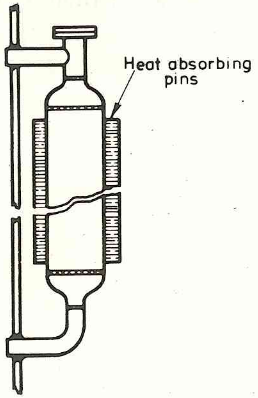


Figure 3.37 The Sunrod patent element

Figures 3.36 and 3.40 or, as shown in Figures 3.34 and 3.35, with inlet connections in the wall of the furnace just below the crown plate and outlets, in the uptake tubes.

In the larger capacity range, the Sunrod marine boiler has been developed. This boiler incorporates a water cooled furnace formed by a fusion welded tube panel. The tubes are connected at their lower ends to a toroidal header and their upper ends are attached to the steam chamber. A number of large downcomers ensures good circulation (see Figure 3.40). The fire tube is water cooled by a separate header and the number of uptake tubes increased accordingly. Each of the uptake tubes contains a Sunrod element. The CPH 140 boiler, for instance, has a total of 39 uptake tubes.

Sunrod boilers are manufactured in a range of sizes varying in capacity from 700 kg/h to 35 000 kg/h and in pressures up to 18 bar. Two such boilers, each having a capacity of 30 000 kg/h and a pressure of 18 bar, were recently installed in a 120.000 DWT OBO carrier to supply all steam requirements including the large turbine driven cargo pumps and cargo heating services.

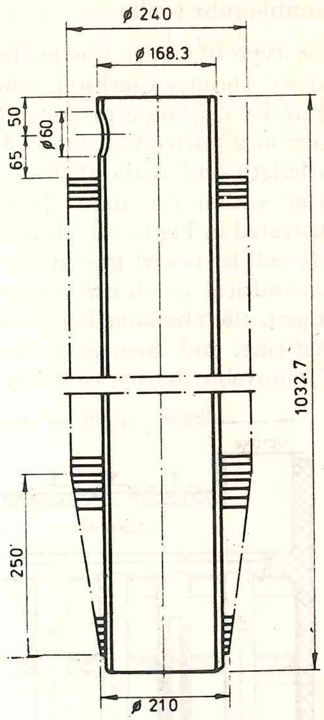


Figure 3.38 Sunrod element tube

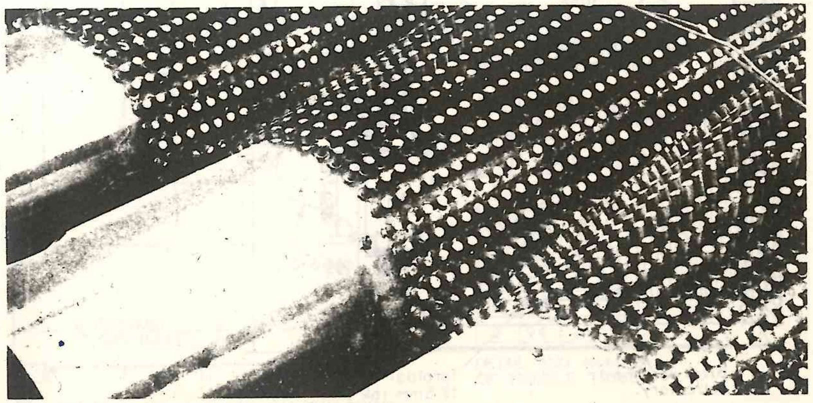


Figure 3.39 Detail of Sunrod tube studs

Thimble tube boiler

This type of boiler was evolved as the result of experiments carried out by Thomas Clarkson, who found that it was possible to generate steam by causing a prolonged series of spasmodic ebullitions to take place in a horizontal, tapered, thimble tube, heated externally along its length and without any means being applied for circulating the water within the tube. Typical designs of thimble-tube boiler are illustrated in Figures 3.41(a) and (b).

It will be noted that the boiler consists of an outer shell enclosing a cylindrical combustion chamber into which all the thimble tubes project, the chamber being attached to the shell bottom through an ogee ring, and through a dished crown and uptake to the shell top. A removable baffle is fitted in the space between the tube outer ends, which is used to control the path of the gases around the tubes. It is claimed that these boilers will operate for prolonged periods without internal cleaning.

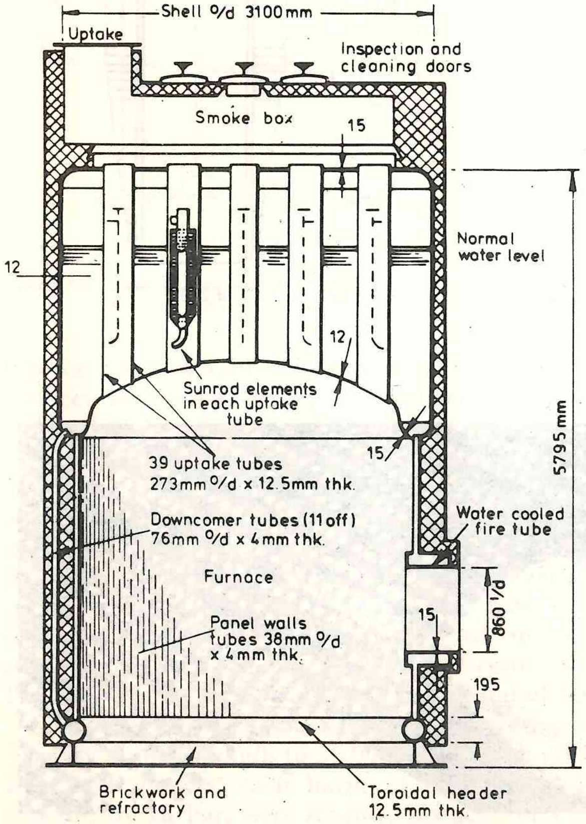


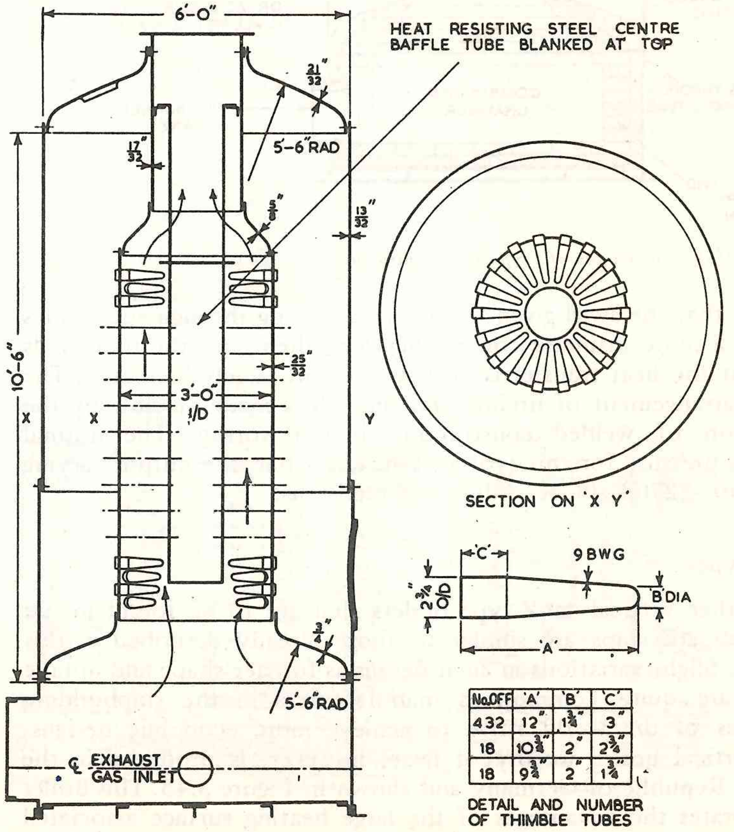
Figure 3.40 *Large capacity Sunrod boiler, Type CPH140*
Working pressure 7.5 bar
Evaporation 1400 kg/h

In certain types, in view of the nature of the tube attachment, i.e. one end only, oily deposits, if present, can be burnt off the outside when the boiler is dry, without injurious effects.

Spanner boiler

Figure 3.42 shows a boiler with all its internal parts of welded construction and with fire tubes of a unique type.

The special section of tube is maintained along each tube length, except at the ends, and is made to twist along the tube axis. It is



No. OFF	'A'	'B'	'C'
432	12"	1 3/4"	3"
18	10 3/4"	2"	2 3/4"
18	9 3/4"	2"	1 3/4"

Figure 3.41(a) *Clarkson thimble-tube boiler*
Working pressure 7 bar
Hydraulic test pressure 14 bar
Total heating surface 28m²

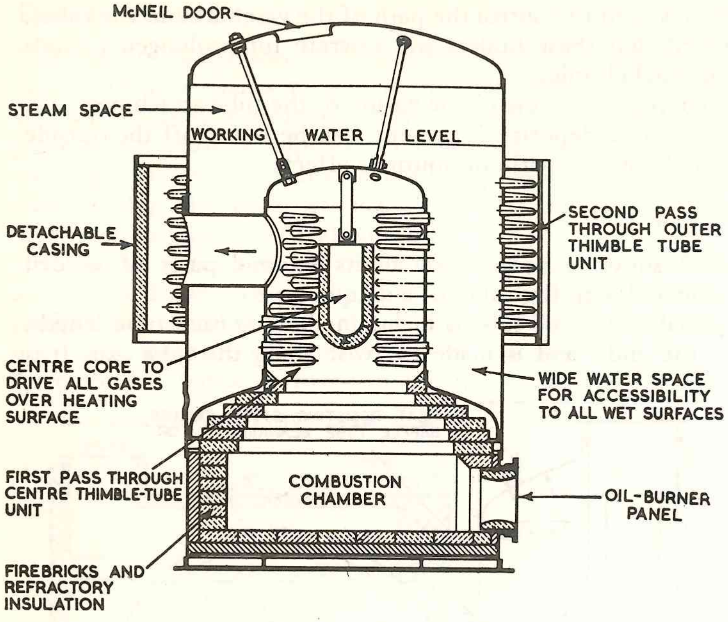


Figure 3.41(b) Cross-section of a typical concentric boiler

claimed that the swirl given to the gases passing through such tubes ensures a more intimate contact between them and the tube walls and that the heat transfer is on that account largely increased. The simple arrangement of firebox and smokebox made possible by the utilization of welded construction is noteworthy. The normal working pressure for this type of boiler is 7 bar, the output varying from 450–2270 kg/h, according to dimensions.

Other types

Most other vertical tank type boilers that are to be found in use today aboard ships are similar to those already described in this chapter. Slight variations in such details as furnace shape and uptake design are quite common as manufacturers in the shipbuilding countries of the world strive to achieve more economic designs.

A vertical boiler worthy of note, however, is produced in the Federal Republic of Germany and shown in Figure 3.43. This boiler incorporates the advantages of the large heating surface associated with the Scotch type horizontal boiler, and the compactness of the Cochran type vertical boiler.

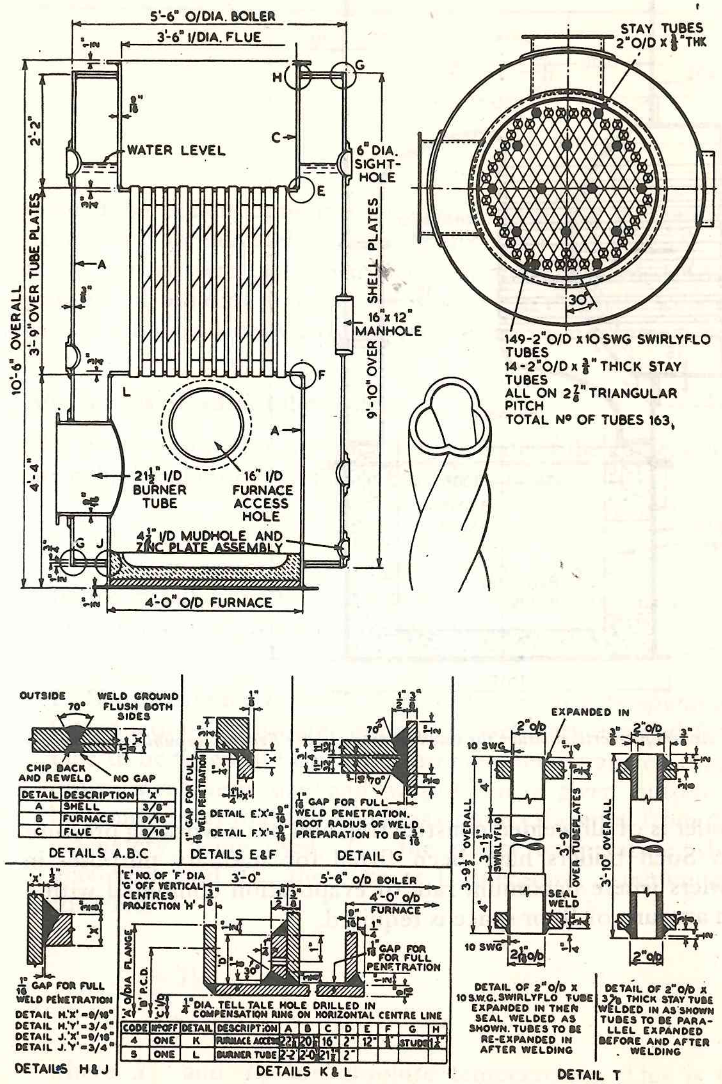


Figure 3.42 Constructional details of a Spanner oil-fired donkey boiler

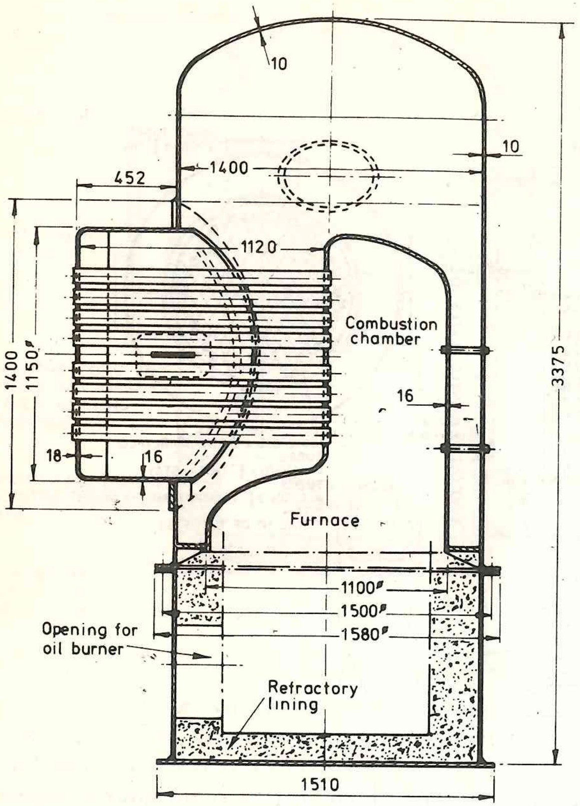


Figure 3.43 An unique vertical boiler for trawlers made in the Federal Republic of Germany

The boiler is of all welded construction and has a working pressure of 7 bar. Such boilers have been fitted for auxiliary purposes in large trawlers where maximum rate of evaporation combined with a minimum amount of floor space is required.

4 Water tube boilers

Water tube boilers came into extensive use in the mercantile marine during and immediately following the 1914–18 War. At this time many berths were laid down at Hog Island Shipyard, USA., for the purpose of building standard ships, which in the main were equipped with the Babcock & Wilcox sectional-header-type water tube boilers.

Advantages of water tube boilers

The main reasons for the adoption of water tube boilers in place of the cylindrical multi tubular or Scotch type are:

1. *Saving in weight.* The relative weight of Scotch to water tube boiler installations for equivalent heating surface area, with water at working level, is approximately 3 : 1.

2. *The possibility of using high pressures and temperatures.* The introduction of turbine propelling machinery enabled full advantage to be taken of higher pressures and temperatures, thus cutting down machinery size and weight for a given output. It may be pointed out that to obtain maximum efficiency from the steam machinery being used, T_1, the steam temperature, should be maximum and T_2, the exhaust temperature, a minimum in the equation

$$\frac{T_1 - T_2}{T_1}$$

where T_1 and T_2 are absolute temperatures. This is Carnot's Cycle for maximum efficiency. The limit of working pressure for Scotch boilers, for practical reasons, such as shell thickness (see Figure 4.1) and lack of flexibility, is 20.7 bar.

3. *Greater mechanical flexibility.* The water tube boiler not so sensitive to fluctuating pressures. The Scotch boiler with its poor circulation, especially when raising steam, is very prone to mechanical straining and subsequent grooving in its many flanged attachments. These defects do not exist in the water tube boiler with its rapid circulation and structural flexibility.

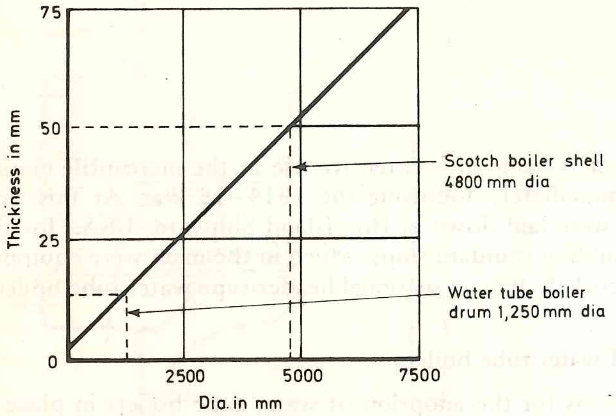


Figure 4.1 Increase of thickness with dia. of welded boiler shells or drums at 17.5 bar w.p. assuming allowable stress of 85 N/mm^2

4. *Rapid steam raising.* A normally specified time for raising steam in a water tube boiler is three or four hours from 'flash-up' to full pressure. The minimum time required will depend upon the initial temperature of the boiler and upon the necessity for avoiding damage which could occur from local overheating. In case of need this time could, with a hot boiler, be twenty minutes whereas with a Scotch-type boiler it is normally considered beneficial to extend this time to the same number of hours.

5. *Saving in space.* The good circulation and ability to withstand forcing and higher pressures have enabled high outputs to be obtained from water tube boilers of very small dimensions when compared to the Scotch type.

6. *Wider safety margin in event of explosion.* The possibility of a serious explosion is considered to be far more remote with a water tube boiler than with a Scotch boiler. In the former, tube diameters are wisely limited and drums are protected from direct radiation or flame impingement. Should a tube fail, the contents of the boiler (much smaller than the Scotch type) escape at a rate determined by the tube bore (see Figure 4.2), whereas, in the latter, serious rupture of an overheated furnace can almost instantaneously release the 30 tonne contents into the stokehold (see Figure 4.3).

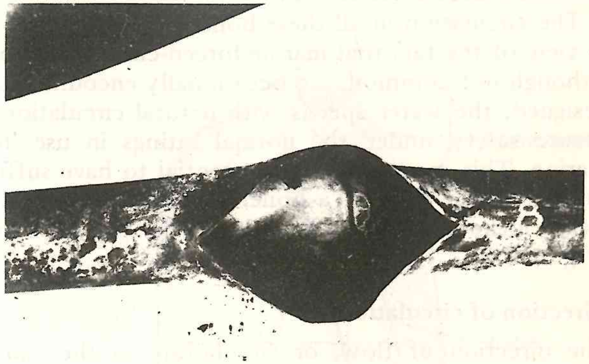


Figure 4.2 Failure of a water tube boiler tube

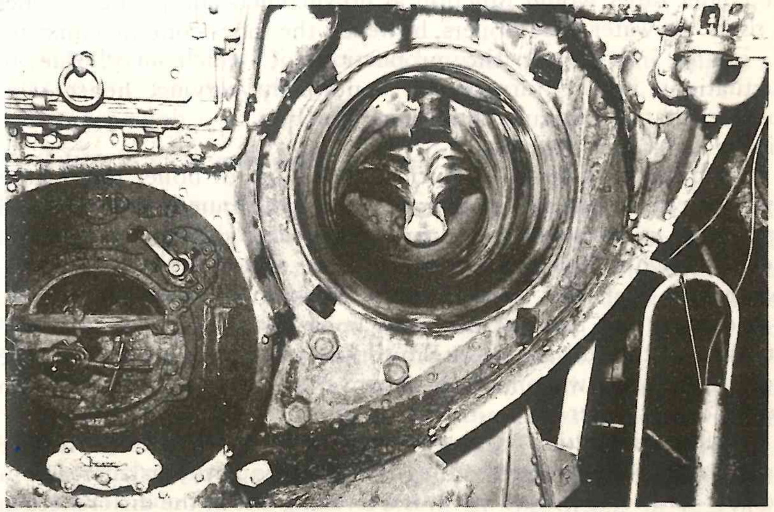


Figure 4.3 Failure of a Scotch boiler furnace

TYPES OF WATER TUBE BOILER

The most commonly encountered types of water tube boiler in everyday use are Foster Wheeler, Babcock & Wilcox, Combustion Engineering, Kawasaki and Aalborg.

It is fitting at this juncture to make reference to Yarrow boilers, for although it is doubtful whether there are many still at sea, the three and five drum types were extensively used in both admiralty and merchant service vessels.

The circulation in all these boilers is natural; this should be noted in view of the fact that marine forced-circulation boiler installations, although not common, are occasionally encountered. When properly designed, the water speeds with natural circulation are adequate to ensure safety under the normal ratings in use in the mercantile marine. This means that it is essential to have sufficient circulation through every tube in a boiler to ensure that it does not become steam locked, and consequently overheated with subsequent failure (Figure 4.2).

Direction of circulation

The direction of flow, or circulation, in the tubes of a vertical-tube type water tube boiler is dependant largely on external conditions. If the tubes contained only water at varying temperatures, it is evident that, due to difference in specific weights, the colder tubes would function as downcomers and the hotter ones as risers. In water tube boilers, however, the tubes contain a mixture of steam and water, the proportion of which may, due to fluctuations in the furnace, be continually varying, hence it is possible that a particular tube may function as a downcomer one minute and a riser the next.

In a bank of tubes of a vertical tube type of boiler the relative speed of circulation will obviously be at a maximum in the front and rear rows, as between these rows exists the greater difference in specific weights. The position of the tubes which act both as downcomer and riser will lie within the bank, their positions relative to the front and back of the bank being largely dependant on the intensity of the furnace heat. From this it will be apparent that the proportion of downcomers to risers varies according to the steam output of the boiler.

Efficient circulation is more easily obtained in a low pressure water tube boiler than in the high-pressure type, as increase in pressure and temperature involves a levelling out in the differences in specific weights of steam and water — the cause of circulation. At the higher pressures, say above 30 bar, it is usual therefore to assist the circulation by the fitting of unheated external down-comers.

Stable conditions of circulation are assisted in some types of water tube boiler by inserting the superheater between the downcomers and risers, this giving a considerable temperature difference between the two nests of tubes and between the specific weights of their contents (see Figure 4.4).

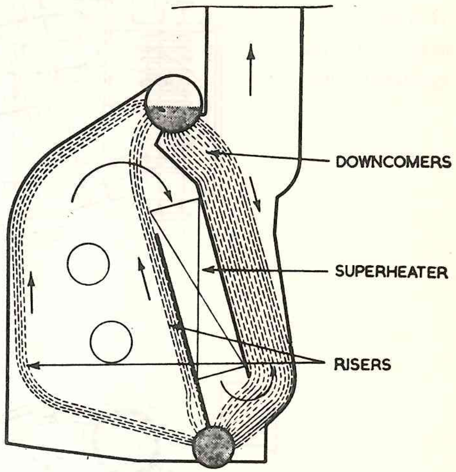


Figure 4.4 'D' type water tube boiler with superheater between downcomers and risers

Circulation in sectional header boilers

The foregoing remarks regarding circulation apply to the vertical-tube-type boilers. With the inclined-tube, sectional-header Babcock type, the circulation always follows the one path, i.e., downwards from the steam drum into the front headers and up the inclined tubes, the steam and water then rising through the rear headers and passing back to the drum by way of the return tubes.

In order that a water-level free from foam and undue ebullition may be obtained, it would appear that the hottest tubes, in which the major part of the steam is generated, should have their outlets at or above the working water-level in the steam drum and that the downcomers should leave the bottom of the drum. In practice, however, with vertical-tube boilers, this reasoning is not generally fulfilled — it would be impracticable in the case of the Yarrow boiler

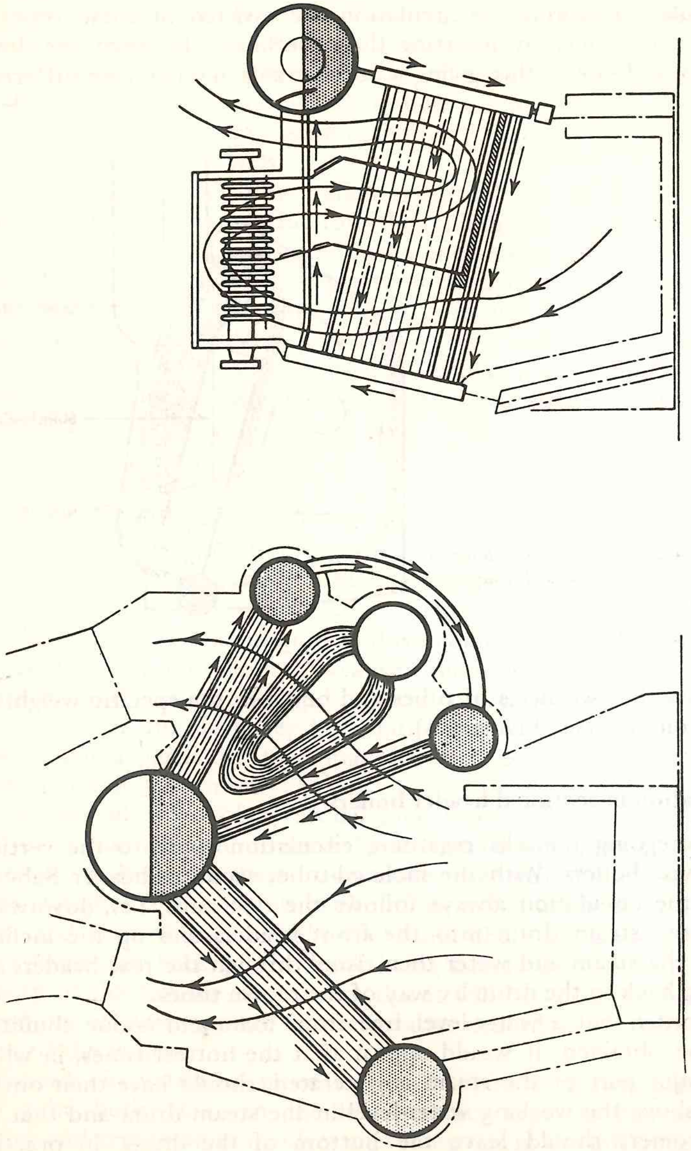


Figure 4.5 Circulation of (left) Yarrow and (right) Babcock & Wilcox sectional header boiler

with its straight tubes, as it has the reverse layout. The Babcock & Wilcox header type boiler, however, as mentioned before, does circulate in this manner (see Figure 4.5).

The question of circulation has been discussed at some length, as all water tube boilers depend upon it for their satisfactory operation.

Present-day types

The design of the main boilers depends on the type of service for which the proposed steam turbine vessel is to be used, e.g. cross channel ferries, cargo vessels, container ships, tankers and passenger liners coming into different categories.

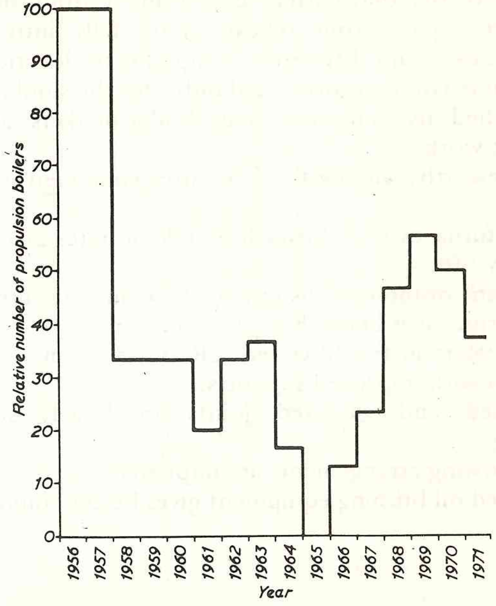


Figure 4.6 Demand for main propulsion boilers

Modern D-type boilers have generating, superheating, feed and air heating surfaces in percentage areas and positions in the boilers to suit the required operating conditions.

In the middle sixties practically all new vessels were propelled by diesel machinery (see Figure 4.6). Reliable slow speed diesel engines were available which burning heavy fuel were economical, and being less complicated than a corresponding steam plant, were more easily automated, thus helping to cope with sea going staff shortages.

The closure of the Suez Canal, however, caused tanker owners to consider the economies of transporting crude oil in greater bulk and this resulted in the design of 200 000 d.w.t. tankers requiring 20 000 kW for propulsion. Such powers were higher than normally available from the oil engines of that period, and presented a great opportunity for the revival of steam propulsion. Boiler and turbine designers took advantage of the situation with the result that steam was once more adopted for the higher powers (see Figure 4.6).

The following sections describe the types of boilers most usually encountered at sea at the present time. Some boilers of early origin were the forerunners of present day high evaporation, advanced steam condition, units.

It is noteworthy that current British main propulsion water tube boiler design, apart from reheat units, falls into two distinct categories whose main difference is superheater location. Figure 4.7 illustrates these two categories, and indicates the similarity in current designs reached by our two main boiler makers after years of development work.

Most noteworthy amongst the features embodied in these boilers are:

1. Larger furnaces with lower heat release rates give tubes a more leisurely life.
2. Membrane or mono-walls practically eliminate refractories.
3. Roof firing gives better heat distribution.
4. Superheaters in the ESD and MR types are in a more sheltered position with improved supports.
5. Expanded and gasketed joints are largely superseded by welding.
6. Soot blowing arrangements are improved.
7. Improved oil burning equipment gives better combustion.

FOSTER WHEELER BOILERS

Modern water tube boilers as designed by Foster Wheeler are based on the D type, those currently in service for marine propulsion purposes being 'D', ESD I, ESD II, ESD III, ESD IV and ESRD (reheat).

In the D-type the superheater is positioned within the main tube bank, whereas in the ESD (External Superheater D) designs it is positioned directly beneath the economiser, thus forming an external vertical convection unit at the side of the boiler which is very accessible for maintenance and water washing.

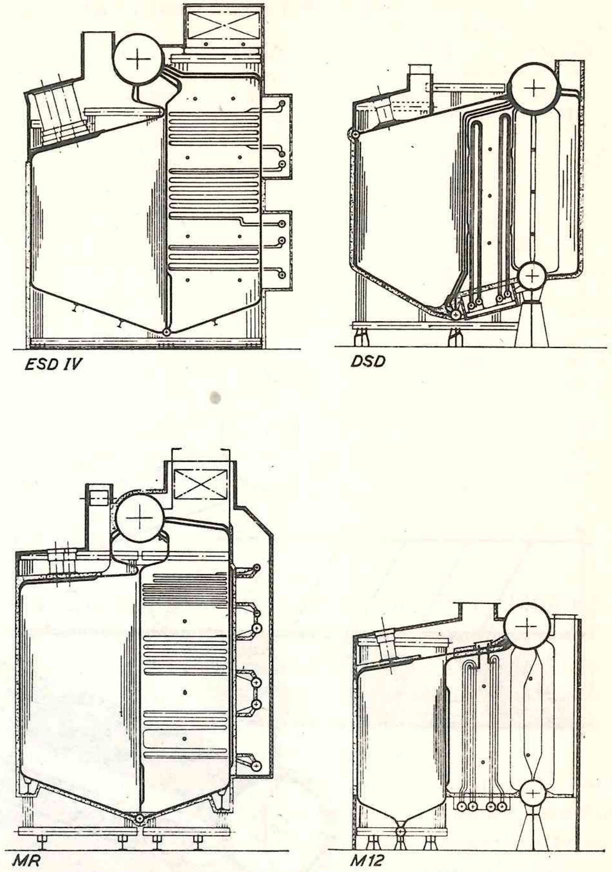


Figure 4.7 British water tube boiler designs
(above) Foster Wheeler
(below) Babcock & Wilcox

The differences in furnace ratings and disposition of heating surfaces for the various designs are shown in Table 4.1. It will be noted from this table that during the period approximately 1960/1976:

1. Furnace ratings rose and then dropped back again.
2. In the case of the D-type the actual boiler tube heating surface percentage is relatively higher and the economiser lower, than in the ESD types.

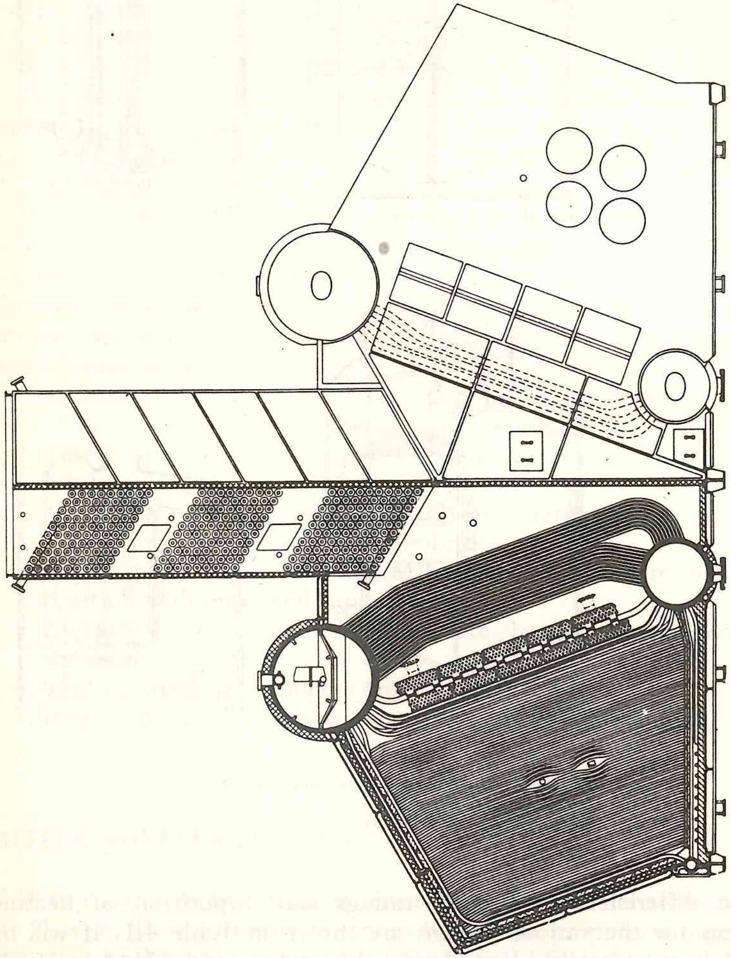


Figure 4.8 Foster Wheeler D-type boiler

Table 4.1 Foster Wheeler boiler data

	D	*ESD I*	*ESD II*	*ESD III*
Evaporation kgh	34 000	34 000	34 000	45 000
Final steam temperature °C	450	450	450	510
Design press. bar.	50	47.5	47.5	73
Final steam press. bar.	41	41	41	63.5
Feed temperature °C	115	115	115	140
Funnel temperature °C	154	154	154	172
Heating surface				
Water wall per cent	3.2	3.8	3.7	9.0
Generating tubes per cent	27.0	7.6	5.37	4.5
Economiser	38.0	54.8	53.4	57.5
Control unit			2.61	
Superheater per cent	7.0	12.8	14.32	13.5
Air heater per cent	24.8	21.0	20.6	15.5
	100	100	100	100
Furnace volume m^3	40	23.5	23.5	46
Radiant surface m^2	46.5	31.6	31.6	66

The D-Type boiler

These units have been built to cover duties ranging from 4536 kg/h evaporation at 14 bar saturated steam to a maximum of 52 000 kg/h, and including steam temperatures up to 510°C (950°F) and pressures up to 60 bar. Those built for main-propulsion requirements generally have steam conditions of 31 bar at 399°C or 41 bar and 454°C. A typical design is shown in Figure 4.8.

All boilers of this type have two drums with a main tube bank consisting of three fire rows and a large number of smaller-diameter generating tubes. Between the two tube groups is the superheater and an access space. The furnace has water-wall tubes lining the side and rear walls and roof. The side-wall tubes which continue across the roof to the steam drum are supplied with water from a lower header, which is fed through floor tubes from the water drum. The rear wall tubes are fitted between a lower and upper header, and the upper header is connected with riser tubes to the steam drum. The two drums are also connected by external downcomers to provide natural circulation in the main bank and the water walls.

The superheaters consist of U-bend elements arranged at right-angles to the boiler tubes and carried in heat resisting steel plates which are themselves supported from the drums on special boiler tubes. The elements are expanded into headers which are fitted with internal baffles to give the number of steam passes required to maintain adequate steam velocities inside the tubes.

The furnace floor and front wall are refractory lined, and the oil burners are located in the front wall. The boilers are usually installed in pairs, being built to opposite hand, with the gas uptakes amidships under the funnel. On leaving the boiler, the combustion gases pass through an economiser and in some cases, a gas air-heater. Soot blowers are fitted to sweep the superheater, boiler tubes and heat-recovery surfaces.

The DSD type

This type known as the double superheater D (DSD) has been developed from the original D design in as much as its superheaters are situated immediately behind three rows of screen tubes, although in this case the U-bend elements are arranged vertically and extend upwards from the headers which are below furnace floor level. A further feature of this design is that the screen tubes terminate at their lower ends in a screen header and not in the water drum as in normal D-type practice.

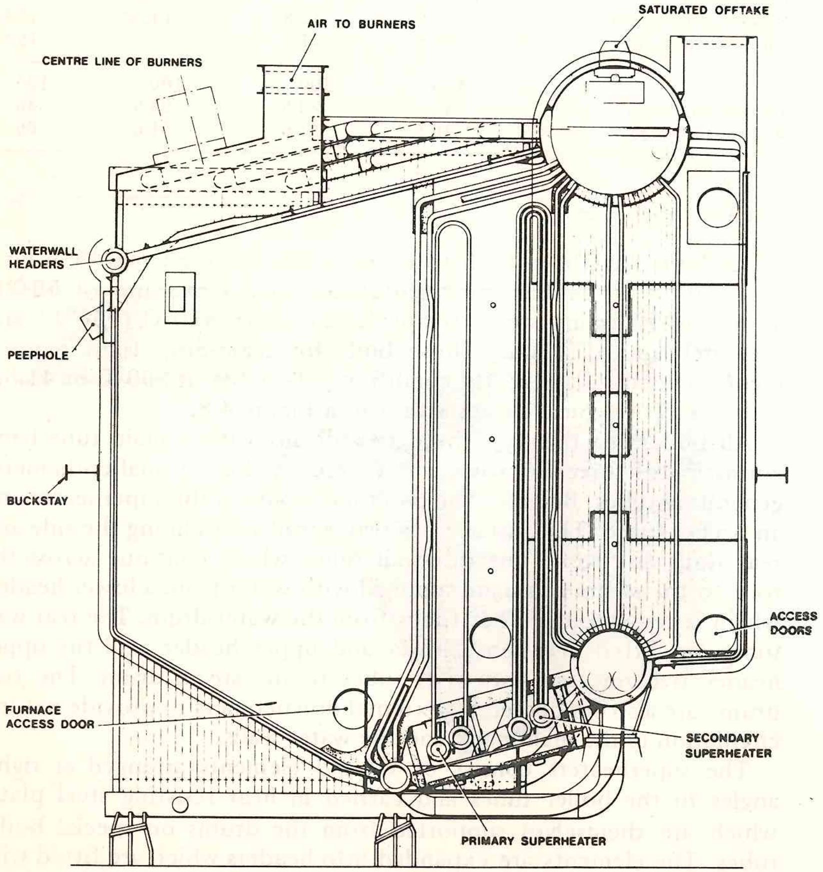


Figure 4.9 Foster Wheeler DSD type boiler

This screen header fed by large bore downcomers from the steam drum or directly from the water drum is positioned so that there is ample space for a double walk-in superheater between the screen tubes and main bank tubes.

The furnace is fully water cooled. The tangent waterwall tubes or Monowall* tubes protecting the furnace side and roof are supplied with water directly from the screen header. The front and rear tangent 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.

Downcomers are connected between steam and water drums to ensure adequate circulation under all steaming conditions. As will be seen from Figure 4.9 there are two superheaters primary and secondary, the steam making a number of passes through each section and control of final steam temperature being achieved by desuperheating, as necessary, between the two sections. All the vertical superheater elements are welded to stubs on the four superheater headers. These boilers, in pairs, with a combined maximum evaporation of approx. 147 000 kgh at 61 bar and 516°C have been installed in several 220 000 d.w.t. tankers.

The ESD I and ESD II types

The ESD I or external superheater D-type design is based on that of the D-type boiler but with the superheater located after the main generating tube bank in the direction of the gas flow and before the economiser. It is also provided with an air attemperator between the first and second superheater passes for control of the final steam temperature (see Figures 4.10 and 4.11).

These arrangements limit the gas temperature at the superheater and reduce the tube-metal temperature, a desirable feature for high-steam-temperature installations. They also reduce slagging and the corrosion of supports associated with high-temperature superheaters located only a few rows from the furnace.

The air attemperator, consisting of a bank of finned tubes, is

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*Monowall is the Foster Wheeler Trade Name for a membrane wall.

located in the combustion air duct and receives steam from the first superheater pass. Simple interlocked air by-pass and shut-off dampers in the air duct (as shown in Figure 4.11) regulate the flow of air over the attemperator surface or through the by-pass, cooling the steam between the two superheater passes and thus controlling the final steam temperature. This control may be either thermostatically or manually-operated.

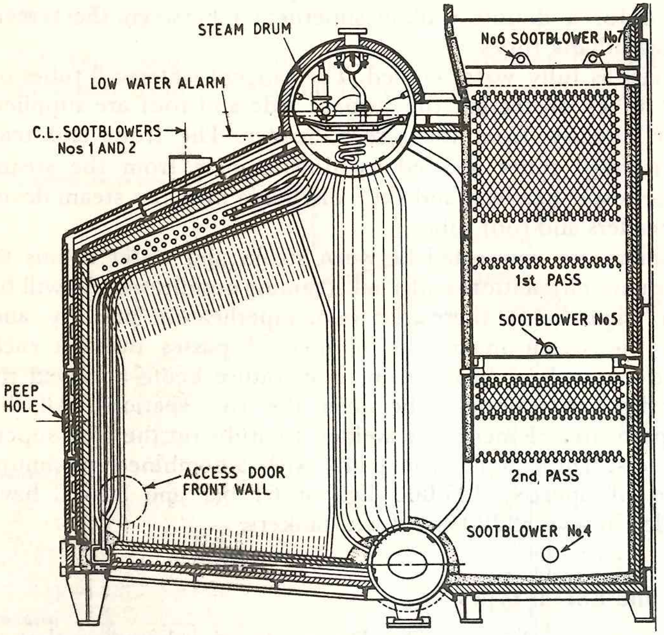

Figure 4.10 Foster Wheeler ESD I type boiler

The main generating tube bank consists of only a few rows of large-diameter tubes, and with the superheater located outside the main generating tube bank, the whole assembly can easily be cleaned and water washed.

Boilers of this type have been built for outputs ranging from 13 500 to 118 000 kg/h and steam conditions up to 52 bar and 516°C.

The ESD I design was evolved some 25 years ago to meet a specification requiring steam at 510°C and 43 bar with a furnace heat release of 5600 MJ/m³. These steam conditions were considerably higher than the 31 bar 390°C limitations commonly used at that time.

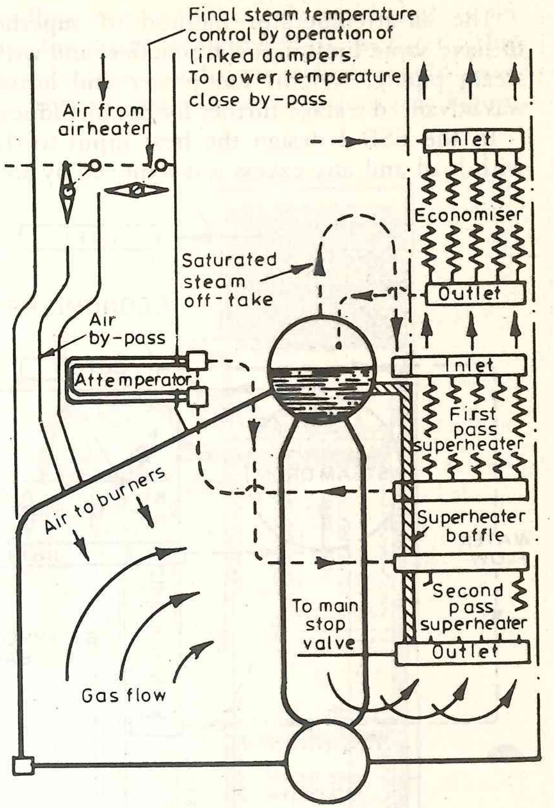

Figure 4.11 Superheater and attemperator arrangement on ESD I boiler

1. The superheaters were in a lower gas temperature zone in an effort to eliminate some of the all too common support-plate troubles, and also to minimize slagging and flame impingement.
2. The superheater was more accessible for inspection, maintenance and water washing.
3. The generating surfaces were simple and easy to clean.
4. Automatic superheat control was provided.
5. Provision was made for low temperature steaming.
6. The size of the furnace was as small as possible consistent with good combustion and flame shape.

Many vessels have been fitted with the ESD I design (Figure 4.10) including some of the largest passenger liners, the designed maximum evaporation per boiler being up to 118 000 kg/h.

The air-attemperator method of superheat control was found to have some limitations in practice, and with a view to saving space, steam piping, weight, fan power and initial cost, the ESD design was advanced a stage further by the introduction of the ESD II.

In the ESD I design the heat input to the superheater increased with load and any excess was removed by an air attemperator. In the later arrangement, the ESD II, the heat input to the superheater is limited to the amount of superheat required, this being effected by providing the superheater itself with an outlet damper, and also a damper-controlled by-pass.

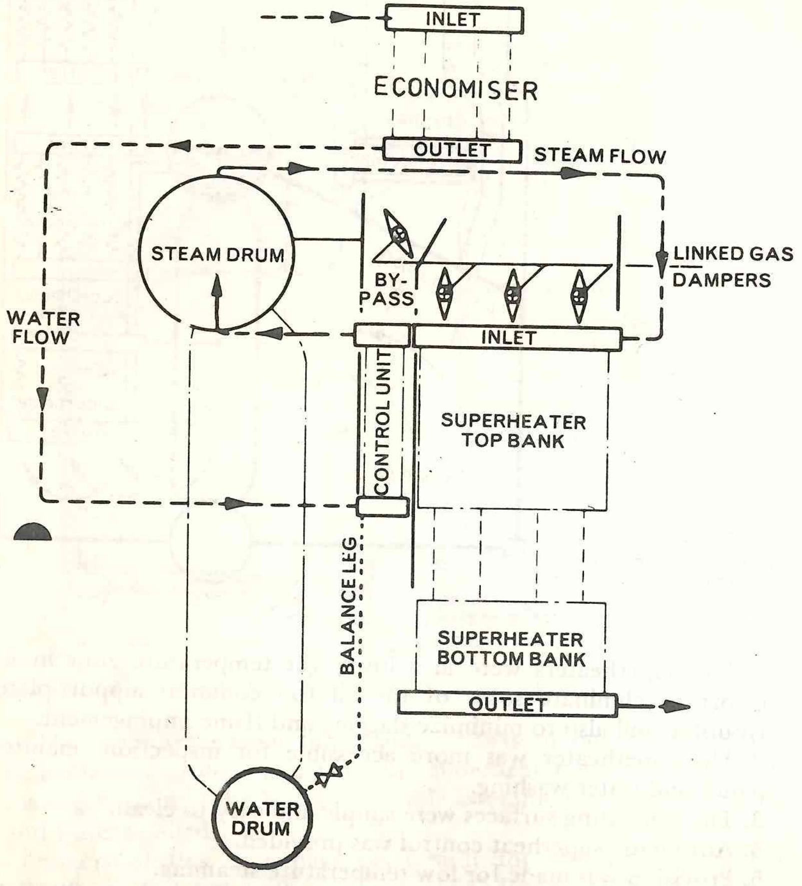

Figure 4.12 Flow diagram for Foster Wheeler ESD II boiler

In this by-pass an up-flow economiser, or 'control unit' – in reality an extentions of the main economiser – is fitted, this absorbing the heat under by-pass conditions, which would have gone into the superheater under damper-open conditions (see Figure 4.12).

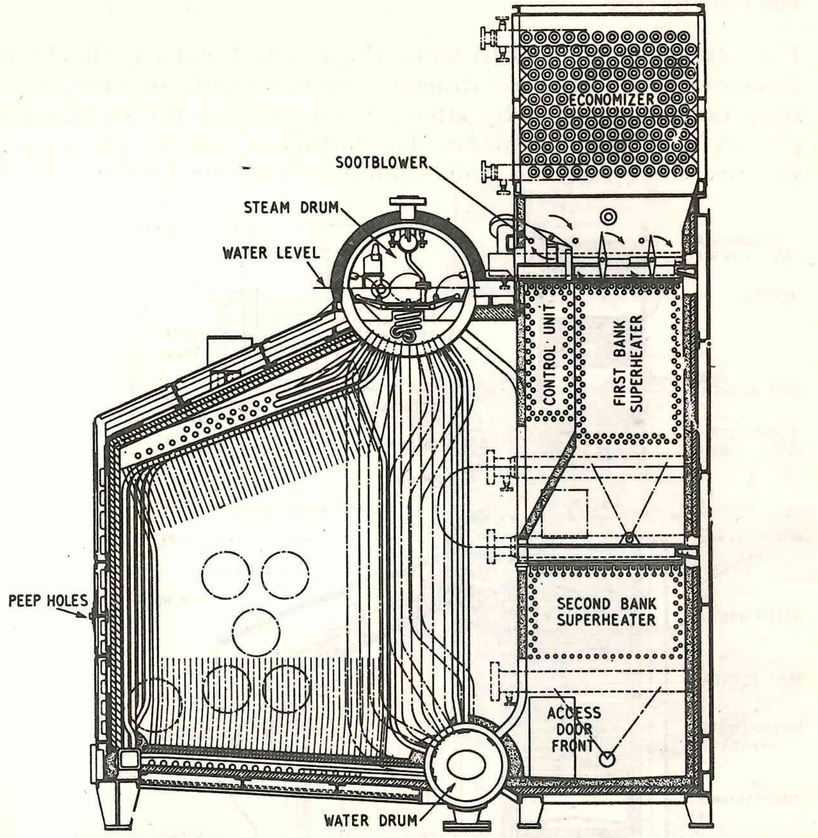

Figure 4.13 Sectional view of Foster Wheeler ESD II boiler

The 'control unit' is constructed and supported in a similar manner to the superheater and carries all the feed-water continuously on its way from the main economiser to the steam drum- any tendency for steaming under conditions of low feed being prevented by the fitting of a circulating connection back to the boiler water drum.

Figure 4.13 shows the general arrangements of this design. Several ships commissioned in 1961 were fitted with these boilers and they have been built with evaporation rates up to 80 000 kg/h of steam at 54 bar and 487°C.

The ESD III type

The Foster Wheeler ESD III boiler (Figures 4.14 and 4.15) has been designed to suit advanced steaming conditions with the final steam temperature controlled by attemperation between the superheater primary and secondary passes. The furnace is large to give a conservative firing rate and proportioned so that the burners can be arranged with ample flame clearances and flame length. The burners are positioned in the furnace roof to meet the flame-length requirement and the furnace is completely water cooled by close-pitched tubes to reduce refractory maintenance to a minimum. External downcomers from the steam drum to the water drum and lower front and rear water wall headers, and floor tubes which connect the water drum to the side water-wall header, ensure an adequate circulation of water under all steaming conditions.

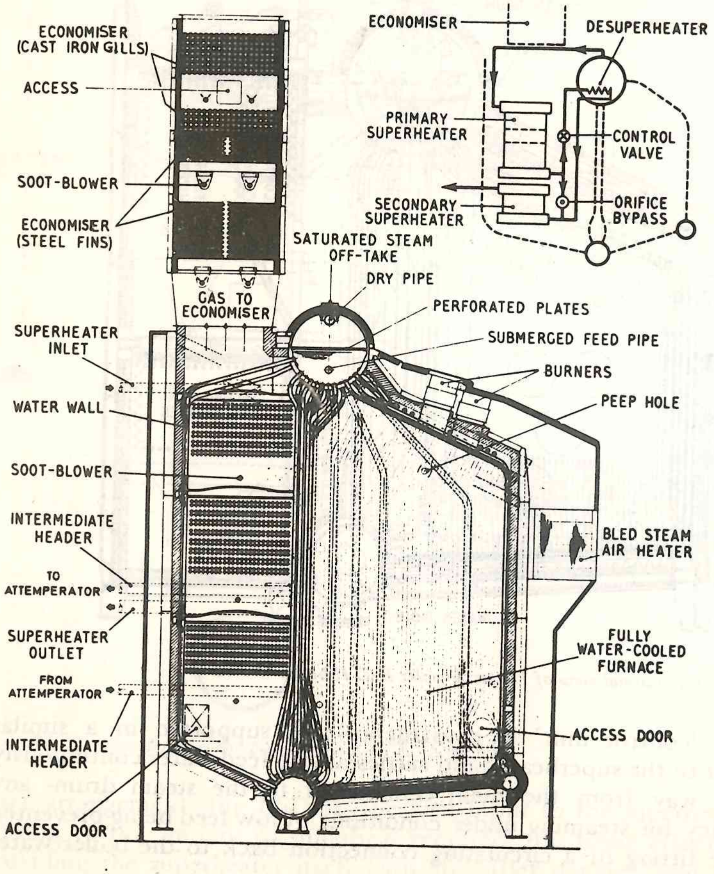

Figure 4.14 Sectional view of Foster Wheeler Type ESD III boiler

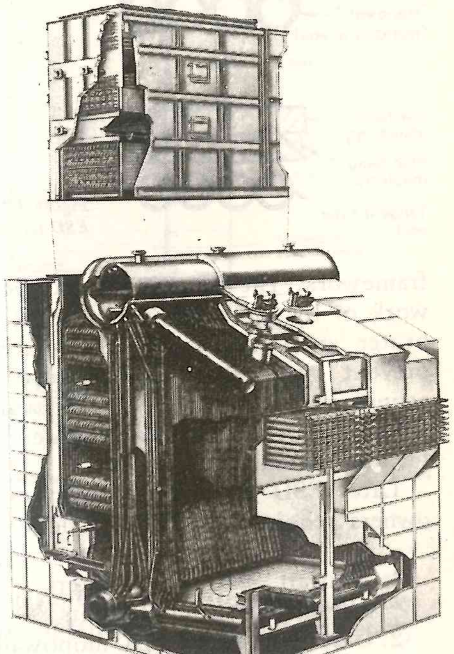

Figure 4.15 Internal view of Foster Wheeler type ESD III boiler

The convection type superheater is shielded from the furnace by a baffle of close pitched generating tubes, the small gap between each tube being sealed by welded strips. The superheater side wall refractory is protected by similarly sealed close pitched tubes. The multi-loop superheater elements are arranged on 'in line' pitching and while the steam flow in the primary (upper) pass is counterflow, that in the secondary (lower) pass is parallel to the gas stream in order to keep the tube-metal temperatures to a minimum.

The economiser is of the extended surface type located above the superheater, the water flow being counter to the gas flow. The extended surface is formed from cast iron gills in the primary (low-temperature) section and steel gills in the secondary (high-temperature) section. Alternatively, cast iron gills only may be used throughout.

The structural framework and casings are of robust design to carry the loads required, the boiler and superheater having a common framework. The economiser may be supported by the boiler framework or by the ship's structure as required. The boiler and superheater are double-cased, the space between being pressurised to prevent gas leakage and reduce the casing temperature. The economiser is normally single-cased. The refractory and insulating linings are of monolithic construction and the materials are suitable for water washing.

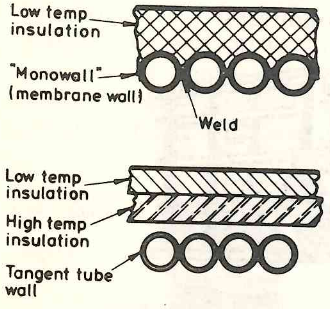

Figure 4.16 Alternative furnace tube arrangements on ESD III boiler

Later ESD III boilers incorporate various modifications to suit owners' requirements, these include:

1. Athwart ship superheaters – this resulting in more easily supported shorter elements.
2. Gas tight all welded monowalls in lieu of refractory backed tangent tubes (see Figure 4.16).
3. Full enclosure of the superheater convection space by monowalls in lieu of front and rear walls of refractory.
4. Variation in number of screen tubes between furnace and convection space from four to eight.

A typical example of an ESD III unit embodying these modifications as fitted in the largest tankers is shown in Figure 4.17.

Superheated steam temperature control

The final superheated steam temperature is controlled by attemperation (desuperheating) of the steam between the primary and

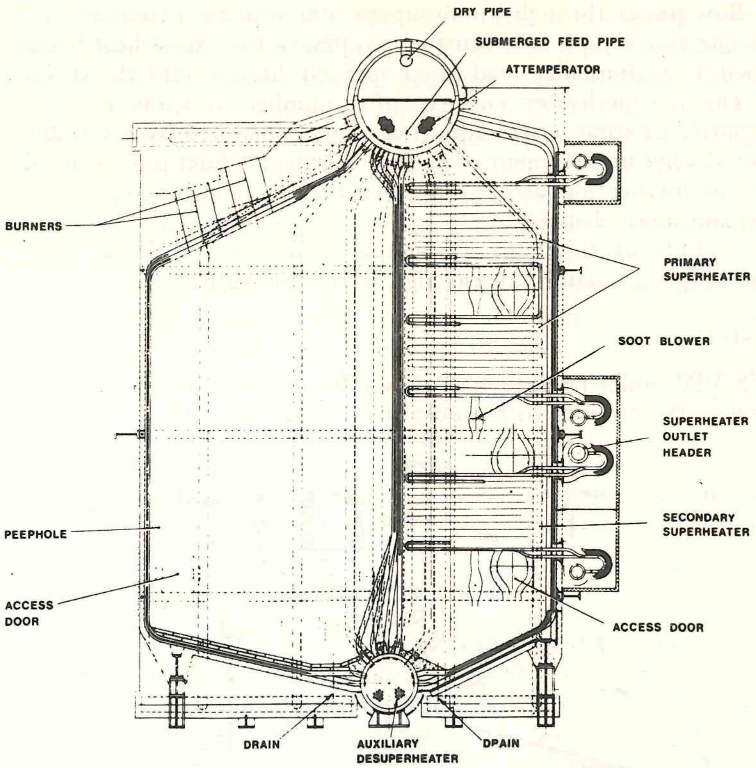

Figure 4.17 Later type of ESD III boiler with modifications showing mono-wall construction

the secondary steam passes of the superheater. Attemperation may be by means of a drum type desuperheater or an external-spray type, as required.

When a drum-type control desuperheater is fitted, a proportion of the steam flow from the primary pass is diverted through the desuperheater which is located in the steam drum, and the excess heat is transferred to the water in the drum. The desuperheated steam is mixed, before entry into the secondary pass, with the remainder of the steam flow which has by-passed the desuperheater. The proportion of steam passing through the desuperheater is controlled by an orifice plate in the by-pass line and a control valve in the line to the desuperheater or by an inter-linked valve in each line. The total steam flow passes through the secondary pass under all steaming conditions.

When an external spray type desuperheater is fitted the total steam flow passes through the desuperheater which is fitted into the connecting steam pipe between the two passes, the excess heat being absorbed by high-quality feed-water sprayed directly into the steam flow. The desuperheater consists of a number of spray nozzles, the quantity of spray water admitted being controlled by a suitable sequential valve arrangement or metering device. A liner pipe is fitted in the desuperheating area to protect the outer steam pipe from erosion and thermal shock.

Single units of this type are at sea as the main boiler of large tankers with evaporation rates as high as 100 000 kg/h.

The ESD IV type

The ESD IV boiler (Figure 4.18) is similar in design to the ESD III the main structional differences being brought about by the extensive use of Monowalls. The whole unit is completely encased within these walls and in addition a Monowall is used to form a gas tight screen between the furnace and superheater sections. The tubes of the lower part of this screen open out to form two rows of open pitched tubes over which the furnace gases pass before entering the superheater section. As there are only two rows of open pitched screen tubes, in lieu of the 4 to 6 in the ESD III design, they can be easily accomodated at their lower ends in a header, and accordingly in this ESD IV design the water drum has been dispensed with.

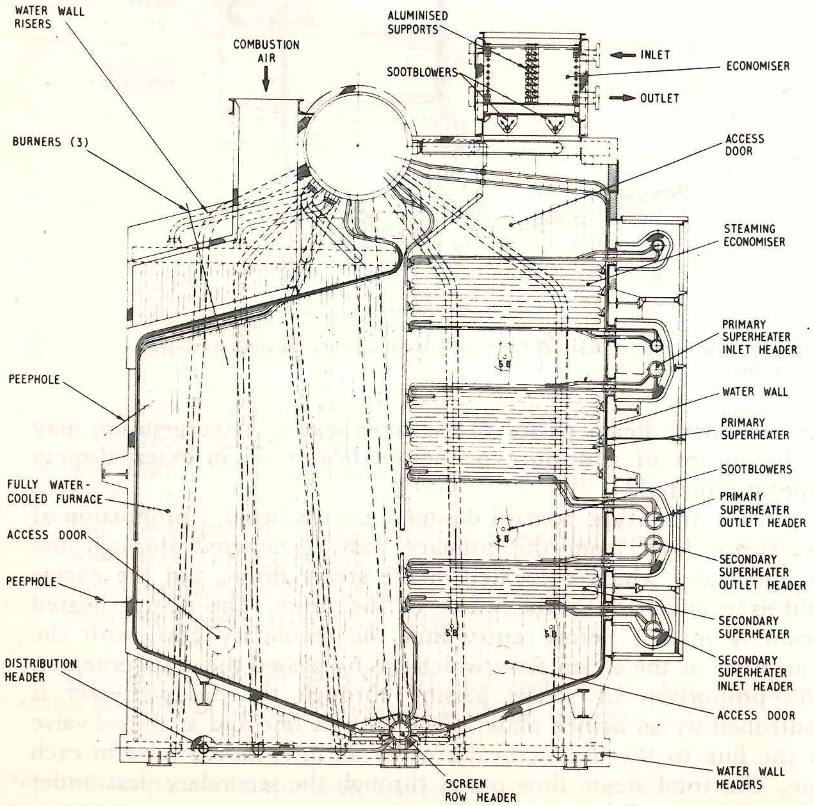

Figure 4.18 Foster Wheeler type ESD IV boiler

All tubes in these boilers are welded to stubs or directly to headers, this obviating possible leakages at expanded ends. As in the later examples of the ESD III design the superheaters and economisers are arranged athwartships, this ensuring easier support of the shorter elements. Steam temperature control is, as in the ESD III type, by attemperator in the steam drum.

Single units of this type with evaporation rates as high as 120 000 kg/h, supplemented by a smaller auxiliary 'get you home' unit form the boiler installation of a number of large tankers.

The Foster Wheeler reheat boiler

The Foster Wheeler reheat boiler is known as the ESRD (External Superheater Reheat D-type) and is shown in Figure 4.19. This roof fired boiler is encased with monowalls and is complete with superheater, superheat control attemperator, reheater with control dampers, economisers and gas air heater.

The screen between the furnace and the convection section containing superheater and reheater is a monowall, which, local to the screen header opens out to form two rows of open pitched tubes over which the furnace gases pass en route to the superheater. The screen header is fed by large bore downcomers from the steam drum. The superheater space side monowall tubes are connected directly between the steam drum and screen header and serve as supports for superheater, reheat and by-pass economiser elements. All boiler tubes are arranged with welded connections to the steam drum and headers. The downcomers and risers are welded between stubs on both steam drum and headers.

A division wall separates the superheater space into two sections — the reheat section and the by-pass section. The reheat section contains the secondary superheater, the second pass of the primary superheater and the reheater. The by-pass section contains the first pass of the primary superheater and the bare tube by-pass economiser.

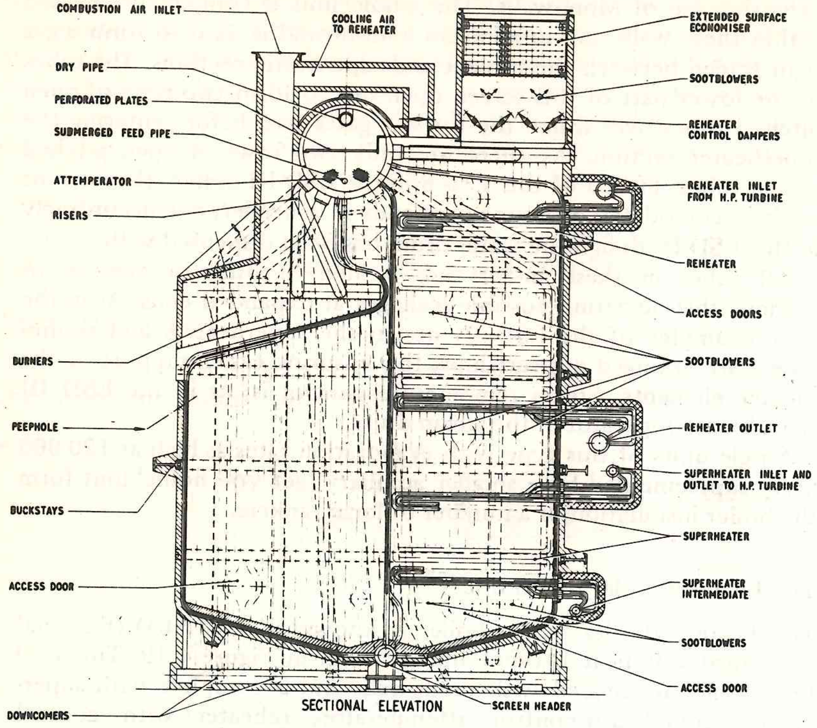

Figure 4.19 Foster Wheeler ESRD boiler

The superheater is arranged athwartships in two sections, primary and secondary, on a common horizontal plane. The primary section is arranged in two passes the first of which is contra flow gas and steam to give efficient heat exchange, the second being parallel flow to minimise metal temperatures. The secondary superheater is arranged for parallel flow gas and steam, again to minimise metal temperatures.

The top four rows of superheater tubes in each bank are situated above the by-pass opening in the division wall, to protect the reheater. All superheater elements are arranged 'in line' for easy cleaning and inspection and are attached to header stubs by butt welds. Steam temperature control is by automatic attemperation between the primary and secondary sections.

The reheater is of the convection type arranged athwartships in two banks above the second passes of the primary and secondary superheaters – the elements are 'in line' and welded to stubs, as in the superheaters. Reheat steam temperature control is effected by dampers above the reheater and the by-pass economiser.

During long periods of steaming without the need for reheat, i.e. when running astern or cargo pumping, the reheater is protected by cooling air from the F.D. fan. Closing of the reheat dampers automatically opens cooling dampers to admit air above the reheater. The bare tube by-pass economiser consists of multi loop athwartship elements above the first pass of the primary superheater. It is arranged for parallel flow to accomodate the possibility of steaming and the elements are supported by heat resisting lugs from adjacent boiler tubes. An extended surface economiser with steel gilled tubes is fitted above the control dampers.

Figure 4.20 shows the gas flow through the superheaters, reheater and economisers for ahead operating conditions. Gases pass from the furnace to the cavities below the superheaters. The majority of the gas passes over the second pass of the primary superheater, thence to the secondary superheater and the reheater, with a parallel gas flow passing over the first pass of the primary superheater and the by-pass economiser.

Reheat temperature control is achieved by modulation of the reheat control damper, which determines the flow of gas across the by-pass economiser, and allows mixing of the two gas streams via the division wall opening.

Figure 4.21 shows the corresponding gas flows for astern operation, when there is zero steam flow in the reheater. Operation of the reheater shut off damper causes the gas flow across the second pass of the primary superheater and the secondary superheater to be by-passed across the division wall opening and mix with the gas emerging from the first pass of the primary superheater. The combined gas flow then passes over the by-pass economiser. Cooling air from the burner wind box is passed over the reheater tubes under astern conditions to prevent thermal shock to the reheater when steam flow is later resumed.

For both ahead and astern operation, the combined gas stream leaving the dampers flows across a steel finned economiser before reaching the regenerative gas air heater.

Two well known past designs of Foster Wheeler are the controlled superheat and D reheat types.

Foster Wheeler controlled superheat boiler

This boiler consists of a two furnace steam generator with an economiser superheater and, if required, an air heater of either the

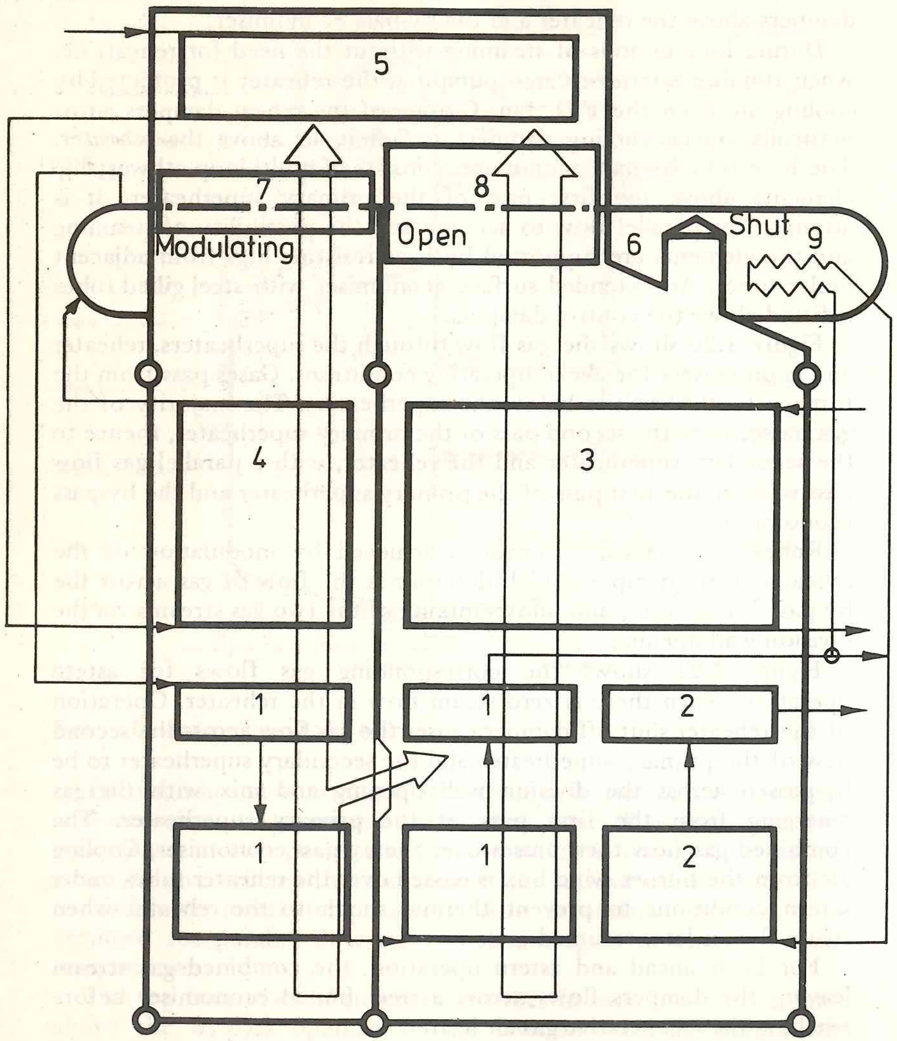

Figure 4.20 Gas flow through ESRD boiler — ahead operation

1.	Primary superheater	6.	Reheat cooling damper
2.	Secondary superheater	7.	Reheat control damper
3.	Reheater	8.	Reheat shut-off damper
4.	Bypass economiser	9.	Attemperator
5.	Steel finned economiser		

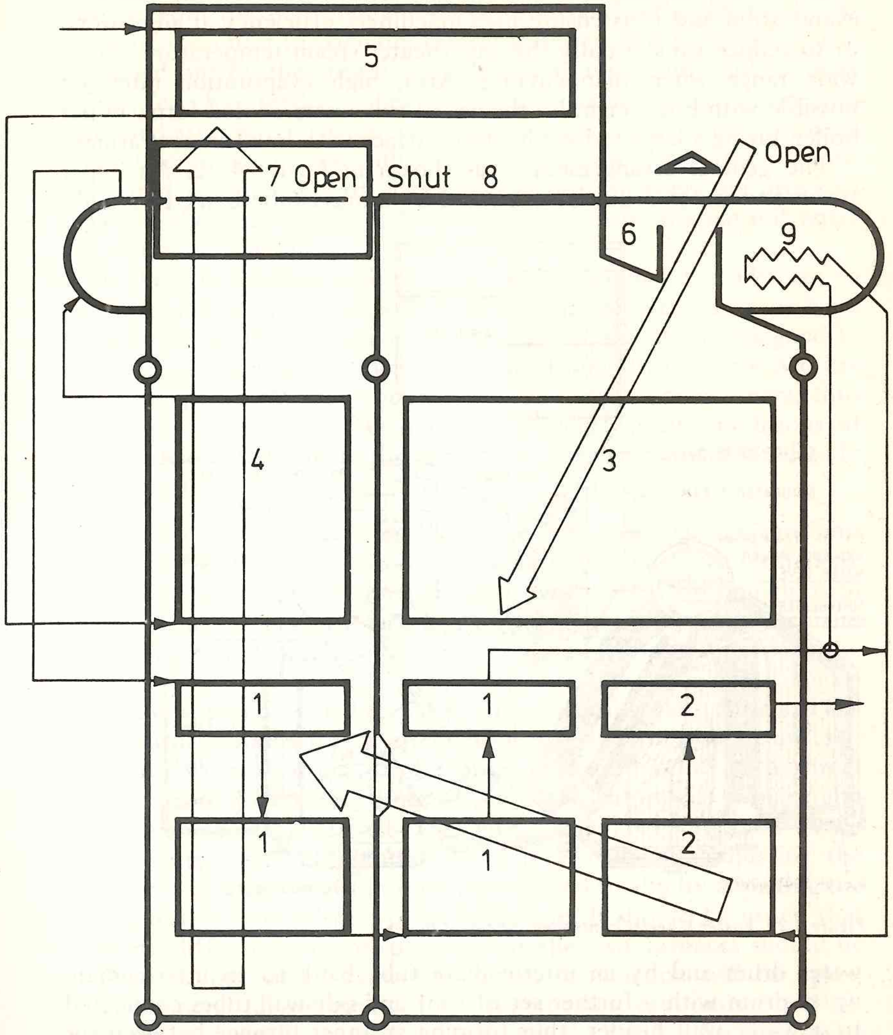

Figure 4.21 Gas flow through ESRD boiler — astern operation

1.	Primary superheater	6.	Reheat cooling damper
2.	Secondary superheater	7.	Reheat control damper
3.	Reheater	8.	Reheat shut-off damper
4.	Bypass economiser	9.	Attemperator
5.	Steel finned economiser		

flue-gas or bled-steam type. The design is such that it is possible to maintain full superheated steam temperature over a wide range of evaporation and thus ensure high machinery efficiency at all powers, or to reduce substantially the superheater steam temperature over a wide range when manoeuvring. Also, high evaporation rates are possible with low weight by the use of two water-cooled furnaces per boiler, giving a large radiant heating surface with low furnace ratings.

The general arrangement is as shown in Figure 4.22. An upper steam and water drum is connected by a main tube bank to a main water drum and by an intermediate tube bank to an intermediate water drum with a further set of roof and side-wall tubes connected to a water wall header, thus forming an inner furnace between the main and intermediate tube banks and an outer furnace between the roof and side-wall tubes and the intermediate tube bank.

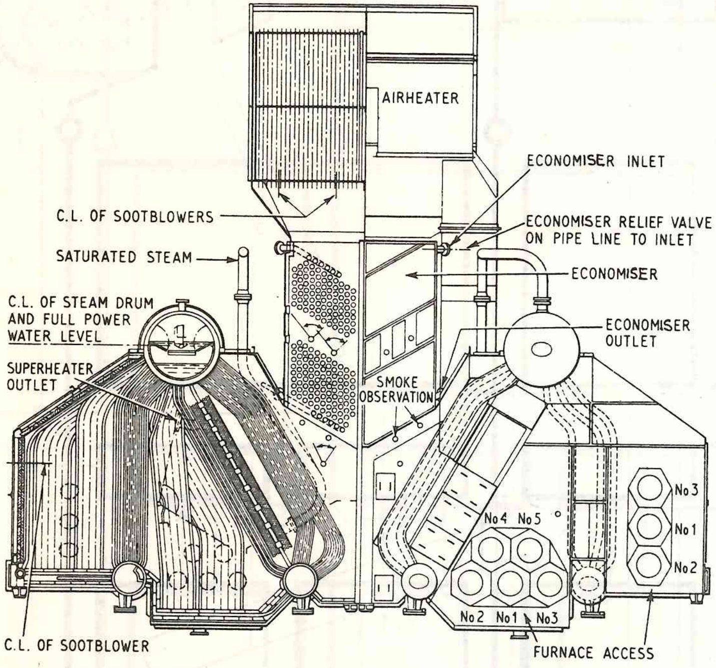

Figure 4.22 Foster Wheeler controlled superheat boiler

The main tube bank has its first three rows of tubes adjacent to the inner furnace of 50 mm o.d., with the remainder of the tubes 32 mm o.d., and the intermediate bank has two rows on either side (i.e. adjacent to both furnaces) of 50 mm o.d., with the remainder 32 mm o.d.

The roof and side wall tubes of the outer furnace are of 50 mm o.d. with water feeder tubes of the same size supplying the water-wall header from the intermediate water drum and set under the brickwork of the outer furnace floor. Rear water cooling of both furnaces is carried out by the provision of water wall tubes and headers, these being fed by feeder tubes from the main water drum and intermediate water drum for the centre and outer furnaces respectively; again these tubes being set below the furnace floors. Unheated downcomers of adequate size and numbers are provided between the upper and two lower drums to assist the natural water circulation in the boiler.

In the intermediate tube bank the two rows of tubes adjacent to the inner surface are segregated from the remaining tubes of the bank by a baffle in the intermediate drum and this baffle is designed to include a downcomer at each end of the drum. Hence, these two fire rows are provided with their own independent downcomers, thus preventing a reversal of flow in them under certain conditions of firing, such as flashing up the inner furnace when burners are already alight on the outer furnace.

Firing. The furnaces are fired by oil-fuel burners located in the front walls. The gases of the outer furnace pass through the intermediate tube bank and into the inner furnace, where they intermingle with the gases in the inner furnace and pass with them through the main generating tube bank, economiser and gas air-heater, if fitted, to the uptakes.

As the superheater is located in the main tube bank, firing of the inner furnace has a direct effect upon the superheated steam temperature, whereas firing of the outer furnace has no such direct effect, hence differential firing of the outer (saturated) furnace and inner (superheater) furnace will give control of the final steam temperature. This differential firing is effected by adjusting the number of burners alight in each furnace and finally by adjusting the oil pressure to the burners of each furnace. It should be noted that extreme differences of oil pressures at the two furnaces should be avoided or the air/oil ratio for correct combustion will be upset.

The general arrangement of the superheater, economiser and air-heaters for controlled superheat boilers is the same as for the D-type boilers.

D-type reheat boiler

The Foster Wheeler reheat boiler (Figure 4.23) is used in conjunction with a reheat-geared turbine system. The boiler is based on the D-type design with a single furnace, the main bank of which has been

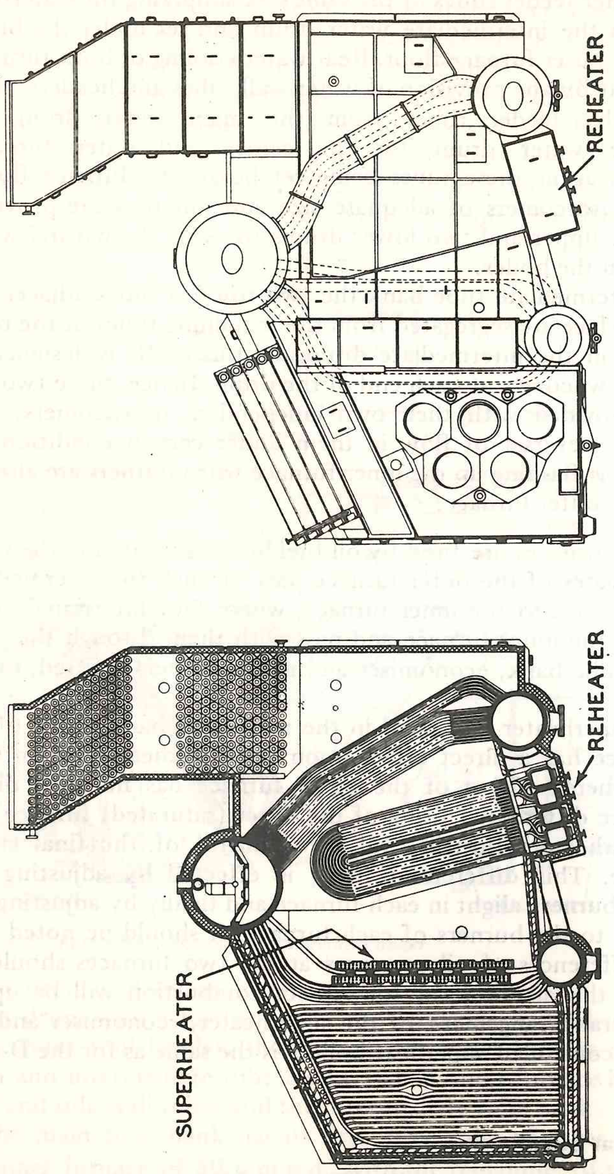

Figure 4.23 Foster Wheeler reheat boiler

divided into two sections with two water drums, one for the fire rows and one for the main generating tubes, both sections being fitted with separate downcomers.

In the space between two sections of the main bank, and protected from the direct furnace radiation, is a reheater of special design which receives two separate steam flows from separate sources, the port and starboard turbine units. This reheater comprises two pairs of longitudinal headers, one pair for the port turbine steam and the other for the starboard turbine steam. These headers receive exhaust steam from the port and starboard high-pressure turbines respectively and deliver the reheated steam to the port and starboard intermediate or low-pressure turbines.

The steam from the two turbine units is kept separate in the reheater by a system of transverse manifolds and cross-over tubes, while the steam from each turbine is distributed evenly throughout the effective area of the reheater. This ensures that identical reheat temperatures are obtained for both port and starboard turbines, irrespective of local variations in gas temperatures or fouling of the reheater surface.

A superheater is fitted in the space between the fire rows and the reheater. In addition to its function as a reheat boiler, the steam-generating section has an efficiency substantially equal to that of the main boilers, and produces superheated steam in the usual way for the main turbines, thus augmenting the steam supply from the main boilers in the ship.

The unit illustrated in Figure 4.23 is capable of producing 26 350 kg/h of steam at 45 bar, 454°C and of reheating two steam flows,

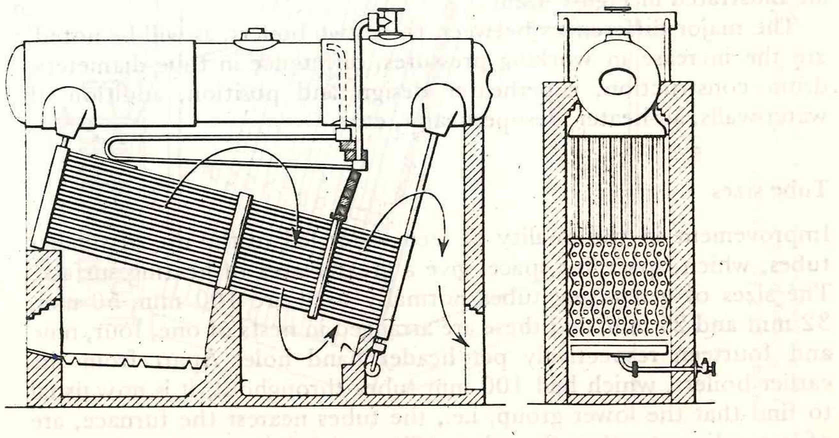

Figure 4.24 Early Babcock boiler

totalling 68 000 kg/h from 322°–454°C. The boiler is fired to give the required amount of reheating and has a fairly flat superheat characteristic, so that the reheat and the superheat temperatures can all be achieved together.

BABCOCK & WILCOX BOILERS

Early Babcock boilers were of the header type and were fitted with tubes of 100 mm diameter throughout, the steam drum was positioned in line with the tubes and the headers of cast iron were connected by nipples and connecting pipes to saddles riveted on the underside of the drum (see Figure 4.24).

Basic design

The major alteration in the layout of this type of boiler took place when, for marine purposes, the drum was re-positioned to lie at right-angles to the tubes and all front or down headers were nippled directly into the bottom of the drum. Since that date the basic design of the header type has remained unaltered, although with increase in pressures and temperatures, drum and header construction, tube diameters, superheater design and position, etc., have altered considerably.

The Babcock & Wilcox header-type boiler is essentially a robust and accessible unit, and as such was installed aboard many merchant vessels built in the USA in the period 1939–45. Details of these units are illustrated in Figure 4.25.

The major differences between these two boilers, as will be noted, are the increase in working pressures, difference in tube diameters, drum construction, superheater design and position, addition of water-walls, air-heater, desuperheater, etc.

Tube sizes

Improvement in the quality of feed water led to the use of smaller tubes, which, space for space, give a greater area of heating surface. The sizes of generating tubes normally used are 100 mm, 50 mm, 32 mm and 25 mm, and these are arranged in nests of one, four, nine and fourteen respectively per header hand hole. Apart from the earlier boilers, which had 100 mm tubes throughout, it is now usual to find that the lower group, i.e., the tubes nearest the furnace, are of larger diameter than the others (Figure 4.26).

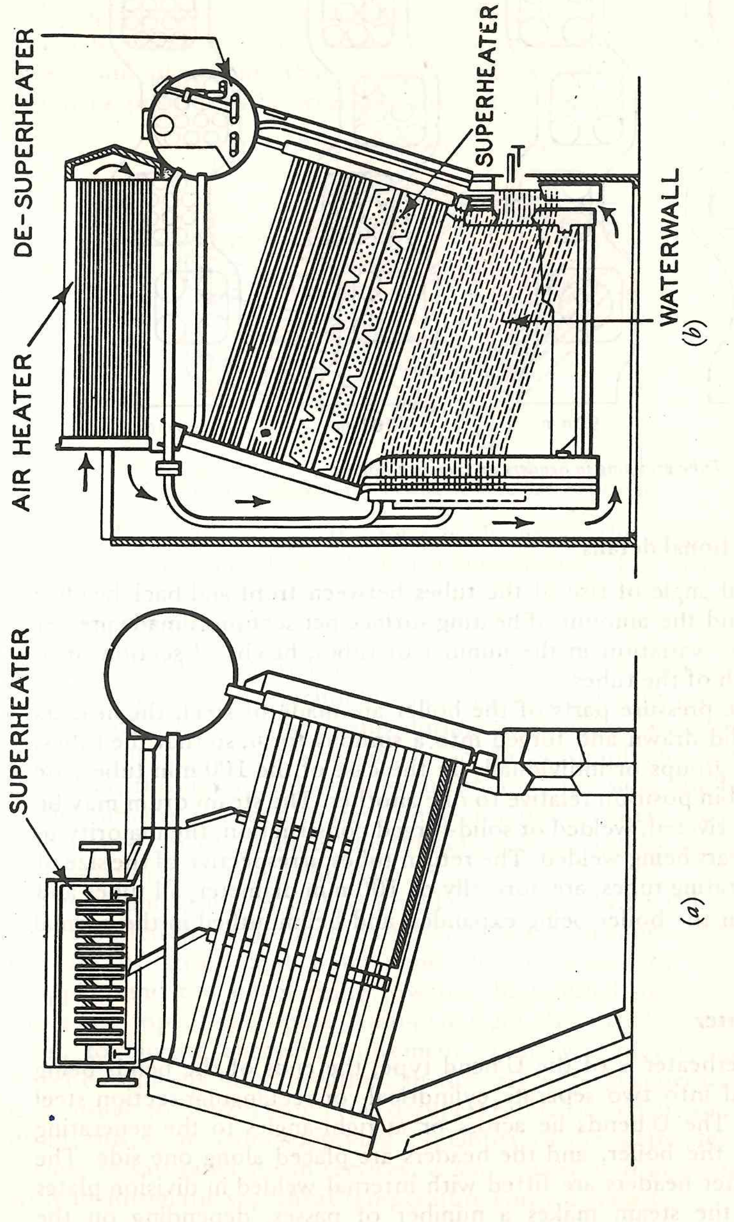

Figure 4.25 Babcock header-type boilers
(a) Working pressure 14 bar; temperature 221°C; 100 mm tubes 3-pass
(b) Working pressure 31 bar; temperature 399°C; 38 mm tubes single pass

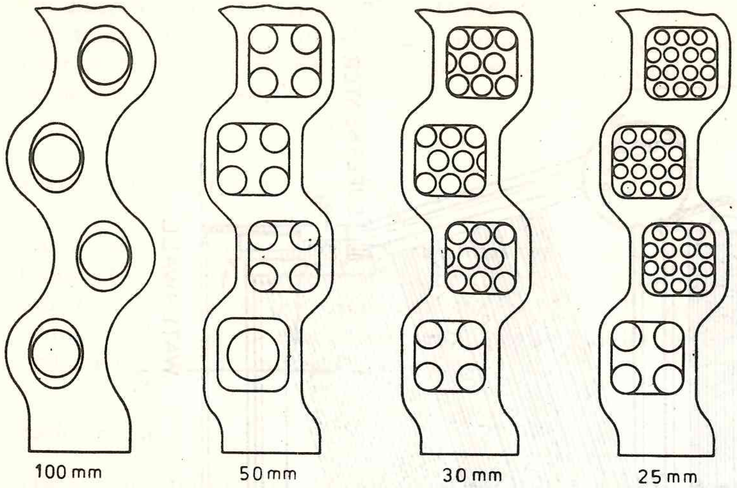

Figure 4.26 Tube grouping in headers on Babcock boilers

Constructional details

The usual angle of rise of the tubes between front and back headers is 15°, and the amount of heating surface per section is made greater or less by variation in the number of tubes, height of section or in the length of the tubes.

All the pressure parts of the boiler are made of steel, the headers being solid drawn and forged into a sinuous form, so that the tubes, either in groups or individually in the case of the 100 mm tubes, are staggered in position relative to one another. The steam drum may be either of riveted, welded or solid-forged construction, the majority in recent years being welded. The return tubes, irrespective of the size of the generating tubes, are normally of 100 mm diameter, all tubes and nipples in the boiler being expanded and bellmouthed in the normal manner.

Superheater

The superheater is of the U-bend type, the ends of the bends being expanded into two separate cylindrical- or rectangular-section steel headers. The U-bends lie across or at right-angles to the generating tubes of the boiler, and the headers are placed along one side. The superheater headers are fitted with internal welded-in division plates so that the steam makes a number of passes, depending on the number of division plates, before leaving the superheater (see Figure 4.27).

In high-pressure units with high superheat temperatures the superheater is moved from its normal position above the first and second passes and placed in what is termed the interdeck position. This interdeck position is between the rows of generating tubes at about one third of the way up the tube bank, where the desired steam temperature can be obtained with a superheater of moderate size.

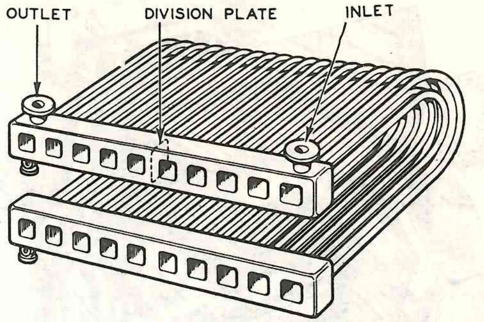

Figure 4.27 Superheater arrangement on Babcock boilers

Arrangement of units

The back headers are free to move on the rear structure, whereas the front headers are anchored, thus ensuring that any variation in tube length when raising steam, during steaming, or when shutting down, is allowed for. It is usual to lead the air supply, hot if from a preheater, through double casings surrounding the sides and bottom of the furnace and then to the front of the boiler, where the burners are situated. In this manner the refractory lined furnace is insulated and radiation losses are kept low.

The steam drum, as will be noted from Figure 4.25 (*b*), is fitted with a bolted-in longitudinal baffle over the return tubes, so that the mixture of steam and water tends to be separated, the water dropping and the steam rising towards the internal steam collector along the top of the drum. Wash-plates are also fitted in the steam drum to obviate excessive movement of the water-level when the vessel encounters heavy weather. In the case of high superheat units it is usual to find a coil-type desuperheater located in the steam drum; this, apart from supplying a quantity of desuperheated steam for use in saturated steam services, is sometimes used in connection with an automatic superheat temperature control system.

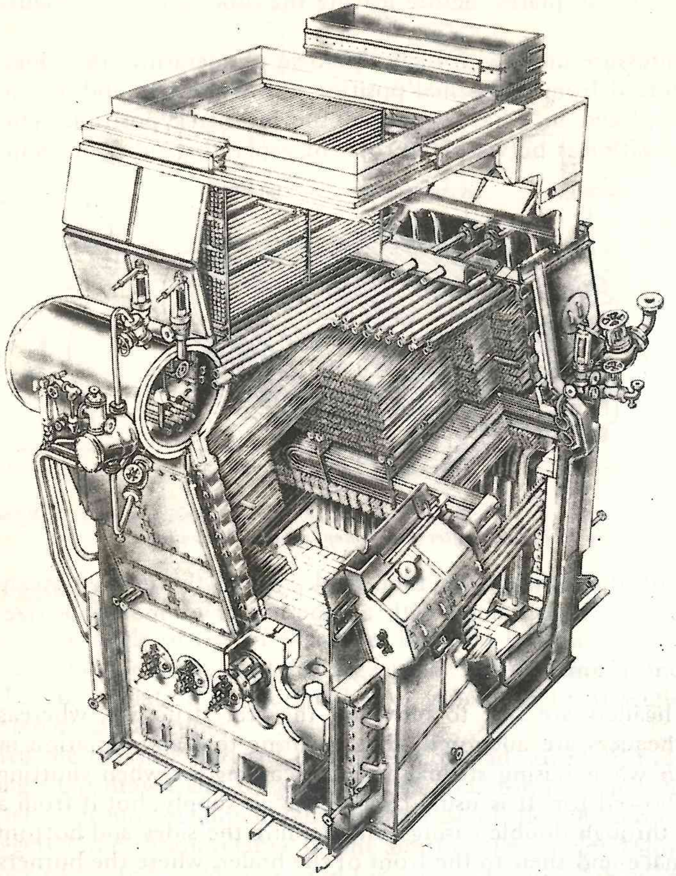

Figure 4.28 Cut-away view of Babcock marine boiler, single-pass header type
The illustration shows the superheater and air-heater; also the studded tubes in the side and rear water-cooled furnace walls

The detailed layout of individual units of this type naturally varies according to the purpose for which each is designed, the basic arrangement remaining the same, with variation in position of superheater, the additon of water-walls, economisers, air preheaters, etc.

Improved methods of feed water conditioning led to the use of smaller tubes, and during the last war, single pass units fitted with 32 mm tubes, interdeck superheater, water-walled furnace and air preheater, producing steam at a pressure of 31 bar and 399°C temperature, were extensively used in both cargo vessels and oil tankers (Figure 4.28), subsequently these steam conditions were raised to 41 bar and 454°C.

BABCOCK BENT TUBE BOILERS

Control of superheat, particularly when manoeuvring, is one of the important factors influencing water tube boiler design. The Babcock & Wilcox bent tube boilers fall into three categories, each one of which employs a different method of superheat control. The first of these, the Controlled Superheat boiler, employs two separate furnaces. Oil burners in one furnace provide the heat for the superheater, which is screened by three rows of boiler tubes, and a separate set of burners in the other furnace heats the saturated steam bank of tubes. The steam temperature is controlled to fine limits by regulation of the firing of the two furnaces, and the full design temperatures can be obtained at low outputs. In addition, these boilers have the advantage that large quantities of saturated steam can be taken direct from the drum, regardless of the superheat output. These boilers with their two furnaces and three drums are rapidly being superseded by the less complicated Integral Furnace and Selectable Superheat types.

Integral furnace boiler

This boiler is a two-drum type with the furnace at one side, formed by an extended screen of tubes which are an integral part of the main circulation system (see Figure 4.29). Boilers of this type have been built for capacities up to 81 500 kg/h for pressures up to 70 bar and for temperatures up to 510°C (950°F), the latter figure being limited by the availability of suitable materials for the superheater.

As will be seen from Figure 4.29, a single bank of tubes is expanded into upper and lower drums; this bank and the side wall are slightly inclined, thus reducing the overall width of the boiler base. The furnace roof and side wall are composed of tubes expanded into the steam drum and into a header at the base of the side wall. The rear wall is water-cooled with straight tubes parallel to the main bank and expanded into top and bottom headers, all these headers being connected by suitable downcomers and risers to the steam drum. Bare tubes are often used for these rear and side walls, but sometimes they are of stud tube construction packed with plastic chrome-ore refractory (see Figure 4.30). The front wall has 150 mm of refractory backed by 60 mm of insulation, and the furnace floor is covered by pre-fired bricks resting on the insulated casing.

From the furnace the gases pass through a screen of two, three, four or five staggered rows of 50 mm o.d. tubes before entering the superheater. The main bank of tubes behind the superheater consists of about twenty staggered rows of 32 mm o.d. tubes packed as closely

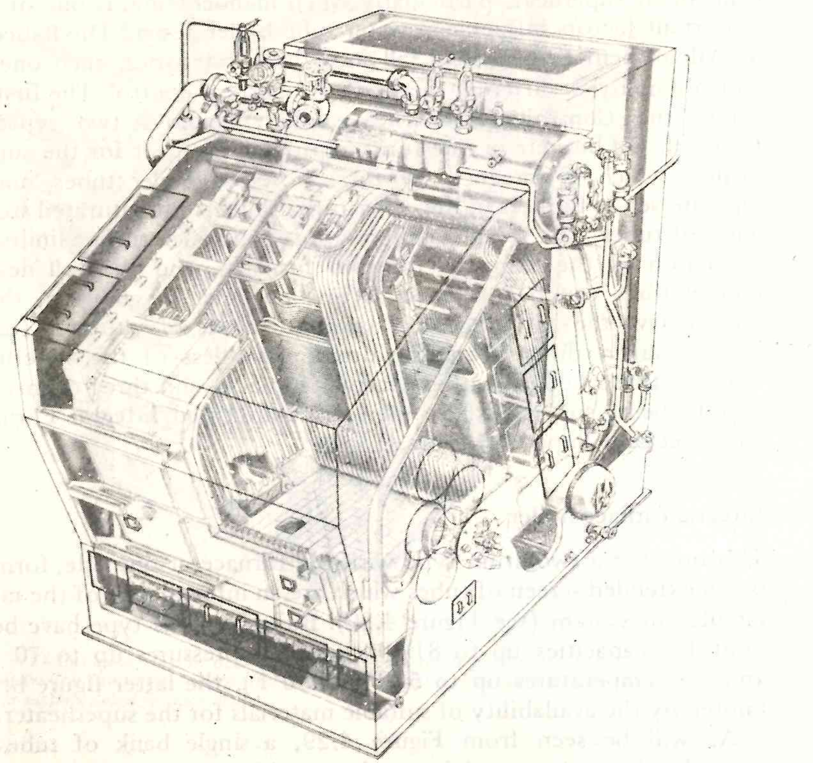

Figure 4.29 Cut-away view of Babcock marine boiler, integral furnace type

as practicable to ensure high gas speeds and heat transmission rates. All these tubes expanded into both drums are bent to form an access space for the superheater and to enable them to enter the drums radially. The screen tubes are also expanded into both drums, and some are used to form baffles to prevent hot gases bypassing the superheater, impinging on drums, superheater headers, superheater

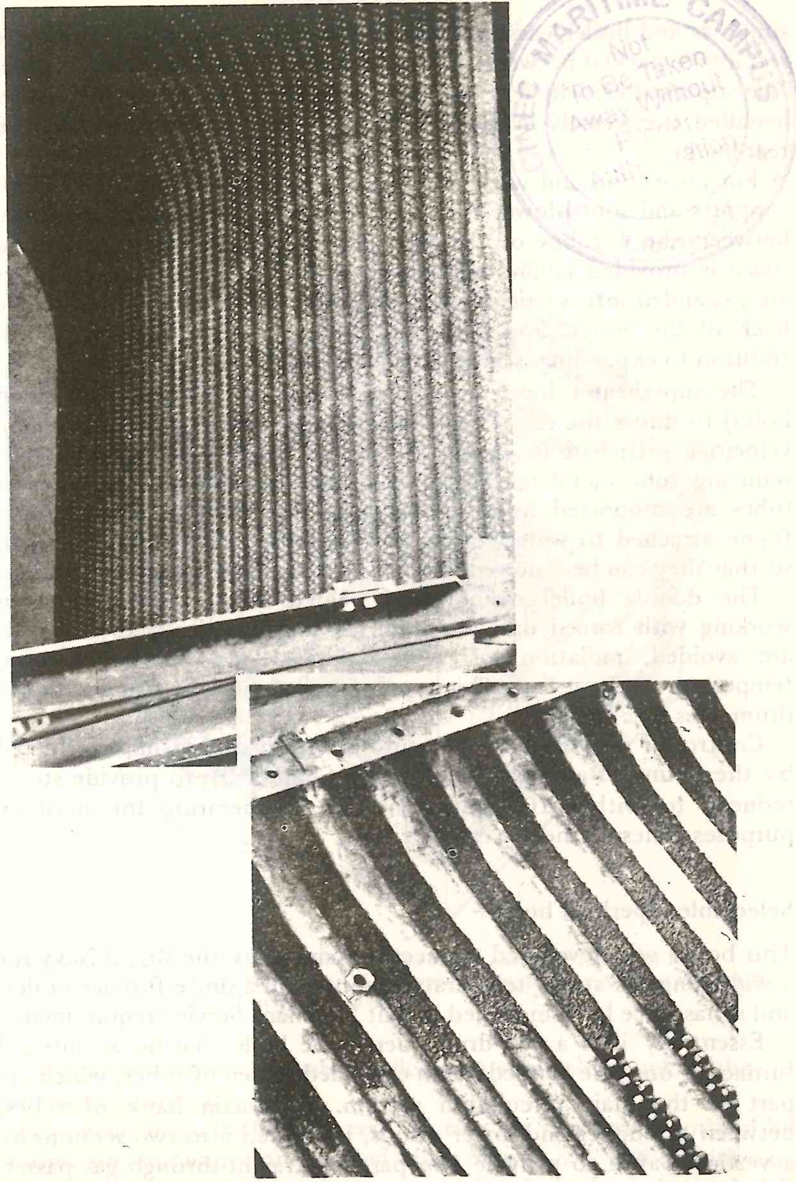

Figure 4.30 Babcock stud walls for use with selectable and integral furnace-type boilers (Left) Furnace view of side wall and roof showing full studding in chrome ore to reduce heat absorption at the front end. Partial studding to receive radiant heat at the rear end. (Right) The outside of the water-cooled wall with plastic chrome ore partly applied to studded tubes. The nut welded to one of the tubes is used for securing the outer insulation.

supports and boiler casings. These baffles are formed by chrome-ore refractory packed between tubes which are studded for that purpose. The superheater, which is drainable, is made up of groups of U-tubes installed transversely in the space between the screen tubes and the rear bank.

For inspection and water washing and to facilitate maintenance of supports and soot blower elements, a walk-in access space is formed between the U-tubes of the superheater, and an additional access space is provided behind the superheater. The ends of the U-tubes are expanded into vertical cylindrical inlet and outlet headers at the back of the boiler. For high steam temperatures the tubes are, in addition to expanding, seal welded inside the headers.

The superheater headers are divided by diaphragms (with drain holes) to direct the steam flow into several passes to produce steam velocities sufficient to ensure a high rate of heat absorption, thus reducing tube metal temperatures to a minimum. The superheater tubes are supported by a special heat resisting cast steel support frame attached to water-cooled support tubes, these being designed so that they can be renewed without removing the superheater tubes.

The double boiler casing is of welded construction and when working with forced draught only, gas and soot leakages outwards are avoided, radiation losses are reduced and the boiler room temperature is kept low. This type of boiler must be fitted with the drum axes fore and aft.

Control of superheat temperature is within certain limits effected by the fitting of an attemperator (see Chapter 9); to provide steam reduced to within 10°C of saturation temperature for auxiliary purposes, a desuperheater can be fitted.

Selectable superheat boiler

This boiler was developed to meet a demand by the Royal Navy for a wide range of steam temperature control in a single furnace boiler, and it has since been modified to suit Merchant Service requirements.

Essentially it is a two-drum, bent-tube boiler having an integral furnace at one side formed by an extended screen of tubes, which are part of the main circulation system. The main bank of tubes, between the upper and lower drums, is divided into two sections by a vertical baffle to provide two parallel straight-through gas passes, *in which the proportions of the total gas flow are regulated* by two sets of dampers at the outlets (see Figure 4.31).

The superheater is contained entirely in one of these passes, and the steam temperature it produces can be selected by adjustment of the dampers. The two sets of dampers are linked together and can be operated by one lever, either by hand or by automatic control, and being in a low-temperature zone, do not have to be of special heat-resisting steel. The uptakes from the dampers subsequently combine and lead the gases to an economiser, air heater or both, before reaching the funnel.

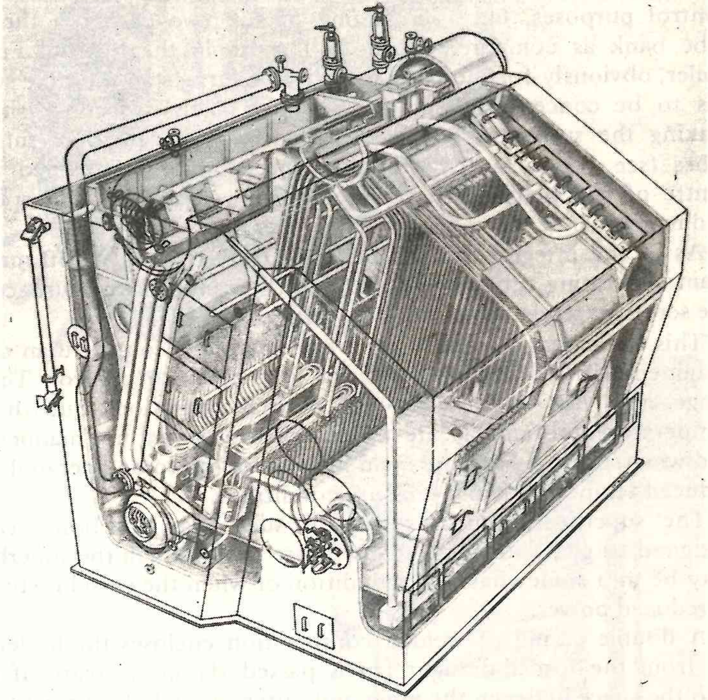

Figure 4.31 Cut-away view of Babcock marine boiler, selectable superheat type Showing a single furnace and two sets of dampers for adjusting the gas flow through the superheated and saturated sections of the boiler.

The boiler furnace is water-walled in a similar manner to that of the integral furnace type.

The main bank baffle between the two gas passages is formed by chrome-ore refractory on studded tubes 50 mm o.d. and 32 mm o.d., this requiring very little maintenance. A gas leak through this baffle merely affects the range of steam temperature control, the superheater being designed to obviate excessive steam temperature in the event of baffle failure.

The superheater is arranged to have several steam passes and with the steam outlet in the cooler part of the gas stream near the rear of the boiler, so that the steam velocities are high and the highest steam temperature occurs in tubes which are in a gas zone of comparatively low temperature; the metal temperatures are therefore reduced and the possibility of vanadium attack is lessened.

In view of the fact that the superheater extends, for superheat control purposes, only across one of the two passes in the main tube bank as compared to the full width in the Integral Furnace boiler, obviously for the same superheater surface all the tube surface has to be concentrated in this one pass. This is accomplished by making the superheater elements into double instead of single U-tubes (see Figure 4.31). Adequate access space is provided in the centre of and behind the superheater for water washing, inspection and maintenance.

As in the integral furnace boiler, staggered rows of 50 mm o.d. main generating tubes screen the superheater from the furnace, and the screen extends across the full width of the boiler.

This boiler has a wider range of temperature control than can be obtained with an attemperator and is simpler to control. The full range may not be necessary in normal operation, but the low temperatures obtainable are useful when warming up, manoeuvring and when, of necessity, the main machinery has to be operated under reduced temperature and pressure conditions.

The superheat control system is such that this boiler can be designed to give full steam temperature even though the superheater may be in a somewhat dirty condition or when the vessel is steaming at reduced power.

A double casing of welded construction encloses the boiler, and air from the forced-draught fan is passed via an air heater if fitted into the space between the inner and outer casing before reaching the burner wind box. The whole unit is thus jacketed by air under pressure, and leakages outwards of gas and soot are eliminated and radiation losses are kept low. This type of boiler must be fitted with its drums fore and aft.

From the foregoing it will be noted that these two types of Babcock & Wilcox boiler have much in common, their main difference being in the method of superheat control. The drums of both types are of fusion-welded construction, and to reduce moisture carry-over to the superheater, the mixture of steam and water discharged into the steam drum from the generating tubes is passed through cyclone separators (see Figure 4.32). Positive circulation in these boilers is achieved by fitting large unheated downcomers

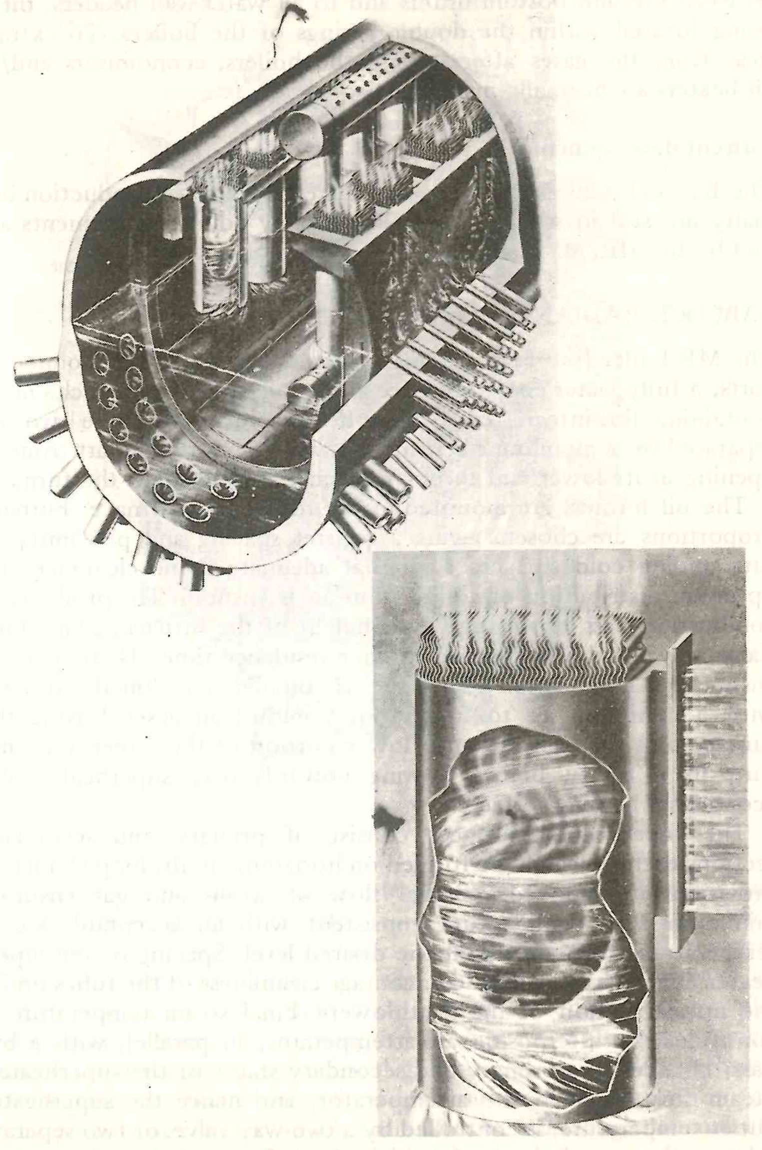

Figure 4.32 Babcock Cyclone steam separator
(Above) Sectional view of boiler drum showing the cyclone steam separators and baffle plates to which the cyclone inlets are connected. (Right) Cut-away view of cyclone steam separator showing vortex formed as the high velocity steam and water mixture enters at the right; bubble free water discharges at the bottom and the steam exit is through the scrubber plates at the top.