The Running and Maintenance of Marine Machinery

edited by Dr J Cowley

Marine Management (Holdings) Ltd for
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The Running and Maintenance of Marine Machinery

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James Templeton studied Mechanical Engineering at The Royal College of Science and Technology, Glasgow, followed by a year at the School of Thermodynamics, University of Birmingham. In 1961 he took up a post with Torry Research Station, MAFF, working on the development of ship board plant for chilling, freezing and refrigerated storage of fish. He joined Christian Salvesen (Seafoods) Limited in 1970 with responsibilities for the specifications and installation of fish freezing and refrigerated storage plant. From 1981 to 1990 he worked on development projects in a number of developing countries as a management, refrigeration and training consultant. In 1990 he joined Lloyd's Register of Shipping, working in the refrigeration department on the appraisal and classification of marine refrigeration installations for refrigerated cargo vessels, liquefied gas tankers and refrigerated containers.

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Robert Thomas joined BP Tanker Co Ltd in 1958 as an Engineer Cadet under the alternative training scheme. On completion of his cadetship he served as an engineer in the fleet before taking up a shore appointment with BP Shipping in 1971. In 1981 he was awarded the Denny Gold Medal for his paper 'Development of Marine Fuel Standards'. After serving in various parts of the BP Group, he joined DNV Petroleum Services as Technical Coordinator in 1992.

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BS MA100; BS 1170; BS 1427; BS 1523; BS 2690; BS 2917; BS 3939; BS 4099; BS 4941; BS 5345; and BS 5750.

Contents

WATER TUBE BOILERS

The major designers of marine water tube boilers are Foster Wheeler (USA, UK), Babcock (USA, UK, Germany), Combustion Engineering (USA) and Kawasaki Heavy Industries (Japan).

All of the above have extensive international licensee networks so that boilers to one basic design can be manufactured in many different places. Although marine boilers have been, and can still be, offered with forced or assisted circulation, present day practice is for these designers to offer main propulsion boilers based upon natural circulation. Forced circulation units will, however, be found in many exhaust gas heat recovery boilers used on motorships. Some of these, and many auxiliary boiler designs, are offered by companies other than these four, but for main propulsion, they are dominant.

From an operational point of view it is essential that the boiler be kept clean. This is particularly true on the water sides as overheating, and subsequent failure, is only prevented by a good supply of water boiling within a clean tube. The importance of this is clear when considering the high heat fluxes found in the furnace zone, where a deposit scale 0.6 mm thick can elevate the tube temperature some 215°C above what it would be were the tube clean. This is because the scale has a very high resistance to heat flow, requiring a large temperature difference to pass the heat flow incident upon the tube. Such an increase in tube temperature can bring the tube material into the range where oxidation occurs, leading to eventual tube failure.

In early designs the need for internal cleanliness was recognised and catered for by making provision to simplify cleaning operations with the mechanical means then in vogue. This meant using straight tubes, or tubes with a minimum number of easy bends, to allow passage of tube cleaning brushes, and the provision of access to the ends of each. As a result the boiler pressure parts were perforated with numerous access openings each of which had to have a pressure tight closure when the boiler was operational. The making and keeping tight all of these fittings was to prove the downfall of the straight tube boiler and encouraged the acceptance of a greater degree of welding in boiler pressure parts and the adoption of chemical cleaning.

External cleanliness is important, not only because of the risk of corrosion associated with the presence of fire side deposits, but also due to the risk of differential fouling. In a superheater, for example, if some parts become more fouled than others the products of combustion will be forced to take a preferential path through the less fouled area, locally increasing heat transfer in this zone and elevating tube temperature as a result. This too can lead to eventual tube failure. Further external fouling means that the products of combustion leave the boiler at a higher temperature, reducing efficiency, wasting fuel and imposing a fire risk.

The object of the circulation system is to provide a good supply of water to all of the heated tubes in a water tube boiler. Heat transferred through the tube walls produces steam bubbles in the water within. Tubes in high heat transfer zones will contain more steam than tubes in lower heat zones so the density of steam/water mixture will be lower in the former than in the latter. If these separate zones are connected top and bottom by collecting vessels, such as drums or headers, then circuits are formed in which the different densities will cause flow to occur—upwards in the low density tubes, downwards in the others. The greater the difference in density, the brisker the flow will tend to be. This is the essence of a natural or gravity circulating system (Fig 1) and in practical designs the principle is enhanced by specific design features such as drum internals aimed at preventing steam inclusion into downflowing tubes

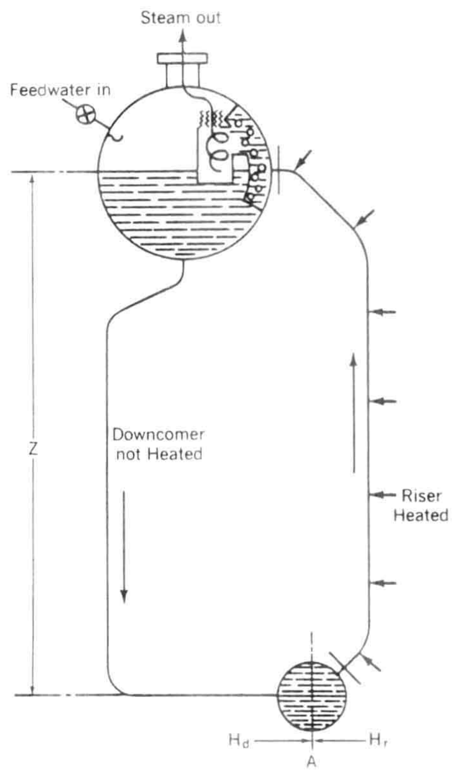

Figure 1 Simple natural circulation circuit (diagrammatic) including primary steam separator in drum.

(to obtain maximum density) or by arranging all downflow tubes to be unheated (for the same reason).

A boiler will be divided into many such circuits with varying heat absorption rates. The flow in each is established at the heat absorption corresponding to maximum load when a total balance flow condition exists. It is normally sufficient to make such calculations at maximum load but further analysis may be required if the boiler is to operate at more than one pressure level and, in the case of a warship, investigation may be needed for extended operation in a heeled damage condition when the circulating head is reduced due to the inclination. The work involved in analysing the many circuits which make up a modern marine boiler is tedious and time consuming and is best achieved with the aid of a computer.

BOILER TYPES

The three main classes or types of water tube boiler in use at sea today are bi-drum convection bank boilers, bi-drum radiant boilers and single drum radiant boilers.

Bi-drum convection bank boilers are developments from the integral furnace boilers introduced in the USA during 1939–45, which were characterised by partially water cooled and highly rated furnace zones followed by a convection superheater receiving some radiant heat from the furnace through a screen of generating tubes and completed by a further substantial bank of smaller bore generating tubes. These units were designed to fit into the small spaces available in the ships of the period, having limited headroom. Steam conditions were modest at around 30 bar, 400°C at the superheater outlet. At these pressure levels a large amount of latent heat has to be provided when generating steam. With the advent of larger ships, particularly VLCCs, and advancing steam conditions up to around 60 bar, 510°C at the superheater outlet, it was possible to consider an alternative design basis characterised by a large, moderately rated furnace, fully water cooled, and followed by a convection superheater receiving no direct furnace radiation. At these higher steam conditions the amount of latent heat added is much reduced and, in combination with the large water cooled furnace, a steaming economiser behind the superheater provides adequate generating surface. Figure 2 shows how the distribution of heat has changed, allowing elimination of the generating bank. A steaming economiser is defined as one where the water temperature rise within is more than 60% of the difference between saturation temperature and that of the inlet water, and it may or may not generate a small amount of steam in service.

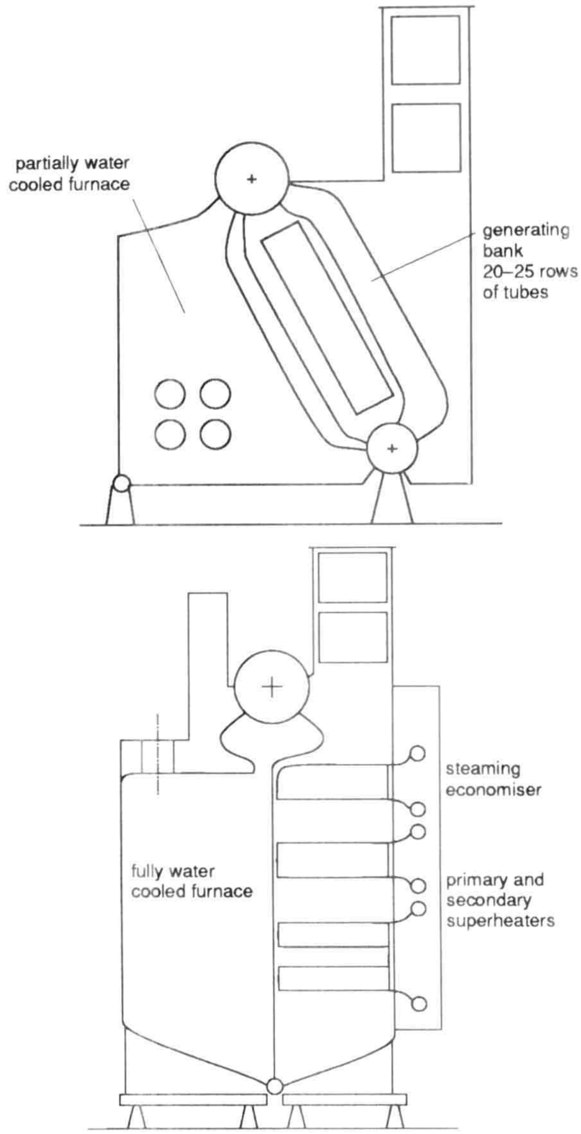

Figure 2 Heat distribution related to steam conditions: a) bi-drum D type, 31 bar 400°C; b) radiant, 63 bar 513°C.

Proportion of total heat added	*bi-drum type*	*radiant type*
to feedwater	20.3%	23.8%
to generation	64.3%	52.9%
to superheat	15.4%	23.3%

The early versions of the bi-drum boiler were an important advance in their time but changes in refining methods on crude from various sources produced residual type fuel oils which began to reveal their shortcomings. The furnaces, being small and employing large amounts of refractory, operated at very high temperature. Flame impingement was not unknown and conditions generally for the refractories were severe and resulted in high maintenance. Refractories broke down requiring replacement. They were frequently covered in glass-like deposits, and on the furnace floor especially thick vitreous accumulations often required the use of road drills for removal.

In the superheater zone the products of combustion were still at high temperature and deposits from impurities in the fuel condensed out on the tubes, reducing heat transfer and steam temperature. Eventually, gas passages between the tubes would become so badly blocked that the forced draught fans would be unable to supply sufficient air to the burners, combustion became impaired and the fouling conditions accelerated. Sodium and vanadium compounds present in the deposits proved very corrosive to superheater tubes causing frequent repeated failure. Due to the fouled conditions there was a loss of efficiency and expensive time consuming cleaning routines were required.

There were many palliative steps introduced between that time and the early 1960s when the first marine radiant boiler was designed. Varying degrees of success were achieved by increasing the proportion of furnace wall cooling using stud tubes or tangent tubes (Fig 3) and by artifices such as wider superheater tube spacing or by removing the whole superheater to a more protected zone at lower temperature. It was, however, the impetus provided by the bulk transportation of crude oil that concentrated minds sufficiently to attack all of the problem areas of the past and to introduce features such as all welded gas tight membrane tube or monowall furnace enclosures (Fig 3) leading to boiler types which have generally proved successful in achieving high efficiency with much reduced levels of maintenance, namely the radiant boiler described in its various guises in the following pages.

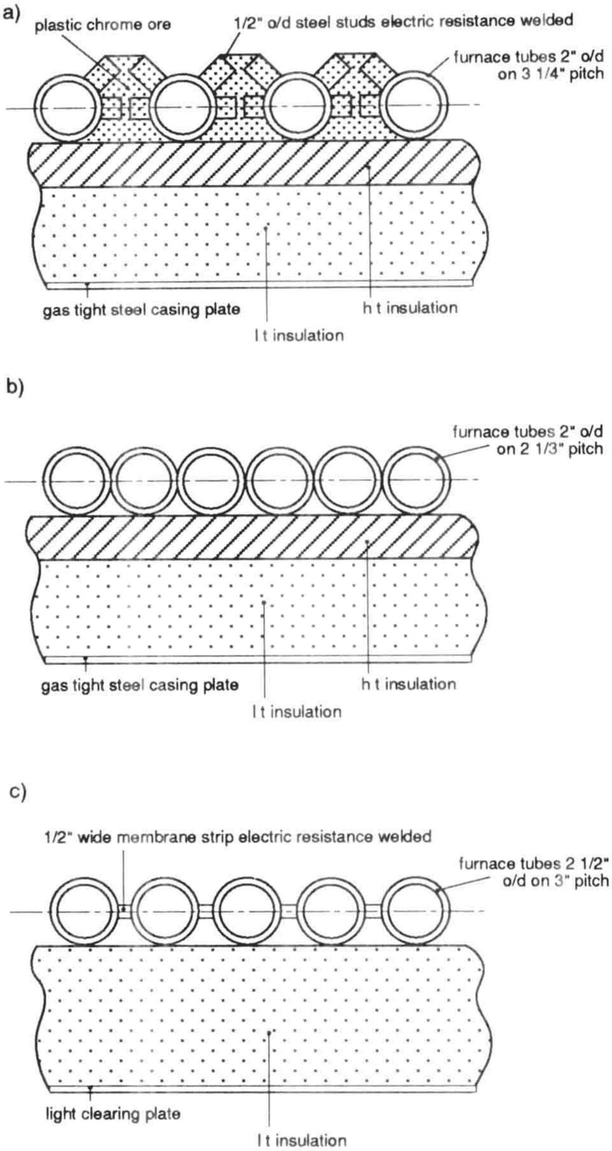

Figure 3 Water cooled furnace wall construction: a) stud tube; b) tangent tube; c) membrane tube panel (monowall).

Foster Wheeler

D type boiler

This is an early bi-drum design in which the two drums are connected by a multi-row bank of small bore generating tubes, and three rows of larger bore screen tubes in front of a U-loop superheater (Fig 4). The furnace side wall tubes extend upwards from a header at floor level, turn over to form the furnace roof and are connected to the steam drum. The furnace rear wall is water cooled and the lower headers of this and the side wall are fed with water from the lower drum. The two drums are connected by unheated downcomer tubes. The front wall and floor of the furnace are refractory lined. The horizontal U-tubes of the superheater are connected to vertical inlet and outlet headers. Baffles are fitted inside the headers, requiring the steam to make several passes through the tubes, thus achieving the high steam velocity necessary to ensure safe tube metal temperature in service. Oil burners are fitted in the refractory front wall of the furnace and, on leaving the boiler, combustion gases pass over further heat recovery surfaces such as economiser (heating feedwater) or air heater (heating combustion air). Steam sootblowers are fitted to give means of on load cleaning of boiler, superheater and further heat recovery tubes.

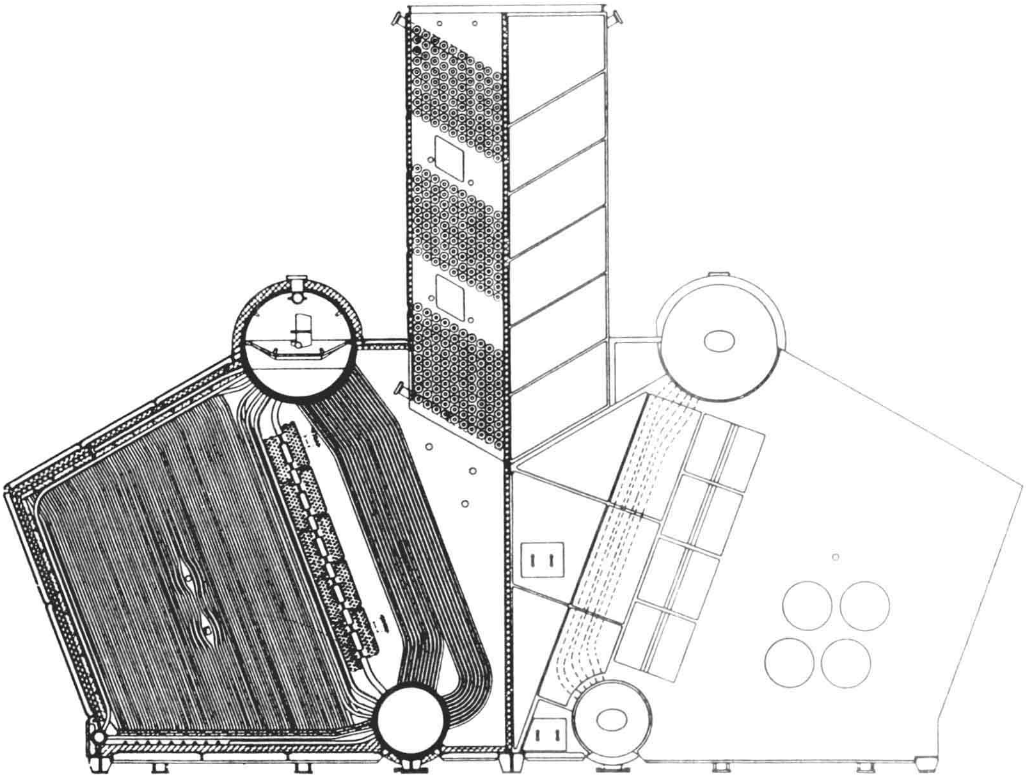

Figure 4 Foster Wheeler D type boiler.

a) b)

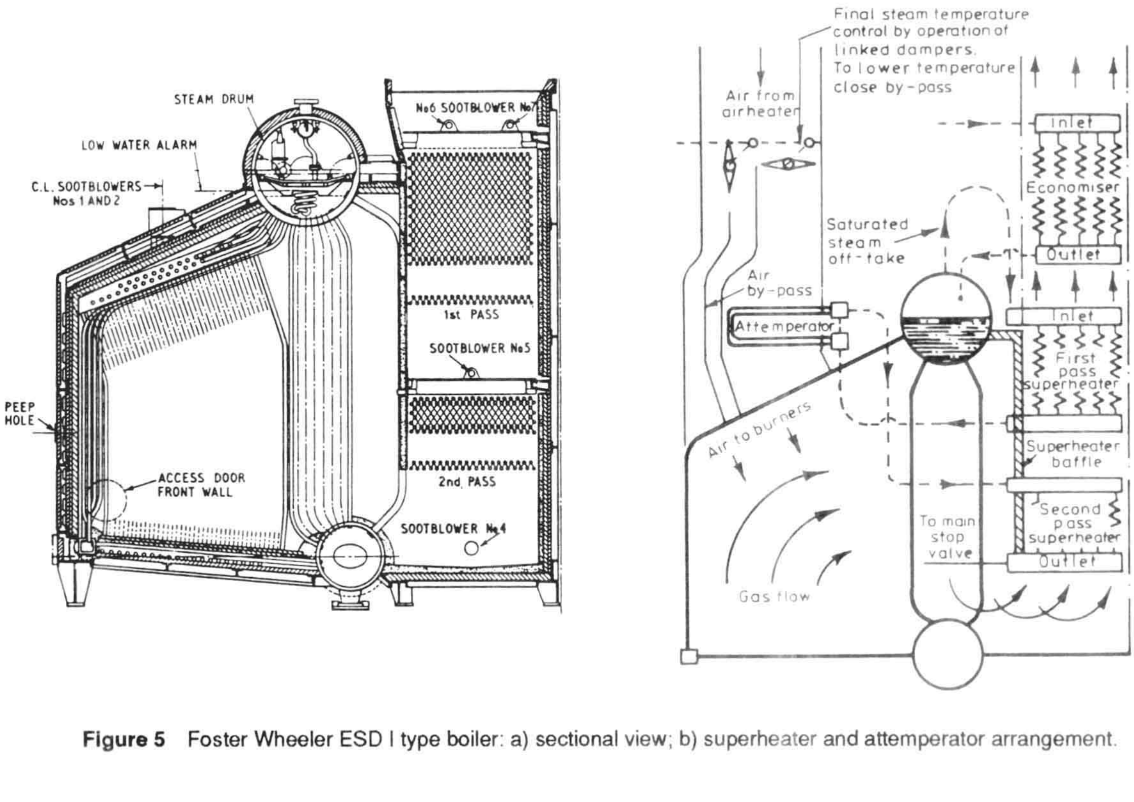

Figure 5 Foster Wheeler ESD I type boiler: a) sectional view; b) superheater and attemperator arrangement.

ESD I and ESD II type boilers

In an attempt to combat the problems experienced with the early 'D' types, Foster Wheeler introduced the External Superheater D type in which the basic construction methods remained as for the D type but the superheater was removed to a position behind the generating tube bank which was reduced in depth. This resulted in a reduced steam generating surface, an increased superheater surface and an increase in heat recovery surface beyond the boiler. Finding itself in a cooler gas temperature zone compared to the D type, the superheater exhibited a much greater rate of change of steam temperature with load and for this reason steam temperature control was adopted, even though design final steam temperature was only 450°C. In the mark I version (Fig 5) steam temperature control was by means of a steam-combustion air heat exchanger and in the mark II by damper control of gas flow over the superheater (Fig 6).

ESD III type

The ESD I and II designs still contained a good deal of refractory material in the furnace zone and very many expanded tube joints and gaskets. It was seen that maintenance could be reduced if these were reduced in extent or eliminated. In the ESD III the furnace was much enlarged and the bi-drum radiant approach appeared with the adoption of complete water cooling and burners mounted in the furnace roof. This increase in radiant surface reduced the need for a large generating tube bank which, in this design, reduced to eight rows in staggered formation, formed from the lowest metre or so of the four rows of tubes separating the furnace from the superheater. The superheater was further enlarged, permitting wide gaps between the tubes. Steam temperature control, now used because of more advanced steam conditions, was achieved by use of a steam-boiler water heat exchanger located in the upper drum (Fig 7).

Refractory was still not eliminated, but was largely shielded from direct radiation by close pitched furnace wall tubes. Many expanded joints also remained. The superheater tubes, being arranged parallel to the drum axis, tended to be long, requiring intermediate support along their length, and this proved to be troublesome in service. Further steps were taken to address these matters and an improved version of the ESD III (Fig 8) used gas tight, all welded monowalls in place of refractory lined casings behind tangent tubes for the furnace, and extended monowall construction to the superheater pass. The number of rows of tubes between furnace and superheater was reduced from four to two and the superheater was now aligned at right angles to the drum axis, the resulting shorter tubes not needing intermediate support.

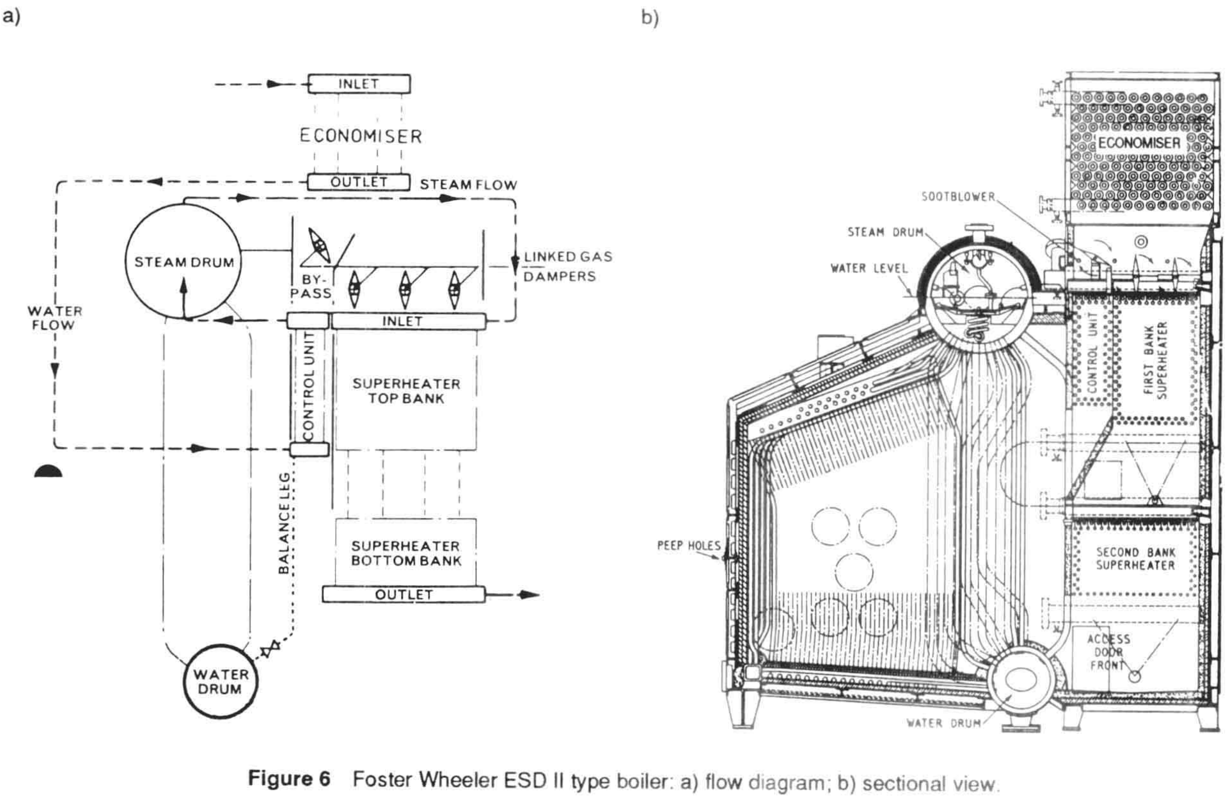

Figure 6 Foster Wheeler ESD II type boiler: a) flow diagram; b) sectional view.

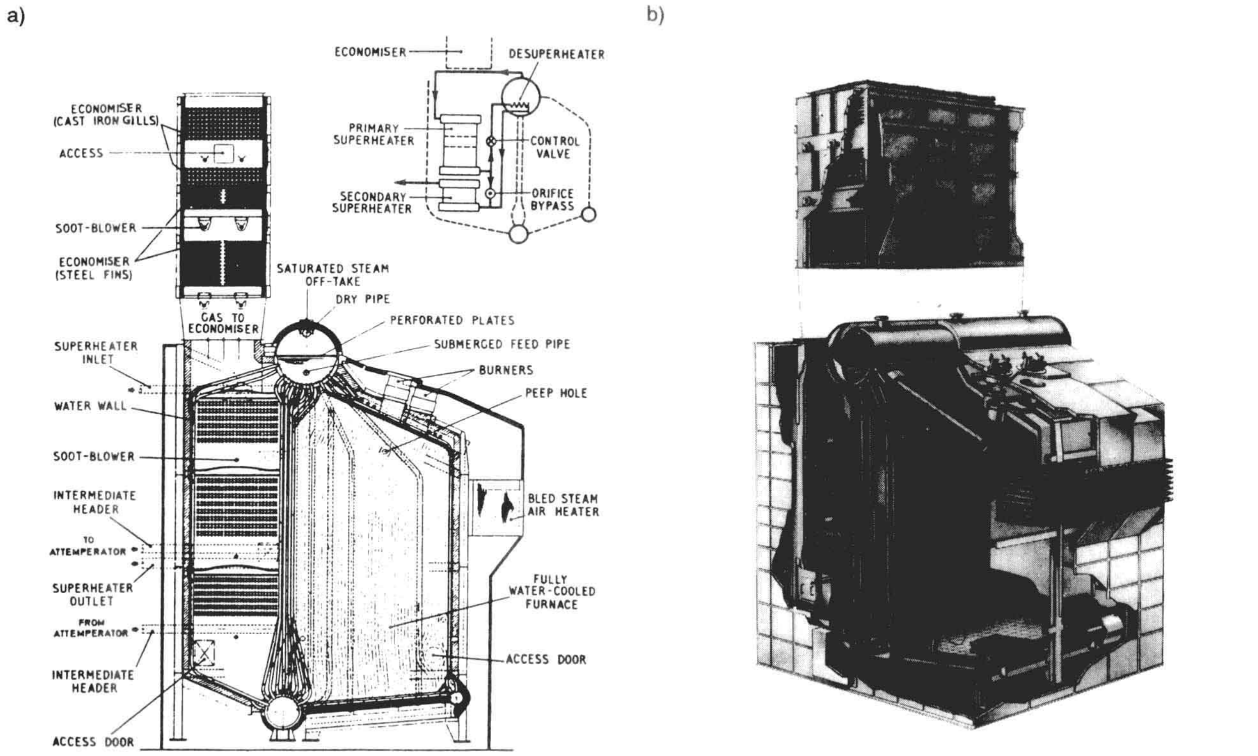

Figure 7 Foster Wheeler ESD III type boiler: a) sectional view; b) internal view.

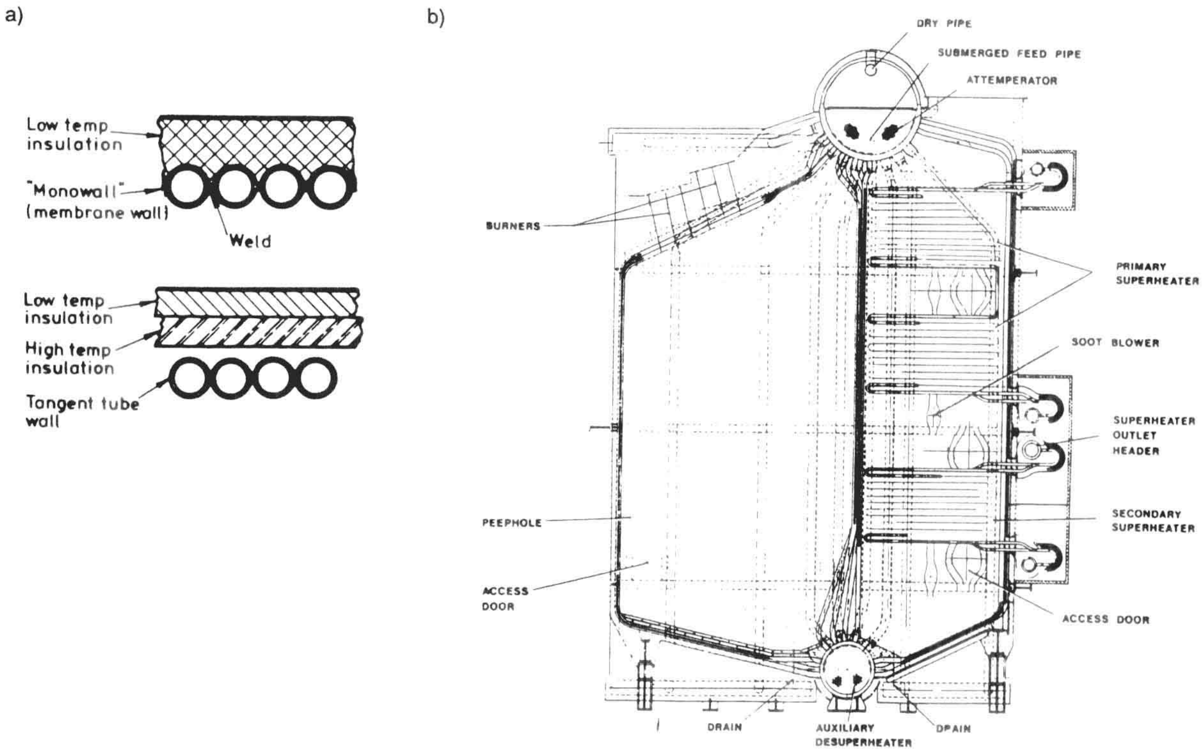

Figure 8 Foster Wheeler ESD III type boiler: a) alternative furnace tube arrangements;b) later type showing mono-wall construction.