The Design and Development of Two-drum Marine Boilers

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The paper outlines the technical and practical considerations which have influenced two-drum boiler design up to the present day, indicates the ideas which are now in the "drawing board" stage and suggests the possible course of future development. Particular emphasis is placed on the problems of external deposits on superheaters and corrosion of air-heaters and economizers.

Economics are also discussed and a typical optimization study for the boiler plant of a 25,000 s.h.p. set of machinery is included.

INTRODUCTION

Improvements in Diesel engine design have reduced maintenance costs and enabled a lower grade fuel to be burnt; also the power available from the single Diesel engine has increased. On the other hand deterioration in the quality of boiler fuel has increased the maintenance costs of a turbine ship. Since the specific fuel consumption of a steam installation is higher than that of the corresponding Diesel, steam engineers have concentrated on burning cheaper fuel and increasing steam temperatures and pressures. This has further increased maintenance and first costs.

A large proportion of the increase in maintenance cost is associated with the boiler plant and every effort must be made to reduce this and increase availability, at the same time, reducing initial costs and simplifying operation. An increase in boiler efficiency would be welcomed but, since current plants are designed for between 86 per cent and 88 per cent of the gross calorific value of the fuel, only modest steps can be expected in this direction.

The maintenance problems which are raised are, generally speaking, only severe with certain fuels and it must be emphasized that many ships are steaming without the troubles highlighted in this paper even with older designs of boilers. It would, however, be reasonable to assume that the quality of the fuel in steam ships in general will deteriorate and a larger proportion of vessels will be burning the troublesome fuels more frequently encountered in tankers at present.

Throughout the paper reference is made to deterioration in the quality of boiler fuel. It is fully appreciated that this is, probably, not the best choice of words and what is really implied is an increase in the proportion of substances in the fuel which gives rise to boiler maintenance problems.

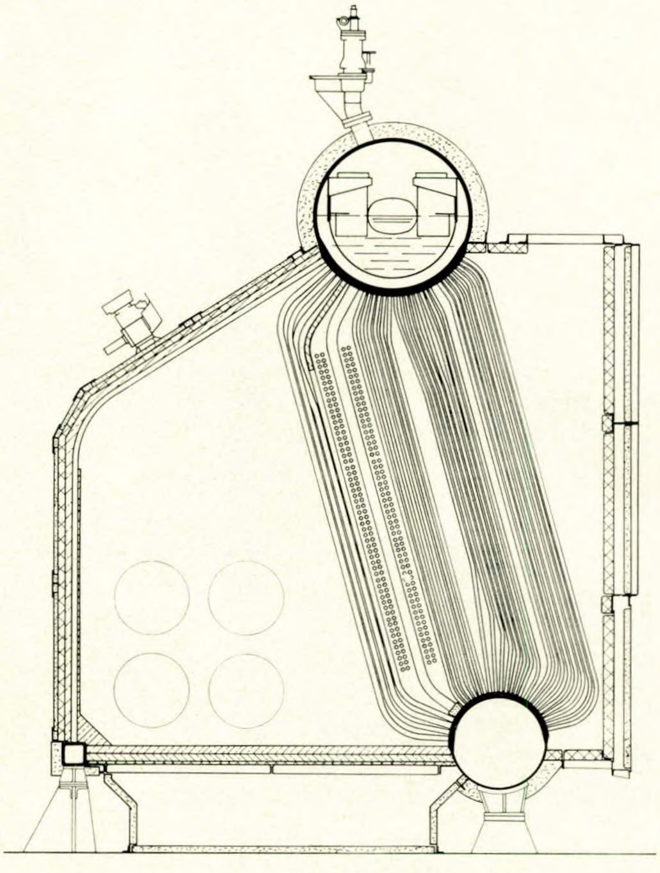

FIG. 1

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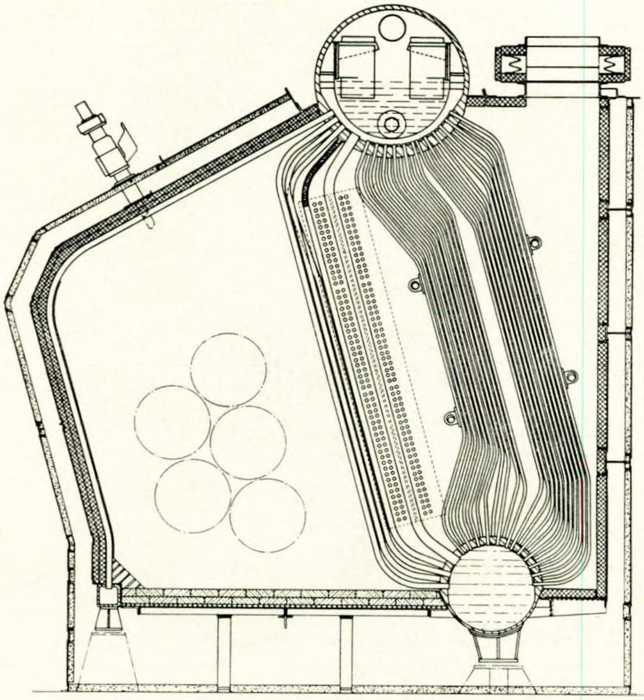


FIG. 2

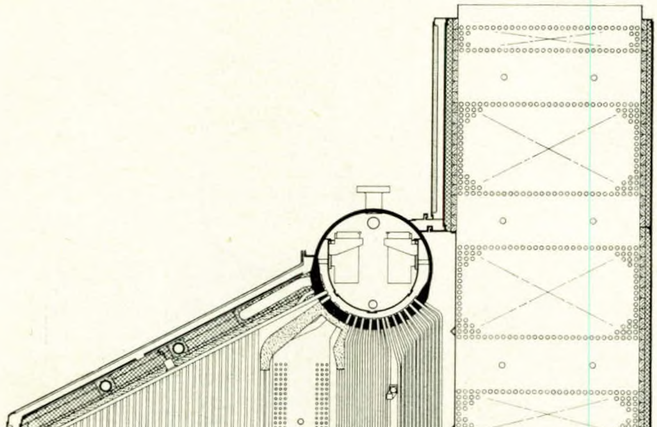


FIG. 3

HISTORY

A typical 1945 two-drum boiler design is shown in Fig. 1. Furnace walls were of 42 per cent alumina pre-fired bricks wherever practical since, with feed water conditions at that time, extensive use of water walls could not be justified. Only the side wall and roof were water cooled to avoid problems associated with bricks suspended from the furnace roof. This unit gave satisfactory service for many years but, as the quantity of vanadium and sodium in the fuel increased, bonded deposits occurred on the superheater tubes and brickwork maintenance increased. These very hard deposits could not be removed by the multi-jet soot blowers then in use and the limited access to the superheater made hand cleaning and water washing difficult. Thorough inspection of the surface after cleaning was impossible. This is essential since repeated inefficient water washing can result in the build up of an even harder deposit containing little soluble matter which may eventually take many days to remove.

Designs were modified to provide access to the superheater. Firstly, a British design (Fig. 2) was produced with a space behind the superheater and a few years later an American design (Fig. 3) appeared with a "walk-in" space in the centre of the superheater. Lower quality fuels became more widely used and the incidence and rate of fouling of superheaters increased. The deposits were difficult to remove by hand cleaning and water washing became the rule. The "walk-in" space was superior for this purpose. Corrosion of superheater supports and soot blower elements and bearings became common and furnace brickwork maintenance increased. Replacement of soot blower elements and bearings was easier in the British boiler but superheater supports were difficult to renew in all designs. Water treatment improved so that maintenance of water wall tubes was reduced. In the late 1950's designs as illustrated in Fig. 4 were common, having two access spaces in the superheater zone and water cooled furnace rear walls. By this time superior refractories were available and the furnace front wall was often built of mouldable refractory containing 60 per cent alumina.

Some earlier boilers had only a single casing at the furnace side, others were single-cased except for the wind-box in which case both forced and induced draught fans were necessary. Later designs were completely double-cased and required only forced draught.

RECENT DEVELOPMENTS

Although the design illustrated in Fig. 4 had better access, little had been done to reduce the effect of bonded deposits. In recent years long retractable soot blowers (rack blowers) and water washing of the fuel itself have been adopted. Ships fitted with either of these two systems are currently steaming for periods of twelve months with little loss of performance due to superheated slagging. The wider use of steam atomizing burners has also effected an improvement and arrangements are now made to simplify and expedite water washing if necessary. With higher steam temperatures, welding of superheater tubes and handhole fittings is more common.

Rack Soot Blowers

The element of a rack soot blower has only two jets and is completely withdrawn when not in use thus reducing element corrosion. There are no supports in the gas zone and, when operating, the element is traversed across the gas passage and rotated at the same time. The jets are thus constantly moving so that larger jets and higher steam pressures are possible without risk of erosion of the heating surface. The increased size of jets and higher steam pressure provide a superior cleaning effect and the movement of the jets gives better coverage of the heating surface. The blowers are operated by a remote controlled electric or pneumatic motor but the element

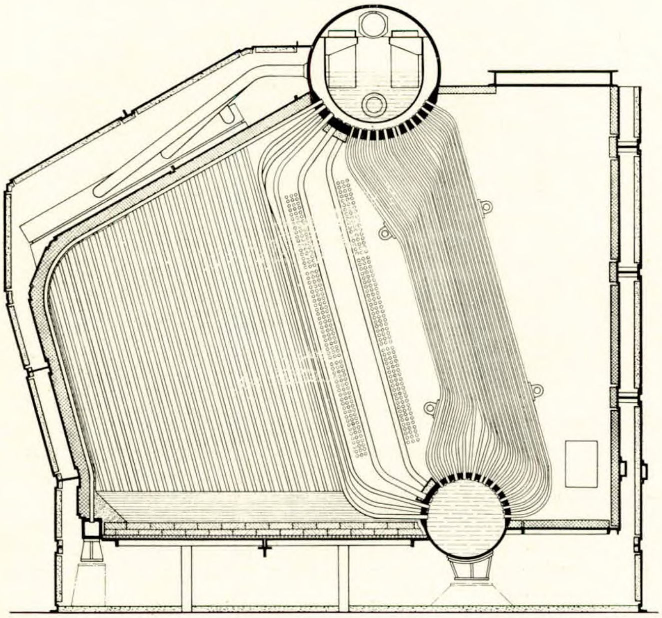


FIG. 4

can be withdrawn by hand if the control or motor fails while the element is inserted.

Fuel Washing

If the sodium content of the fuel is reduced, deposits on superheaters are less troublesome even when vanadium is present. It is difficult to remove vanadium from a fuel but by water washing and centrifuging the amount of the sodium can be reduced. This subject is discussed in detail in a recent paper[(1)].

Steam Atomizing Burners

Service experience in several vessels over the last ten years indicates that, as a result of using "Y-jet" steam atomizing burners, superheater deposits are reduced. Because the CO_2 is higher, the funnel temperature lower and deposits are reduced throughout the plant, the average efficiency in service is improved. With less deposits, soot blowers are not used as frequently. These three factors offset the cost of the steam used for atomization.

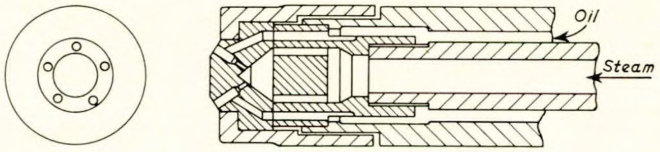


FIG. 5—*Tip assembly of a "Y-jet" steam atomizing oil burner*

In the "Y-jet" burner (Fig. 5), the oil is atomized by steam at sonic velocity. Excellent atomization is obtained at all loads without changing tips and carbon deposits are reduced. The burner operates with a maximum fuel pressure of 175lb./sq. in. and the steam supply pressure is automatically maintained at 20lb./sq. in. above the oil pressure. At service output the water consumption is usually less than 5 per cent of the oil consumption by weight while the "turn-down" exceeds 10:1.

Welded Superheaters

With steam temperatures above 875 deg. F., superheater tubes are often welded to nozzles on the superheater headers; less handholes are provided and these are seal welded. Fig. 6 shows two methods of welding superheater tubes to nozzles. When access is available to both sides of the weld, type "A" is used. Type "B" can be welded from one side providing the tube is bent through approximately 90 deg. immediately after the weld. The site weld for type "A" is by gas, but electric

FIG. 6—*Methods of welding tubes to nozzles on superheater headers*

welding is usual for type "B". In marine boilers it is sometimes difficult to provide adequate access for welding each individual tube to a nozzle and two methods of reducing the number of site welds are shown in Fig. 7. Type "A" has a short manifold into which three tubes are welded in the shop and only one weld is required between the triple tube element and the nozzle. With type "B", Fig. 7, three tubes are forged into one larger tube by a special process. The larger tube is then site welded to the nozzle. Several other alternatives are

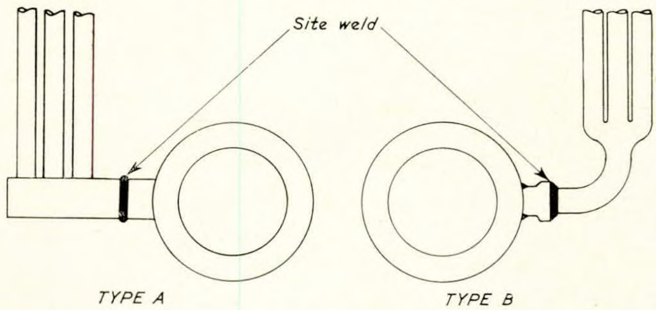


FIG. 7—*Triple-tube superheater elements welded to nozzles on a header*

possible and the choice depends upon the arrangement of heating surface. With welded tubes it is important to provide access to the welds as there is a lot of truth in the saying, "a weld is as good as the welder and the access provided for him".

Two of many types of welded handhole fittings are shown in Fig. 8. Type "A" is gas welded and is easily cut out for inspection and rewelded. Type "B" is similar to the conventional bolted oval handhole fitting but modified to permit seal welding to a mild steel saddle welded to the box. Type "B" requires a special cutting out tool but can be replaced without welding by fitting a shank and bridge piece and providing a gasket for the internal seat.

Summary

In recent years, two-drum boilers, have been installed having all the following features:

1) Access in centre of superheater.
2) Access behind superheater.
3) Rack soot blowers in the superheater zone.
4) Connexions for water washing lances.
5) Water washing drains in the furnace and elsewhere.
6) Welded superheaters.
7) Replaceable superheater tube supports.
8) Steam atomizing burners.

particular installation the machinery contractor was prepared to accept steam up to 950 deg. F. under all conditions of steaming so that steam temperature control was not essential. However a small attemperator consisting of a coil in the water pocket was fitted between the last two passes of the superheater. The attemperator valve would be shut for normal steaming and fully open when manœuvring.

BOILER DESIGN IN 1962

The design already described is typical of boilers building today. The features incorporated have reduced the seriousness of superheater slagging but improvement is still desirable to further reduce maintenance costs, increase availability and permit the more general use of cheaper fuels in steam ships.

The chemistry and mechanism of slagging is complex and not fully understood but it is known that substances which usually become bonded deposits have melting temperatures below 1,600 deg. F. so that they will not adhere to surfaces above that temperature. Service experience and field tests suggest that the slag will not appear unless the surface temperature is above 700 deg. F. and the gas temperature is above 1,600 deg. F. Therefore slagging is avoided if any one of the

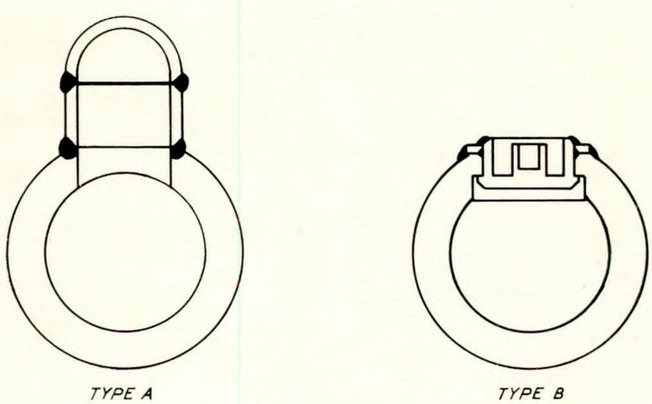


FIG. 8—*Handhole fittings welded to superheater headers*

Such a boiler, illustrated in Fig. 9, was designed for a steam temperature of 950 deg. F. The superheater had a simple U-tube construction with three loops forged into a trifurcation and welded to stubs on the headers. The superheater tubes were 1¼-in. outside diameter on 1¾-in. pitch providing a gap of ½in. between the tubes. The steam temperature characteristics are shown in Fig. 10 and, as can be seen, there is little variation with either load or CO_2. For the

following conditions is met:

1) Surface temperature above 1,600 deg. F.
2) Surface temperature below 700 deg. F.
3) Gas temperature below 1,600 deg. F.

Superheater metal temperatures above 1,600 deg. F. are obviously unacceptable. Item 2 above, would restrict the superheater outlet temperature to 650 deg. F. resulting in an excessive fuel consumption. It is possible, for moderate steam

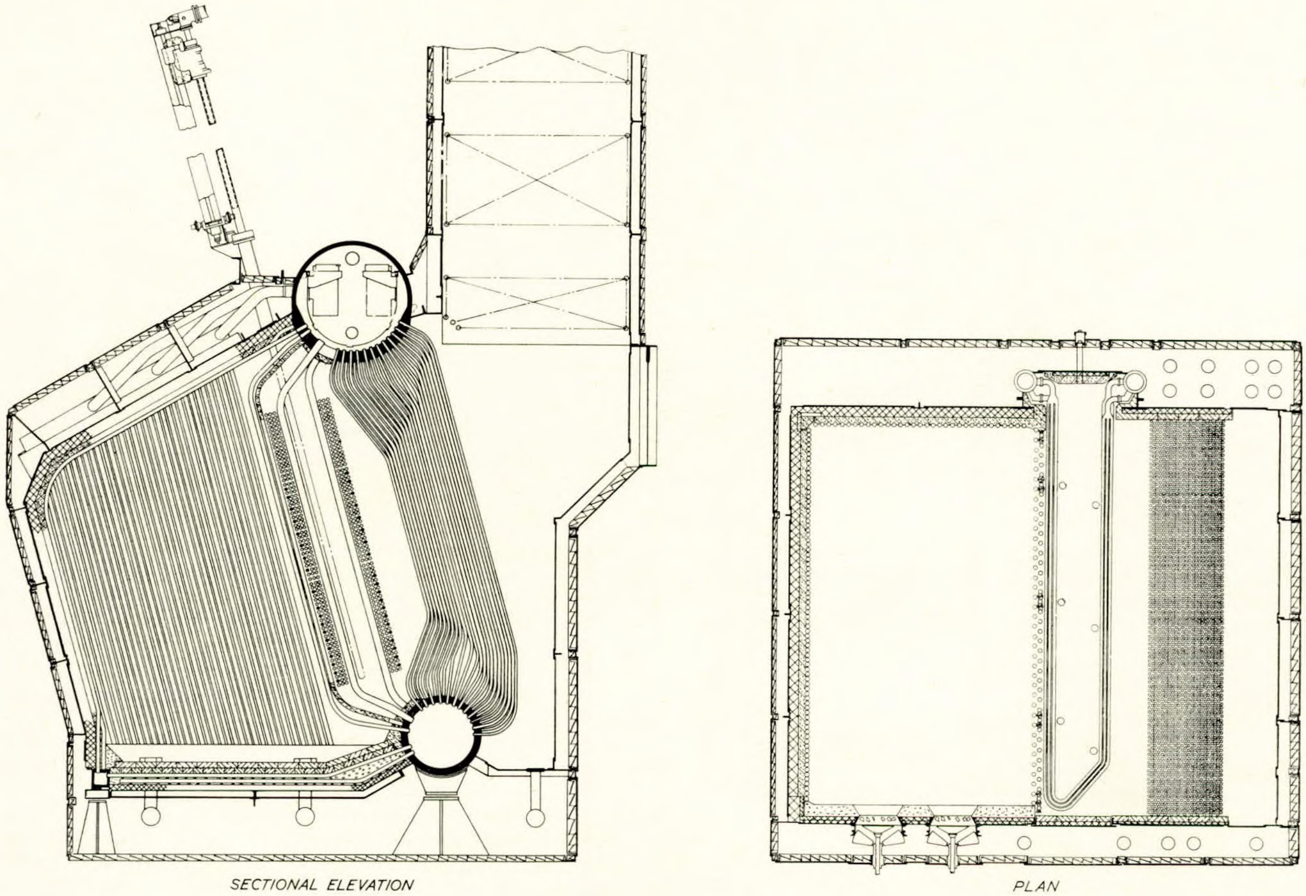


FIG. 9

temperatures (850 deg. F.), to design a superheater with an inlet gas temperature as low as 1,600 deg. F. Such a design (Fig. 11) has been in service for some years. The low inlet gas temperature demands a much larger superheater and the outlet steam temperature increases steadily with load. The superheater is also sensitive to firing conditions and steam temperature control is essential. Currently, this is achieved by providing a section of economizer surface in parallel with the superheater. Dampers control the amount of gas flowing over the superheater and hence the steam temperature. For higher steam temperatures it is necessary to increase the inlet gas temperature and bonded deposits must be expected. It will be shown later that bonded deposits may be most troublesome on superheaters with a moderate inlet gas temperature (1,700-1,900 deg. F.).

If full advantage is to be taken of advances in metallurgy and steam turbine design it is desirable, even when automatic steam temperature control is included, to limit the natural variations in steam temperature with load, when manœuvring and with indifferent firing conditions. To do this the superheater must be placed in a high temperature gas zone and while vanadium and sodium are present in the fuel, bonded deposits will occur. As already stated the extent of these can be reduced by the use of steam atomizing burners, rack soot blowers or by washing the fuel, but the basic design of the superheater itself has a significant effect on the problem.

Service experience indicates that the majority of the slag will form on the first row of superheater tubes. Slag will not be excessive on later rows until the deposit on the first row has reached a maximum. Slag thickness in excess of ⅜in. is rare on superheaters designed for 850 deg. F. outlet temperature with gas temperatures entering the superheater at 2,200 deg. F. In several vessels with gas and steam temperatures as stated and 1¼-in. o.d. superheater tubes on 1¾-in. pitch, complete blocking of the last two passes of the superheater is common and rapid. On other vessels with similar conditions and fuels but where the pitch of the tubes is 2¼in., slagging is experienced but bridging between the tubes is unusual except in certain areas where soot blowing is less effective or the gas

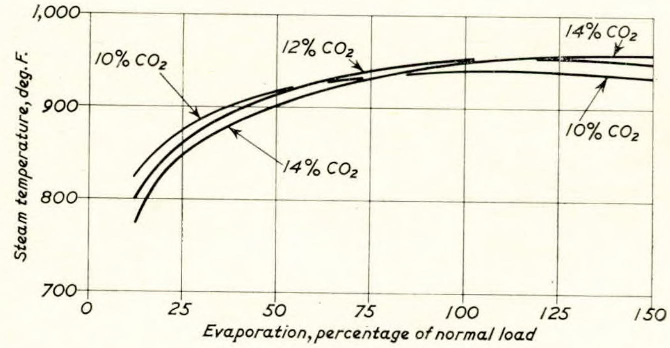


FIG. 10—*Variation of steam temperature with load and CO_2 content of flue gases*

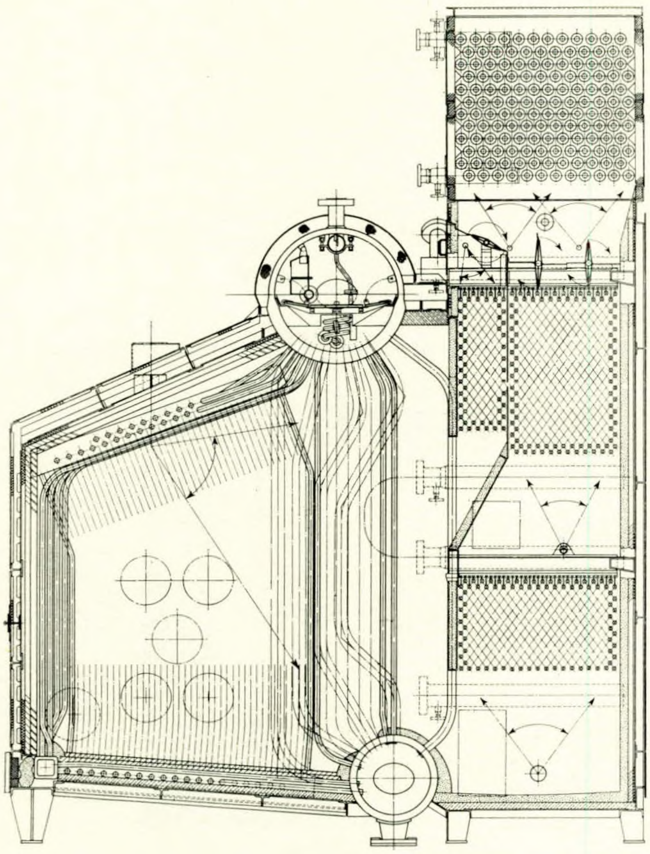


FIG. 11

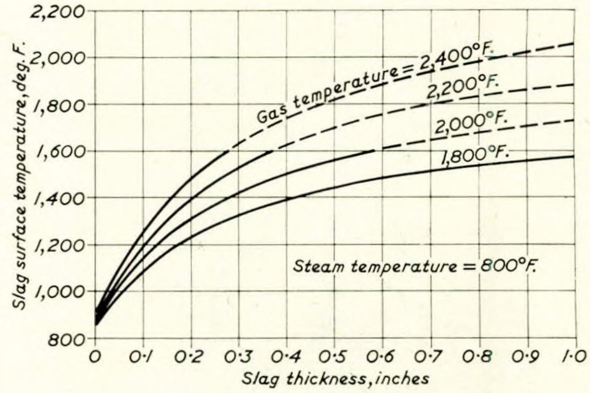


FIG. 13—*Effect of slag thickness and gas temperature on the surface temperature of slag on a superheater tube*

flow pattern is disturbed. This experience is on older designs with multi-jet soot blowers.

A correct analysis of slagging of superheaters is not possible but by assuming a value for the conductivity of hot slag, the effect of various items can be estimated. The answers thus obtained may not be precise but the trends indicate the relative merits of various designs. Figs. 12 to 16 show the effect of variation in gas temperature and steam temperature on the probable maximum slag thicknesses with a constant but typical rate of heat transfer from gas to slag and from slag to steam through the superheater tube and steam film.

Figure 12 shows the variation of slag surface temperature with slag thickness on a superheater designed for an outlet steam temperature of 850 deg. F. and gas entering at 2,200 deg. F. The steam temperature is shown as 800 deg. F. since the last pass of a superheater is arranged with the steam entering the leg nearest the furnace and at this point the full temperature has not been reached. It will be seen that the indications of this curve are in line with service experience and if a gap of at least 1in. is provided between the tubes, slag is unlikely to bridge across and block the superheater.

Figs. 13 and 14 show that if the gas temperature is high enough to cause slagging then the extent of this will be reduced if the inlet gas temperature is increased. This is in line with current American practice where frequently only two rows of

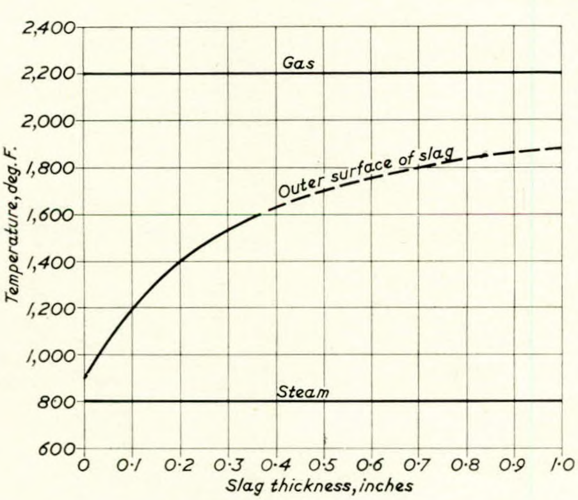


FIG. 12—*Effect of slag thickness on the surface temperature of slag on a superheater tube*

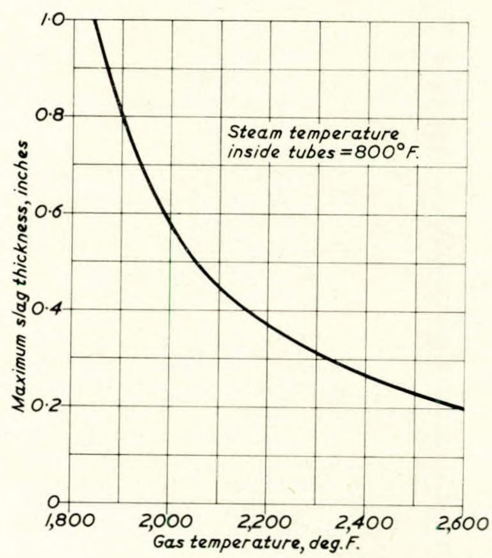


FIG. 14—*Effect of gas temperature on the maximum thickness of slag which will form on a superheater tube*

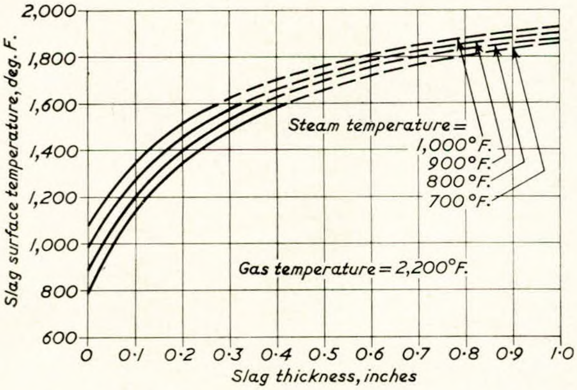


FIG. 15—*Effect of steam temperature and slag thickness on the surface temperature of slag on a superheater tube*

screen tubes are installed. Figs. 15 and 16 show that if the steam temperature is increased then the extent of slagging is likely to be reduced but the effect of steam temperature within the range considered is small.

In the latest British and American boilers the superheater is located in a similar gas temperature zone to earlier designs. The "flat" steam temperature characteristic in Fig. 10, is thus conserved but the pitch of the superheater tubes is increased. Certain American owners now specify the gap between superheater tubes to be at least 1in. With the wider pitch more rows are required and this is accomplished either by installing two superheaters arranged one behind the other or by including tubes of "W" formation.

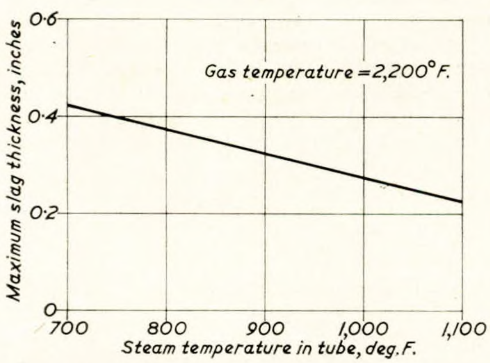


FIG. 16—*Effect of steam temperature on the maximum thickness of slag which will form on a superheater tube*

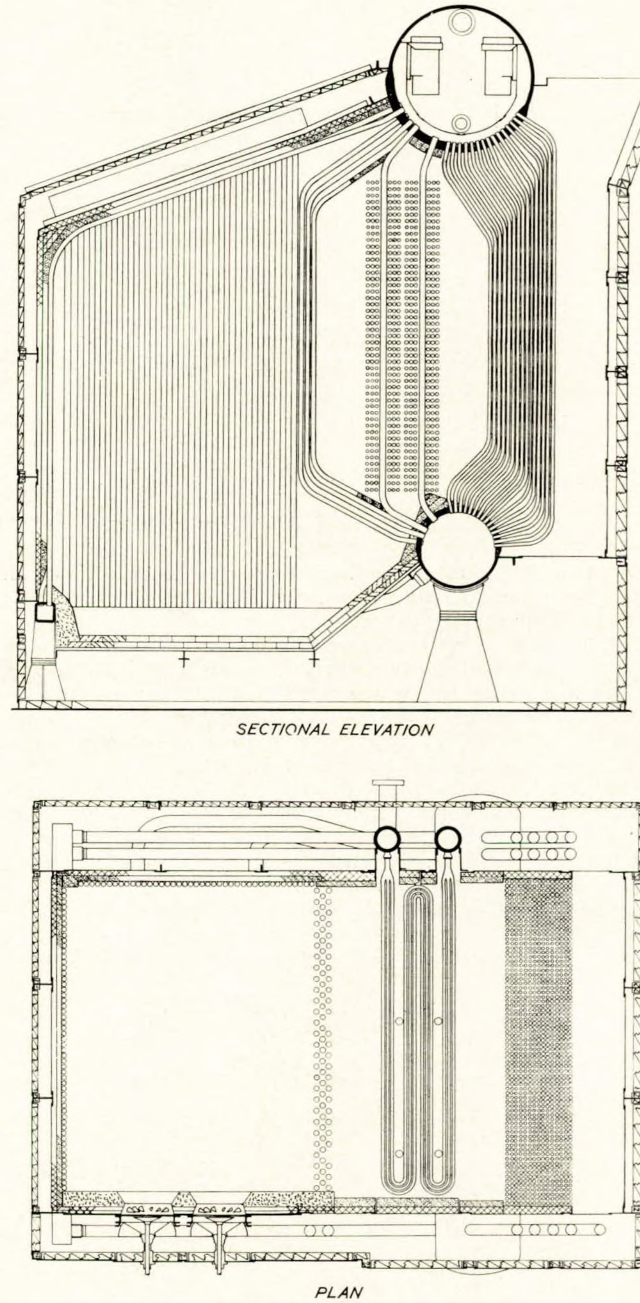


FIG. 17

One such design is shown in Fig. 17, wherein a steam temperature of 950 deg. F. is obtained with 1¼-in. o.d. tubes on 2⅝-in. pitch giving a clear gap of 1⅜in. or almost three times that of earlier designs for the same superheat. It is obvious that this wider pitch will extend the periods between cleaning and for reasons stated previously it is thought that the superheater is unlikely to become blocked by slag. Rack soot blowers, blowing directly into the first row of superheater tubes and "Y-jet" burners, are included. Access is provided immediately before and after the superheater. Separation of the first row of superheater tubes from the screen rows provides direct access to the tubes most likely to slag and an even gas flow over the superheater which will also tend to reduce deposits. A further innovation is the use of "in-line" boiler tubes so that external inspection and boiler cleaning is easier and soot blowers are more effective.

Steam Temperature Control

It has already been shown that the normal variation in steam temperature is small with the designs illustrated in Figs. 9 and 17 but it is probable that, when manœuvring, the superheat may rise temporarily above the design figure. If a feed heater or steam air-heater is out of service the superheater outlet characteristic is raised at all loads. As nominal steam temperatures increase, the safety factor for scantlings in terms of temperature is reduced and it is prudent either to design the pressure parts of the superheater, pipework and turbine for a temperature in excess of the nominal or to install limited superheat control. A small attemperator (Fig. 18) consisting of a coil through which a proportion of the superheated steam is passed, can be located in the water pocket. This is connected by pipes between the outlet of the penultimate pass and inlet to the last pass of the superheater and is bypassed for normal steaming. If, for any reason, high steam temperatures are anticipated, the attemperator is brought into use effecting

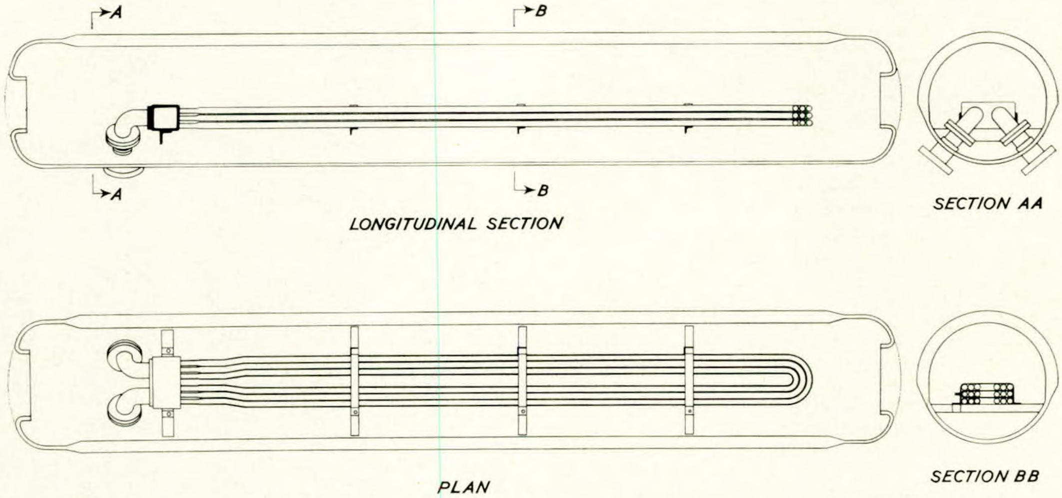


FIG. 18—*Arrangement of an attemperator in the water pocket of a two-drum boiler*

a reduction in steam temperature of about 50 deg. F. at all loads. No automatic control would be provided and the valves would be either full open or shut.

If a vessel operates for extended periods at loads well below the nominal power, superheat control will enable the full steam temperature, and hence maximum plant efficiency, to be obtained at the lower powers. Some turbines require the superheat to be reduced by 100 deg. F. or more when warming through or running astern. In both these cases a larger attemperator could be adopted with automatic control but it is difficult to install in the drums of a boiler especially if large capacity desuperheaters are also required. It could be accommodated in a separate pressure vessel but this is expensive, absorbs space and requires extra high pressure pipe joints.

When a wide range of control is required the boiler illustrated in Fig. 17 can be modified, as shown in Fig. 19, to have two parallel gas paths separated by a plastic chrome ore wall, reinforced by water cooled studded tubes. The superheater is in the path remote from the burners and additional boiler tubes are included in the other gas path. The gas flow over the superheater, and hence the steam temperature, is controlled by dampers at the boiler outlet where the gas is comparatively cool. The dampers are linked together so that both sets are operated by one lever. This principle has been used successfully in merchant and naval boilers for many years. The boiler has all the features of the more simple design except that a "walk-in" space is provided instead of the space before the superheater. This is necessary to permit withdrawal of the superheater tubes between the headers. As only a proportion of the gas flows over the superheater (the dampers are not gas-tight) and the tubes are shorter, the same steam temture could not be obtained without reducing the pitch or an additional superheater consequently the last rows of boiler tubes are replaced by a primary superheater with vertical tubes.

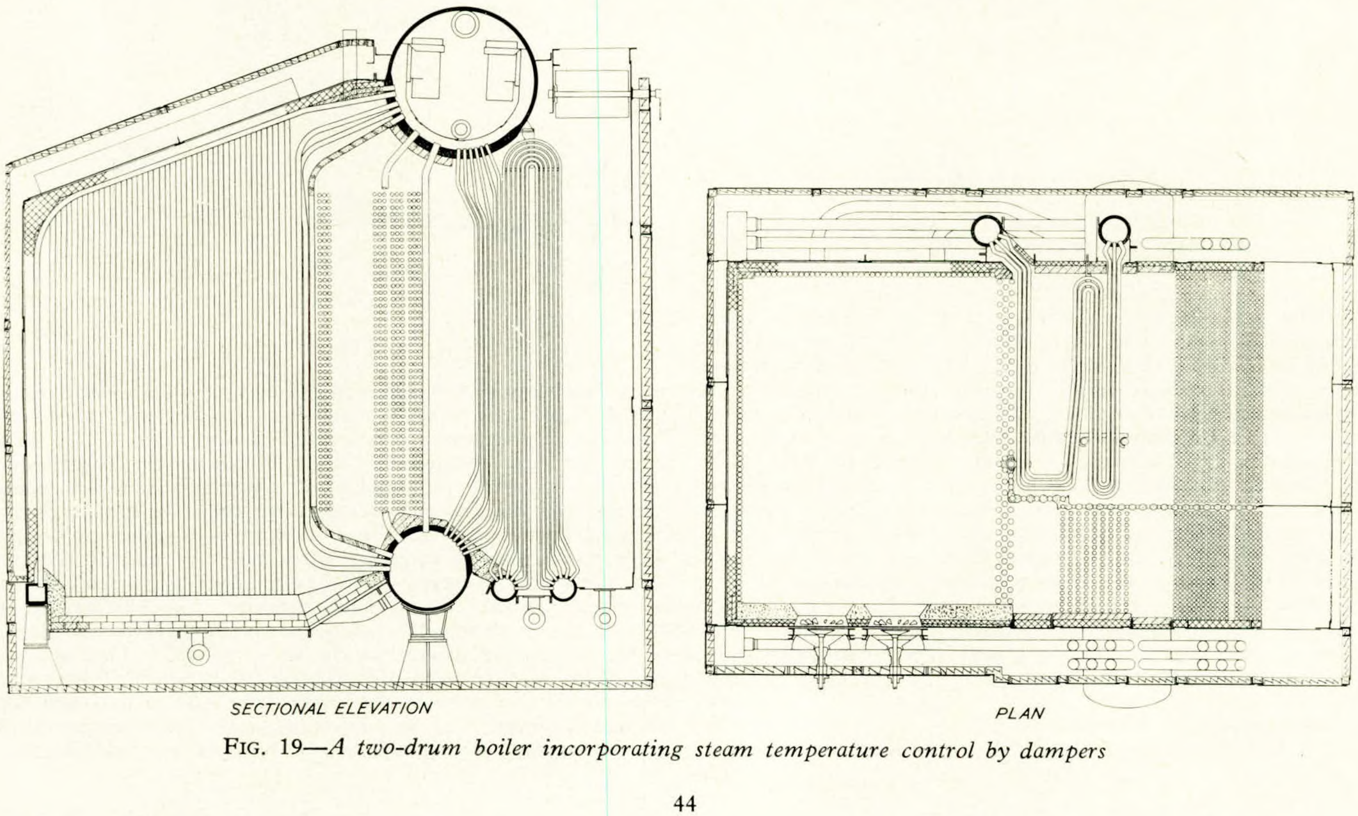


FIG. 19—*A two-drum boiler incorporating steam temperature control by dampers*

the primary superheater is in both passes of the boiler and the tubes are in line with and on the same pitch as the boiler tubes. For a final steam temperature of 950 deg. F., the steam leaves the primary superheater at about 650 deg. F. For lower steam temperatures the size of the primary superheater is reduced and the boiler surface increased.

Furnace Design

In the design illustrated in Fig. 17 the roof tubes are lower than in earlier boilers so that, to obtain the same furnace volume, the furnace floor is lower, increasing the length of the gas path from the burners to the superheater. If required the front wall could be water cooled but this would increase the width. The boiler could be arranged for side firing by increasing the height between the water pocket and the furnace floor and accommodating the burners beneath the water pocket

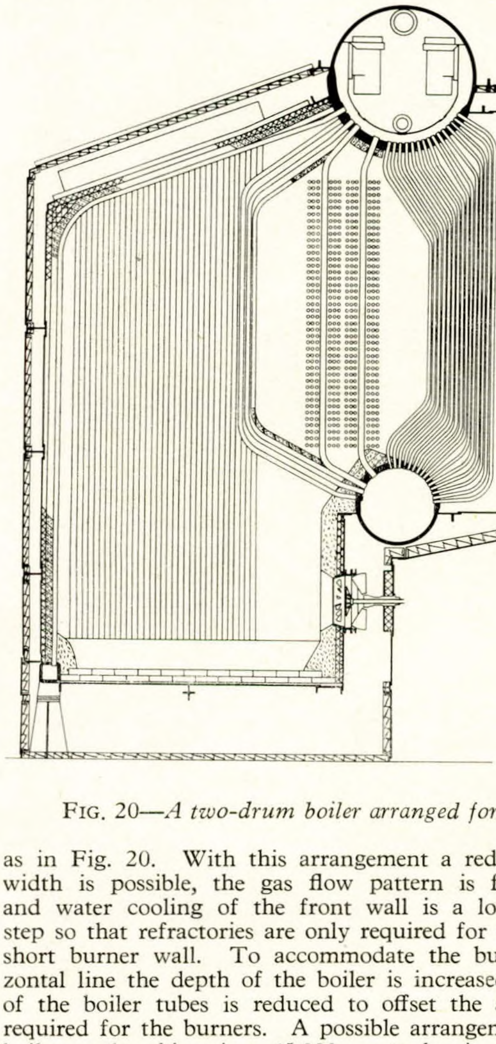


FIG. 20—*A two-drum boiler arranged for side-firing*

as in Fig. 20. With this arrangement a reduction in overall width is possible, the gas flow pattern is further improved and water cooling of the front wall is a logical and simple step so that refractories are only required for the floor and the short burner wall. To accommodate the burners in a horizontal line the depth of the boiler is increased and the length of the boiler tubes is reduced to offset the additional length required for the burners. A possible arrangement of side-fired boilers and turbines in a 65,000 ton tanker is shown in Fig. 21. This would simplify centralization of automatic control and provide a compact machinery arrangement.

With the acceptance of welding by most shipyards, large bore feeders are now run between the water pocket and the water wall headers in the air space between the inner and outer casings. Tubes under the furnace floor are thus avoided since they are liable to external corrosion, cannot be readily inspected or renewed and, being the lowest point in the boiler, collect internal deposits which are difficult to remove. There is also the risk of damaging the tubes if the furnace floor brickwork has to be renewed particularly if there is a heavy slag on the floor.

As steam pressures advance more strict control of feed

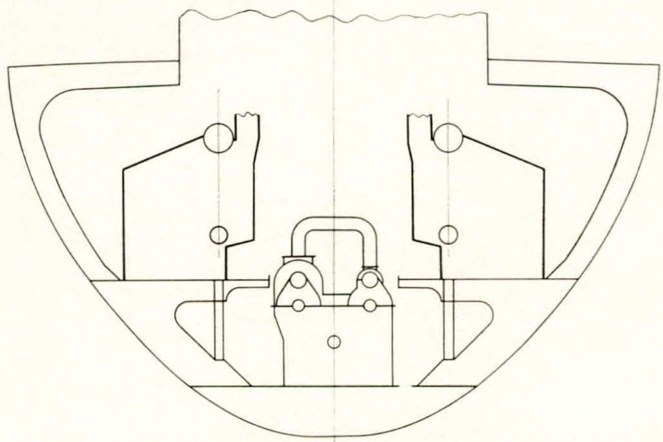


FIG. 21—*An arrangement of side-fired boilers in a 65,000 ton d.w. tanker*

and boiler water quality are essential if furnace tube failures are to be avoided but it is desirable to simplify replacement of furnace side and roof tubes. In some boilers the furnace and water wall tube shapes have been designed to allow replacement of a tube without cutting furnace casings. This causes the furnace shape to be inflexible and replacement of tubes is not easy since when the damaged tubes are removed the refractory behind them will fall out and is difficult to re-install. Alternatively the furnace roof can be constructed of long narrow flanged panels each running the full width of the roof in the same direction as the tubes as in Fig. 22. The flanges

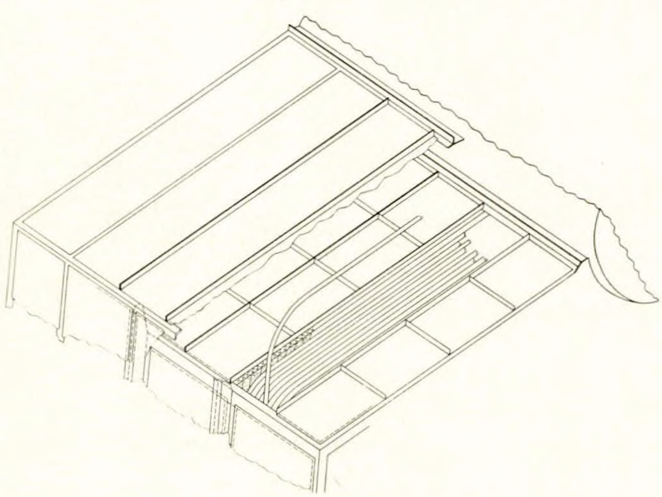


FIG. 22—*A method of designing casings for easy renewal of furnace tubes*

of adjacent panels are welded together and provide the stiffness of the casing. To replace a tube the appropriate outer casing panel is cut out followed by the corresponding inner panel thus exposing the insulation and refractory which can easily be removed. The damaged tube can then be withdrawn through the roof casing and a new tube installed by reversing the process.

Casings

All boilers are completely double-cased to reduce radiation losses and eliminate soot leakage. With this arrangement induced draught fans are unnecessary. A small proportion of cold air from the forced draught fan is permitted to bypass the air-heater and flow between the double casings at the sides of the boiler before passing to the burners. This provides very cool casings and improves the habitability of the boiler room. Sometimes this principle can be carried further depending upon the relative position of the air-heater and the air inlet to the boiler casings.

Alternative Designs

Several variations of the boiler design, illustrated in Fig. 17, have been produced recently, mainly in the United States; some of these incorporate two superheaters in preference to the "W" shaped tubes and access spaces are arranged in a variety of different places. Designs with vertical superheaters have been considered but if the tubes are to drain and also be on a wide pitch more headers are required. One such design is shown in Fig. 23. The all-welded secondary superheater is positioned furthest from the furnace so that the steam temperature characteristic is not as "flat" as with the horizontal superheater. The rack soot blower must travel horizontally and considerable space is required behind the boiler to accommodate its support beam. The soot blower could be arranged to withdraw to the front of the boiler but this interferes with the firing aisle unless the boilers are arranged with uptakes outboard. However, as can be seen in the plan view, the arrangement of superheater tubes in the boiler is excellent for burning low quality fuels. For a final steam temperature of 950 deg. F., a gap of over $2\frac{1}{2}$in. is provided between the superheater tubes in the first six rows while the later rows are of $1\frac{1}{4}$-in. o.d. tubes on $2\frac{5}{8}$-in. pitch. The later rows of superheater tubes and the boiler tubes are arranged "in-line".

It is possible to reverse the position of the superheaters so that the secondary is nearer the furnace thus restoring the flat characteristic but increasing the maximum metal temperature. This modification would tend to reduce the effect of slagging as the metal temperature of the first row of superheater tubes would be increased.

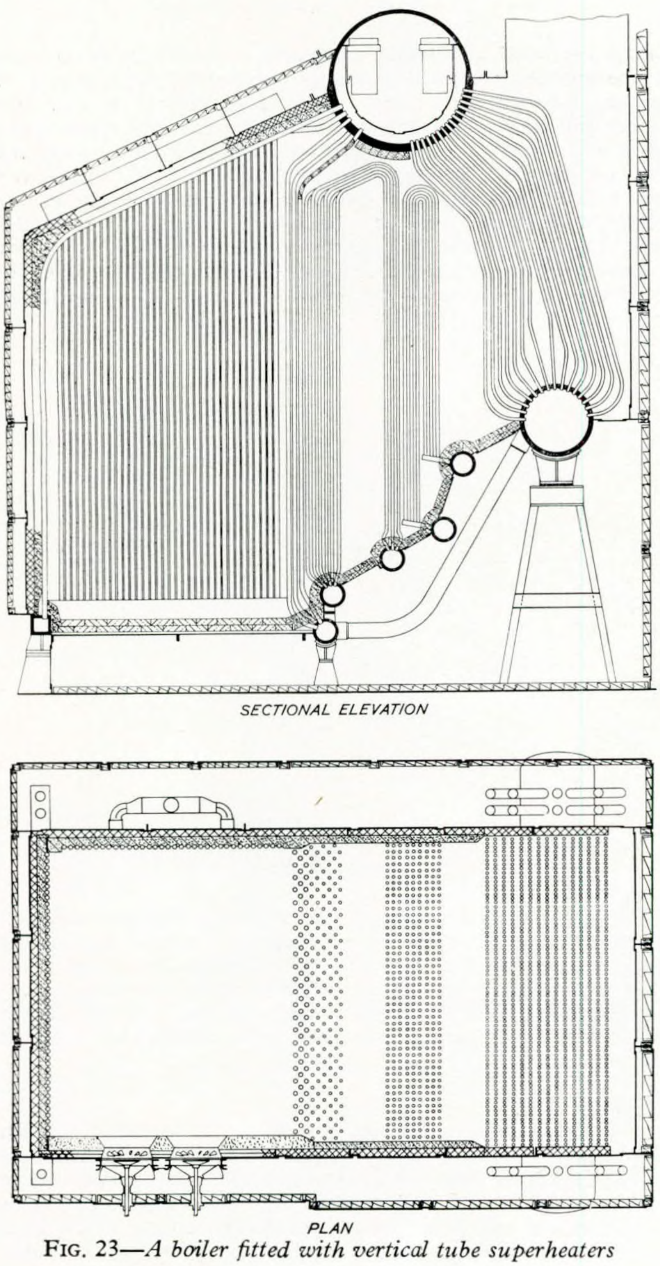


FIG. 23—*A boiler fitted with vertical tube superheaters*

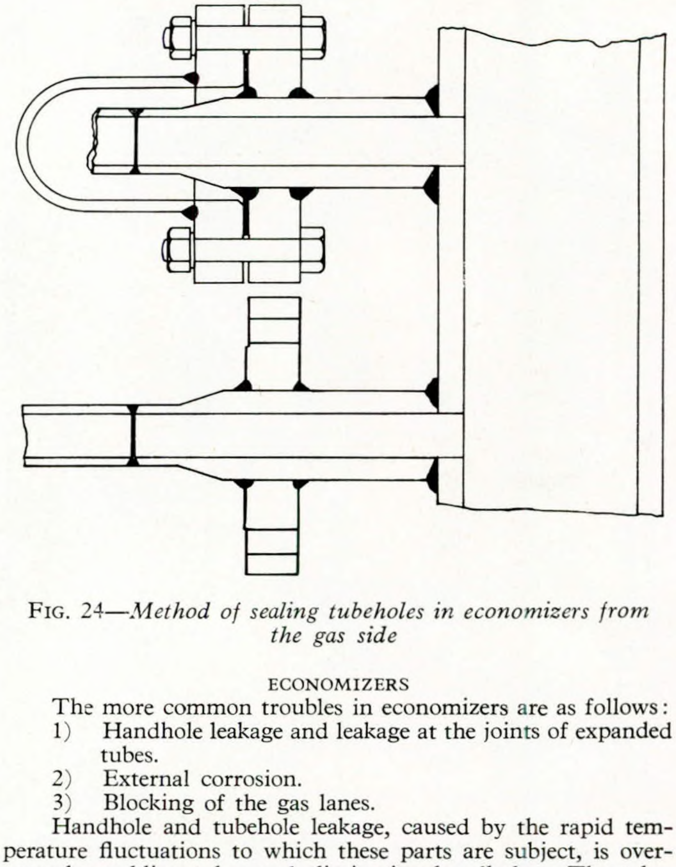


FIG. 24—*Method of sealing tubeholes in economizers from the gas side*

ECONOMIZERS

The more common troubles in economizers are as follows:

1) Handhole leakage and leakage at the joints of expanded tubes.
2) External corrosion.
3) Blocking of the gas lanes.

Handhole and tubehole leakage, caused by the rapid temperature fluctuations to which these parts are subject, is overcome by welding tubes and eliminating handholes. The tubeholes can be blanked off from the gas side in the event of tube failure as shown in Fig. 24.

When burning fuels containing 4 per cent sulphur, corrosion can be eliminated with mild steel economizers providing a high CO_2 is maintained and the water temperature is above 280 deg. F. at all times and to ensure this a nominal feed temperature of 300 deg. F. is preferable. A typical extended surface mild steel economizer tube is shown in Fig. 25. If

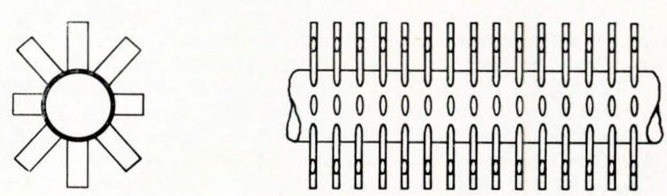


FIG. 25—*Section of mild steel extended surface economizer tube*

lower feed temperatures are dictated by other considerations then it is best to protect the mild steel tubing from acid corrosion by cast iron gills, and two typical designs using 2-in. o.d. tubes are shown in Fig. 26. An Italian manufacturer markets a heating surface using 1-in. o.d. mild steel tubes and circular cast iron gills similar to type "A" (Fig. 26), claiming significant saving in space, weight and cost, but to achieve this the gill pitch has been reduced from 1in. to ⅝in. and may therefore foul more quickly. However, the space between the tips of the gills is considerable so that, if fouling does occur, there will be loss of performance but the gas resistance of the economizer may not be excessive. With cast iron gills, acid attack can be expected if the feed temperature at any time falls below 240 deg. F., and it is preferable to adopt a design feed temperature of 250-260 deg. F.

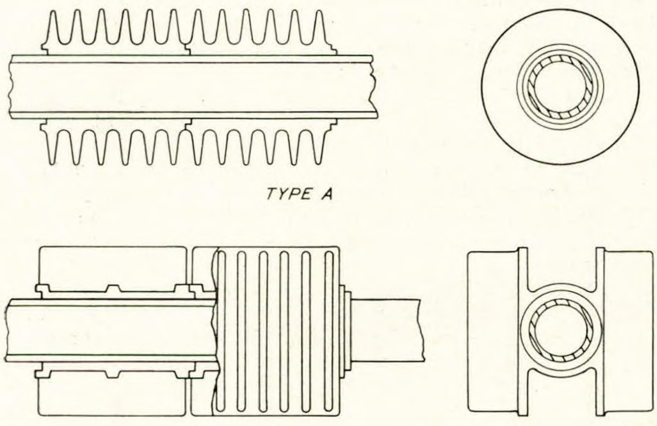


FIG. 26—*Sections of economizer tubes with cast-iron gilled protection shrunk on to mild steel tubing*

With some of the poorer qualities of fuel encountered today, blocking of air-heaters and economizers, with deposits and corrosion products is serious when the metal temperature is below 220 deg. F. This type of deposit is not always easy to remove.

AIR-HEATERS

Up to the late 1940's most European steamships had air-heaters with vertical tubes whilst, in American-built vessels, horizontal tubes were used. Both types gave good service, but in Europe the horizontal tube air-heater fell into disfavour when a number of fires occurred in this type. Neither design is a serious fire hazard when the plant is operated correctly, but when a fire occurs it is more isolated in the vertical type, because the deposits which initiate the fire are contained within a tube and, therefore, burning is likely to be restricted to a few tubes. In the horizontal design, once a fire starts it can readily spread throughout the gas side of the air-heater. During the war American 15-knot vessels steamed in slow convoys often with very low oil pressures, without being permitted to use soot blowers. This created the necessary conditions for fires in both air-heaters and economizers, but little was heard of economizer fires since, at that time, few merchant ships had economizers.

With lower quality fuel, corrosion and blockage of the air-heaters became worse. The deposits on air-heaters proved impossible to remove in vertical tube designs but could be cleared by water washing on the horizontal type.

It was soon realized that corrosion was a function of metal temperature and, provided that the metal temperature was above 280 deg. F., it was thought that in general little trouble would be experienced. With the tube diameter and length and general shape acceptable in a marine air-heater, the mean metal temperature of the tubes is considerably closer to the temperature of the fluid flowing outside them (i.e. the gas in a horizontal tube design or the air in the vertical type) and this, together with the ease of cleaning, encouraged the swing to horizontal tube air-heaters in Europe, particularly as after the war little was heard of fires in tubular air-heaters. Unfortunately, in assessing the metal temperatures in horizontal tube air-heaters, the designers at first disregarded the cooling effect of the vortex created as air enters a tube and the reduction in gas speed which occurs close to the tube plate. These factors can be overcome by fitting ferrules in the first part of the tube but corrosion is still experienced for a short distance from the tube plate due to the cooling effect of the plate itself.

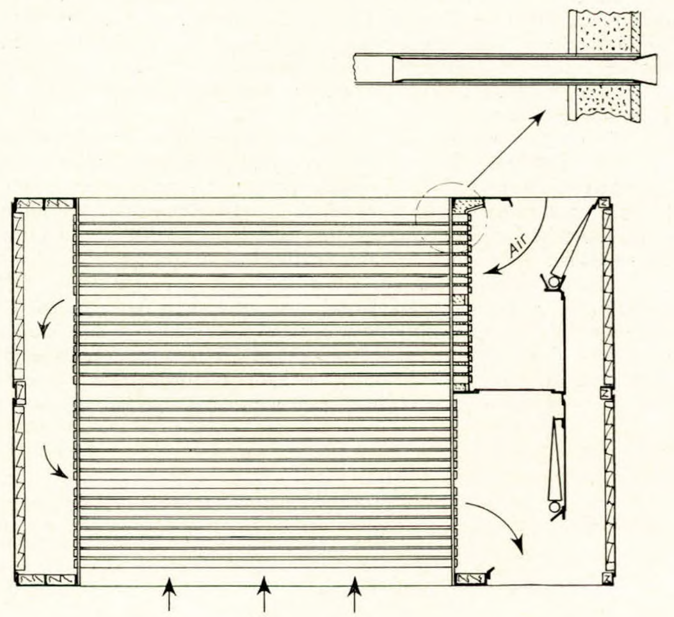


FIG. 27—*Typical horizontal tube air-heater with ferruled tubes and an insulated tube plate*

A modern design of air-heater, illustrated in Fig. 27, has the tube extended 4in. past the tube plate and a ferrule six diameters long inserted at the inlet. The extension forms a key for insulation to eliminate cooling of the tube plates and tube ends by the incoming air and improves the performance of the air-heater, since a smaller part of the effective heating surface is ferruled.

With this design of air-heater, corrosion is generally reduced but still remains a problem in certain ships required to steam at a reduced power for any length of time or burn fuel with a very high sulphur content.

Over ten years ago, experiments were made with various coatings on air-heater tubes and vitreous enamel seemed to offer the best chance of success but this line of approach was discontinued for the following reasons. Enamelled tubes cannot be expanded into a tube plate without cracking the enamel therefore various glands were designed but these were expensive and prevented the tubes from being placed in an ideal arrangement. Many enamels were tried, some resisted corrosion but cracked badly, due probably to differential expansion between the enamel and the tube; others did not crack, but were unable to resist the acid. Superior vitreous enamels are now available and experiments have been re-opened with encouraging results. The cost of the tubes with which experiments are being conducted at the present time is more than twice that of the corresponding plain mild steel air-heater tubes, but if production increases, this may well be reduced. If these tubes prove satisfactory, as seems quite probable, gas air-heaters can be designed for higher efficiencies than at present without risk of corrosion. Blocking will also be reduced as the majority of deposits on air-heaters are corrosion products and other deposits will not adhere so readily to the enamel.

ECONOMICS

Designs submitted by different boiler makers for the same project or as alternatives by the same maker may differ from each other in the following respects unless the specification is unusually comprehensive:

1) Efficiency and basis of calculation thereof.
2) CO_2.
3) Fan pressure.
4) The proportion of total fan discharge pressure absorbed by individual parts of the plant.

In the United States most designs are based on 14 per cent CO_2 while in Europe the figure varies from 13 per cent to 14 per cent depending upon the burner manufacturer. The higher figure is preferable as it improves efficiency and corrosion of air-heaters and economizers is reduced by operating with low excess air.

Two otherwise equal designs may have different efficiencies and fan pressures. Higher fan pressures reduce the boiler plant cost but increase the fuel consumption, the cost of fans and motors and possibly the cost of the turbo-generators. Higher efficiencies reduce the cost of fuel but increase the cost of the boiler plant and, possibly, the maintenance charges.

The optimum design efficiency and fan pressure will depend upon the type of vessel, the service it is required to perform, the power, the feed system and the type of boiler selected. The time required to optimize a design is considerable and therefore this is only carried out for certain projects and the designer uses his experience when preparing other schemes. The following optimization study was recently prepared for a 26,000 s.h.p. set of machinery and the basic data is given in Table I.

TABLE I

Number of boilers	2
Normal evaporation	94,000lb./hr./blr.
Maximum evaporation	110,000lb./hr./blr.
Superheater outlet pressure ...	600lb./sq. in.
Superheater outlet temperature ...	950 deg. F.
Feed to primary economizer ...	250 deg. F.
Feed from primary economizer ...	290 deg. F.
Feed to secondary economizer ...	360 deg. F.
Ambient air temperature ...	100 deg. F.
Air temperature leaving steam air-heater	320 deg. F.
CO_2	14 per cent
Funnel gas temperature	344 deg. F.
Efficiency at normal load ...	88 per cent of G.C.V.
Gross calorific value of fuel ...	18,500 B.t.u./lb.
Oil consumption at normal load	6,600lb./hr./blr.

In order to optimize the plant the following assumptions were made:

1) Price of fuel = £7 10s. per ton.
2) Time at sea at normal power = 270 days per annum.
3) Capital charges = 15 per cent of cost per annum, i.e. for an alteration to be economic, the reduction in annual fuel cost so effected must be equal to or greater

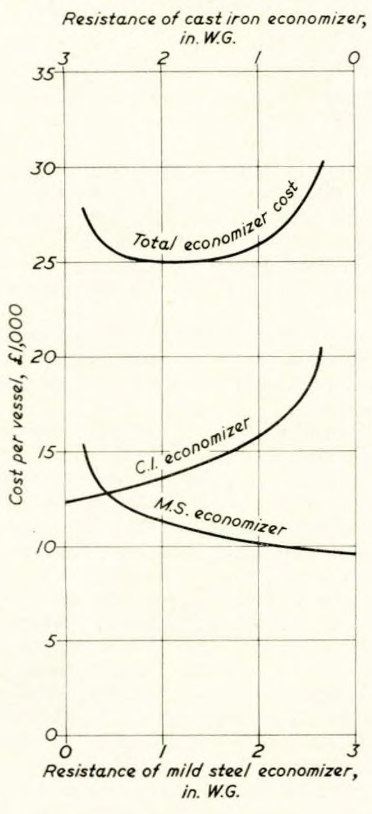


FIG. 28—*Optimization of ratio of resistances of economizers when total economizer resistance is 3in. w.g.*

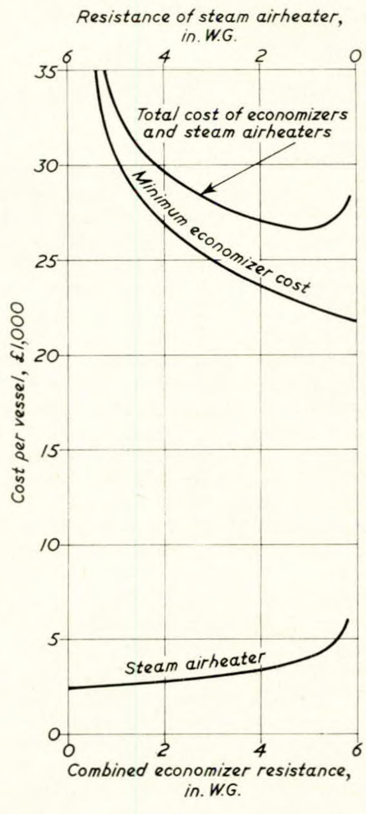


FIG. 29—*Optimization of ratio of resistances of economizers and steam air-heaters when combined resistance is 6in. w.g.*

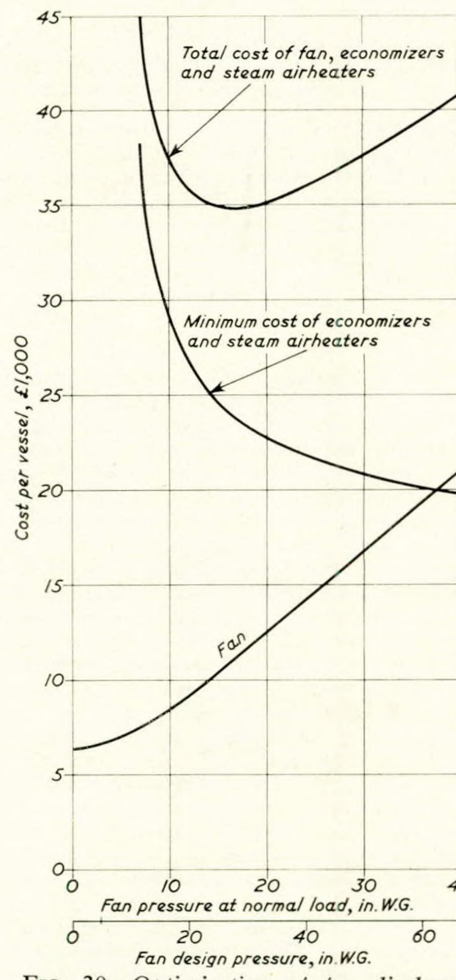


FIG. 30—*Optimization of fan discharge pressure for minimum capital cost*

than 15 per cent of the increase in capital cost involved.

4) In assessing the fan design capacity margins of 10 per cent and 20 per cent were added to the volume and pressure respectively required at maximum load.

The arrangement of heating surfaces in the boiler and superheater, the number of burners and the funnel and duct design were determined purely from considerations of maintenance and operation and were unchanged throughout the study. The basic design incorporated a series feed system wherein a primary, cast iron gilled economizer heated the water from 250 deg. F. to 290 deg. F. after which an intermediate feed heater increased the temperature to 360 deg. F. before the feed entered the secondary, mild steel economizer. A two-stage steam air-heater was also included supplied with steam at 15 and 165lb./sq. in. gauge.

Optimum Fan Pressure

The changes in price of each of the economizers for resistances at normal power up to 3in. w.g. are shown in Fig. 28. The scale of resistance for the primary economizer increases from right to left and this is reversed for the secondary economizer so that the two curves can be directly summated to establish the upper curve of variation in total cost of the economizers for a combined resistance of 3in. w.g. Since there is no change in fuel consumption the optimum is achieved when the cost is a minimum and this occurs when the resistances of the primary and secondary economizers are 1·8in. w.g. and 1·2in. w.g. respectively.

By repeating the process for different values of total economizer resistance the curve of minimum economizer cost was obtained, and, by a similar method to that described above, combined with the cost of the steam air-heater as shown in Fig. 29 to indicate the optimum combination of these items. In a like manner the fan pressure for minimum capital cost was established as in Fig. 30.

With higher resistances, more fan power is required and the fuel consumption is increased. An overall fan efficiency of 15 per cent was assumed to allow for the efficiency of the boilers, turbo-generators, electrical transmission, fan motors and transmission, and the fan itself. The annual cost of fuel to drive the fan was then added to the change in capital charges (15 per cent of the change in plant cost) to establish the optimum value of 19·5in. for the fan design pressure as shown in Fig. 31. The corresponding fan pressure at normal power is 11·7in. w.g., and by retracing the steps outlined above the optimum individual resistances given below were established. The figures in brackets are the values actually adopted as commercial heat exchangers can only be obtained in certain sizes whereas the curves drawn assume an infinite variety.

Fixed resistances (boiler, burners, etc.)	6·0in. w.g.	
Primary economizer	2·74in. w.g.	(2·65)
Secondary economizer	1·83in. w.g.	(2·00)
Steam air-heater	1·13in. w.g.	(1·05)
Total	11·7in. w.g.	

It can be seen from Fig. 31 that any fan design pressure from 13-25in. w.g. could be adopted without increasing the net cost by more than £300 per year (approximately 0·1 per cent of the total fuel bill ≡ 0·0005lb. of oil/s.h.p.-hr.). Studies were also made for overall fan efficiencies of 10 per cent and 20 per cent and the ranges of design pressure, at the optimum cost plus £300 per year, were 12·5-22·5in. w.g. and 13·5-27in. w.g. respectively, so that within these limits of fan efficiency any design pressure from 13·5-22·5in. w.g. would be reasonable. The higher figure reduces weight, space and first cost but

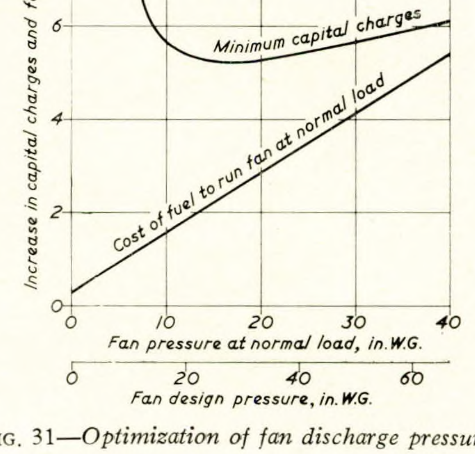


FIG. 31—*Optimization of fan discharge pressure*

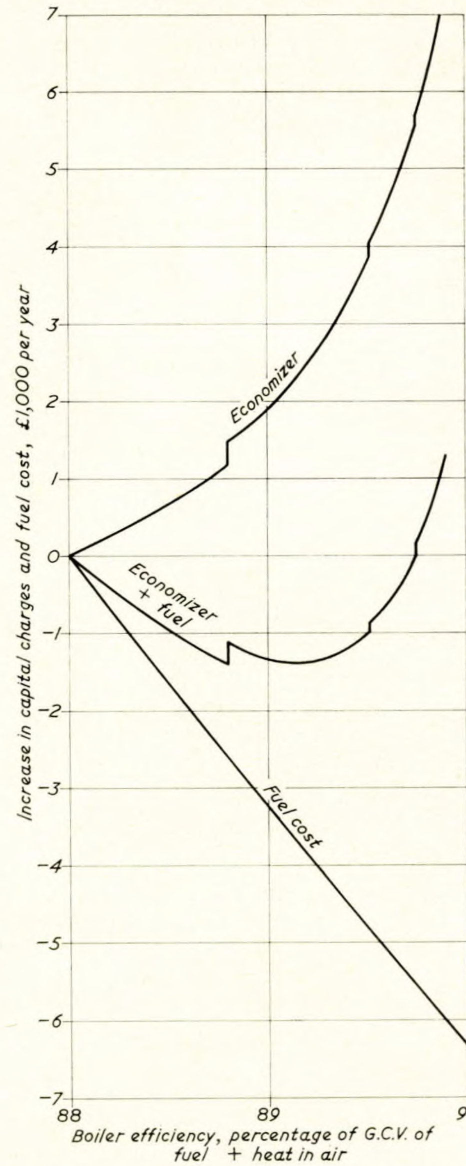


FIG. 32—*Optimization of boiler efficiency with a series feed system*

Scheme		1	2	3	4	5
Feed system		Series	Straight	Straight	Straight	Straight
Primary feed temperature	deg. F.	250	360	360	280	300
Secondary feed temperature	deg. F.	360	—	—	—	—
Temperature rise in primary economizer	deg. F.	40	—	—	—	—
Air temperature leaving steam air-heater	deg. F.	320	200	150	255	270
Gross calorific value of fuel and heat in air = total calorific value (T.C.V.)	B.t.u./lb. of fuel	19,350	18,885	18,695	19,100	19,155
Boiler efficiency	per cent T.C.V.	88·8	88·25	88·75	88·5	88·2
Saving in capital charges	£/year/ship	Basis	4,570 × 0·15 = 685	3,470 × 0·15 = 520	9,430 × 0·15 = 1,415	8,130 × 0·15 = 1,220
Increase in fuel bill	£/year/ship	Basis	1,770	160	960	1,930
Net saving	£/year/ship	Basis	− 1,085	+ 360	+ 455	− 710
Saving in weight	tons/ship	Basis	19	22	42	39
Space occupied by one boiler						

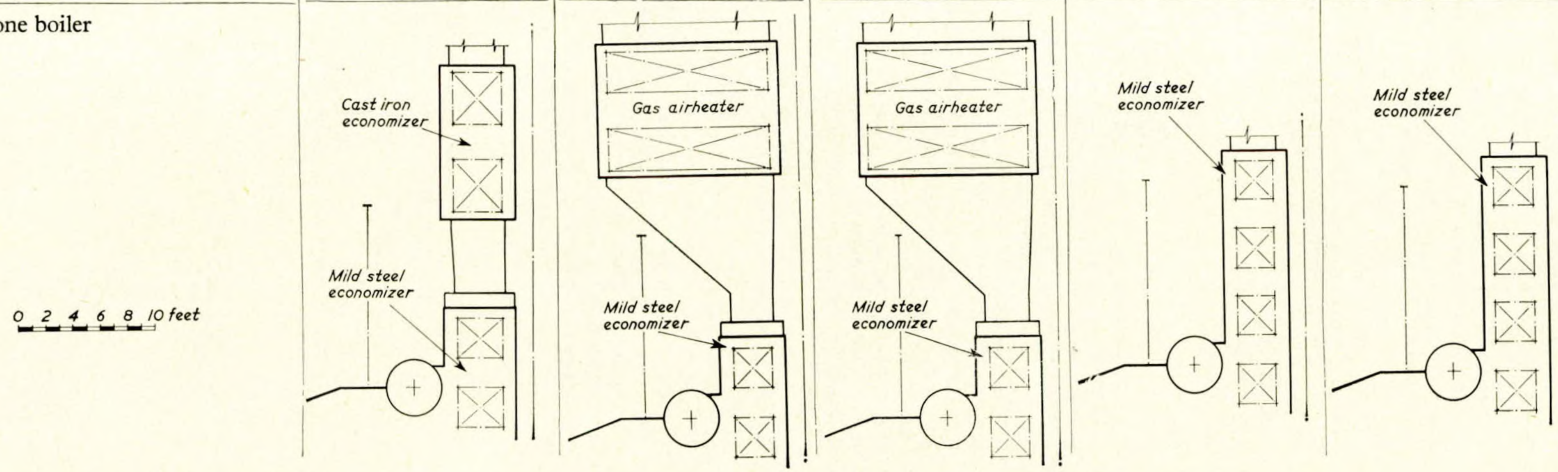


FIG. 33—*Comparison of optimum boiler plant designs with various arrangements of economizers and air-heaters*

increases the maximum electrical loading which might necessitate a larger size of turbo-generator.

Optimum Boiler Efficiency

The basic design referred to above, had an efficiency of 88 per cent which would be improved if the height, and consequently the cost and resistance, of either economizer were increased. This aspect was studied and the size of economizers adjusted so that the total fan power required remained as in the basic scheme. The water temperature rise in the primary economizer was maintained at 40 deg. F., as specified, throughout the study.

The increased capital charges for the economizers and reduction in fuel bill are shown in Fig. 32. If the number of banks of economizers was neglected these factors combined to show an optimum efficiency of 89·1 per cent, and any efficiency from 88·75 per cent to 89·45 per cent could be adopted without increasing the net annual cost by more than £300. However, there is a limit to the number of rows of economizer tubes which can be satisfactorily cleaned by soot blowers, so that with higher economizers more banks and more soot blowers are required. This is reflected in Fig. 32 by the steps in the curves. The step at 88·8 per cent efficiency is larger than the others since at this point it was necessary to increase the number of banks from two to three in both the primary and secondary economizers. The modified curves result in an optimum efficiency of 88·8 per cent and this occurs when each economizer has two banks of the maximum height. With this higher efficiency there is a small increase in weight and space and the capital cost is raised by £7,750 but the fuel cost is lower by £2,580 per annum so that the rate of return on the investment is 33 per cent per annum.

Alternative Cycles

The study was carried further to embrace four alternatives with straight feed systems as below:

a) Feed at 360 deg. F. with mild steel economizers and gas air-heaters (Scheme 2)
b) Feed at 360 deg. F. with mild steel economizers and gas air-heaters, with vitreous enamelled tubes in the first air pass. (Scheme 3)
c) Feed at 280 deg. F. with mild steel economizers. (Scheme 4)
d) Feed at 300 deg. F. with mild steel economizers. (Scheme 5)

For these schemes the fan power was maintained as for the basic scheme but otherwise the optimum designs were selected in a similar manner to that described above. The effect of changes in the feed cycle on the overall ship efficiency was ignored except insofar as it influenced the optimum boiler efficiency. In other words, in assessing the variation in the fuel bill, it was assumed that, with equal boiler efficiencies, the fuel consumption was the same on all schemes being 13,200lb./hr. of oil when the boiler efficiency was 88 per cent of the gross calorific value of the fuel including the heat given to the air in the steam air-heater. The designs selected corresponded to the step in the curve nearest to, and at a lower efficiency than, the theoretical optimum and it was fortuitous that in no case did this result in a penalty of more than £300 per annum. The relative capital charges and fuel costs for the designs thus selected are shown in Fig. 33. Schemes 2 and 3 with mild steel economizers and gas air-heaters show positive and negative savings respectively and a similar effect occurs between schemes 4 and 5 so that, if turbine cost and efficiency is ignored, there is little to choose between the series feed system and straight feed systems either with economizers and gas air-heaters or with economizers only. The variation in weight and space of the boiler plant is also indicated in Fig. 33. Boiler plant economics as considered above should not be used as the sole criterion for the choice of machinery and comments on other aspects follow.

Series Feed System

It has been shown above that with a series feed system there is an economic advantage in increasing the boiler efficiency up to 88·8 per cent but the weight is increased. Studies made for other vessels in conjunction with a turbine designer and manufacturer indicated that the overall economy of the ship is improved if the water temperature rise in the primary economizer is reduced below the 40 deg. F. specified for this project, but assessment of turbine costs and efficiency, though very relevant, is outside the scope of this paper. The economics of steam air-heater design might also be investigated to determine the relative value of 1, 2 or 3 stage steam air-heating and the effect of terminal temperature differences in these heat exchangers.

Straight Feed System with Gas Air-heaters

The turbine heat rate of these schemes is comparable to that of the series feed system and there is a saving in weight of about 20 tons but more space is required. At 600lb./sq. in. boiler pressure there is little to choose between the two schemes but at higher pressures the gas air-heater is more attractive as increases in feed temperature leaving the H.P. feed heater have a smaller effect on the costs of this arrangement.

With optimum boiler efficiency and air at 160 deg. F. the boiler plant economy is equal to that of the series feed system but the minimum tube metal temperature is 250 deg. F. and if plain mild steel tubes are installed, corrosion can be expected. To avoid this the air temperature can be increased to 200 deg. F. adversely effecting the boiler plant economy but reducing the heat rate. Alternatively, the tubes in the first pass could be protected by vitreous enamel and this has been allowed for in the costs of scheme 3 as shown in Fig. 33. However, due to the limited experience with this type of tube it would be prudent, at the present time, to build into the vessel the facility to increase the air temperature leaving the steam air-heater to 200 deg. F. If vitreous enamelled tubes continue to give satisfactory service, then it is possible that the steam air-heater could eventually be eliminated increasing the boiler efficiency by a further 0·5 per cent and saving the cost and complication of the steam air-heater and its associated pipework in future vessels.

Straight Feed System without Gas Air-heaters

If the feed temperature is chosen at 290 deg. F. the annual cost of the boiler plant is equal to the series feed system but the turbine heat rate is higher. Against this must be set the saving in space, weight and cost on the rest of the machinery due to the elimination of the intermediate feed heaters and associated pipework. The weight of the boiler plant alone is reduced by about 40 tons and further savings occur in the rest of the machinery. Another important feature is that, due to the reduced weight of the economizers, it is easier to build them integral with the boilers. This avoids the weight and complication of supports from the ship's structure. There is less leakage of air through both inner and outer casings so that, in practice, efficiency is improved and the fan power is reduced. Operation is more simple as fewer valves are included.

The turbine heat rate can be reduced by increasing the feed temperature or by bleeding at a higher pressure for the steam air-heaters but this must be balanced against the increased capital costs so incurred. If lower feed temperatures are considered then the optimum boiler efficiency increases but cast iron gilled economizers are required and with prices current in Britain today the extra cost so incurred more than outweighs the improvement in boiler efficiency.

Summary

Fan pressures at normal power between 8·5 and 13·5in. w.g. give the best overall economy with the normal arrangement of electric fans.

The optimum boiler efficiency is between 88 and 89 per cent depending upon the feed cycle chosen.

The choice between a gas air-heater scheme and series feed system with a boiler pressure of 600lb./sq. in. is largely a matter of preference, but at higher pressures the air-heater shows an advantage. A straight feed system with economizers only, may not give the highest overall efficiency but offers significant advantages in weight, space, initial cost and simplicity which may outweigh the additional cost of fuel.

Other Factors

As already stated, the foregoing study takes no account of the economics of the turbine and feed system design as this is beyond the scope of the present paper. Other factors which have not been discussed are detailed below.

1) The difference in cost between alternative makes of economizers, steam air-heaters and fans.
2) The effect of reducing the water temperature rise in the primary economizer of a series feed system.
3) The effect of reducing the physical size of the boiler itself and hence increasing its draught loss and reducing the price.
4) The variation of cost with furnace volume.
5) The use of a different type of boiler.
6) The cost of introducing steam temperature control compared with the overall improvement in economy gained by operating the plant continually at the highest acceptable temperature.
7) Capitalization of weight and space.
8) Capitalization of effect of overall efficiency on bunker requirements and hence cargo carrying capacity.
9) The effect of different fuel costs, rates of return and steaming days per year.
10) The effect of steaming at part loads on the overall economy. This is not uncommon due to variation in trade requirements and freight rates and can have a significant influence on the optimum design.
11) The fan pressure was only optimized for the basic scheme and the selected figure used for all other schemes. There would probably be a marginal improvement in the overall economy of the gas air-heater schemes if the fan pressure was increased and *vice versa* for the schemes with mild steel economizers only.

THE FUTURE

The basic efficiency of a steam turbine plant can be improved by increasing the pressure or temperature or bleed rate or by the use of reheat. Further gains can be achieved by reducing the cost or improving the efficiency of individual parts of the plant and by careful integration of the plant as a whole. A wider degree of automatic control would only be economic if it resulted in a reduction of personnel or reduced maintenance costs.

Steam Pressure

Apart from the increase in initial cost, higher steam pressures present no problem to the boiler designer but strict and correct control of feed and boiler water quality is essential. At 850lb./sq. in. the best economy is obtained by adopting a high feed water temperature and gas air-heaters; the advantage of this arrangement is greater with higher pressures. The current experiments with coated air-heater tubes may therefore encourage the use of higher pressures.

Steam Temperature

Many ships have been in service for several years with a steam temperature of 850 deg. F. and recently there has been a tendency to increase to 900 deg. F. or even 950 deg. F. As experience at 950 deg. F. grows it is possible that a modest improvement in efficiency may be achieved by advancing to 1,000 deg. F. but higher temperatures are unlikely due to the risk of corrosion of superheater tubes when burning fuels containing vanadium or sodium. This could be overcome by burning a more expensive fuel but the additional cost so incurred must be balanced against the improvement in efficiency. Oil fired plants have been designed for land use with steam temperatures well in excess of 1,000 deg. F. and in some of these a separately fired secondary superheater is included. It is then only necessary to burn distillate fuel in the secondary furnace so that the additional fuel cost is reduced. The marine-type boiler, shown in Fig. 34, uses this principle and is installed in a research establishment. It has two furnaces and two superheaters and is capable of producing steam at pressures from 600lb./sq. in. to 1,200lb./sq. in. at any selected temperature from 750 deg. F. to 1,200 deg. F. Although built as one unit, there is a gas-tight baffle wall between the main boiler and the secondary furnace so that the gases from the main furnace cannot pass over the secondary superheater. If the main

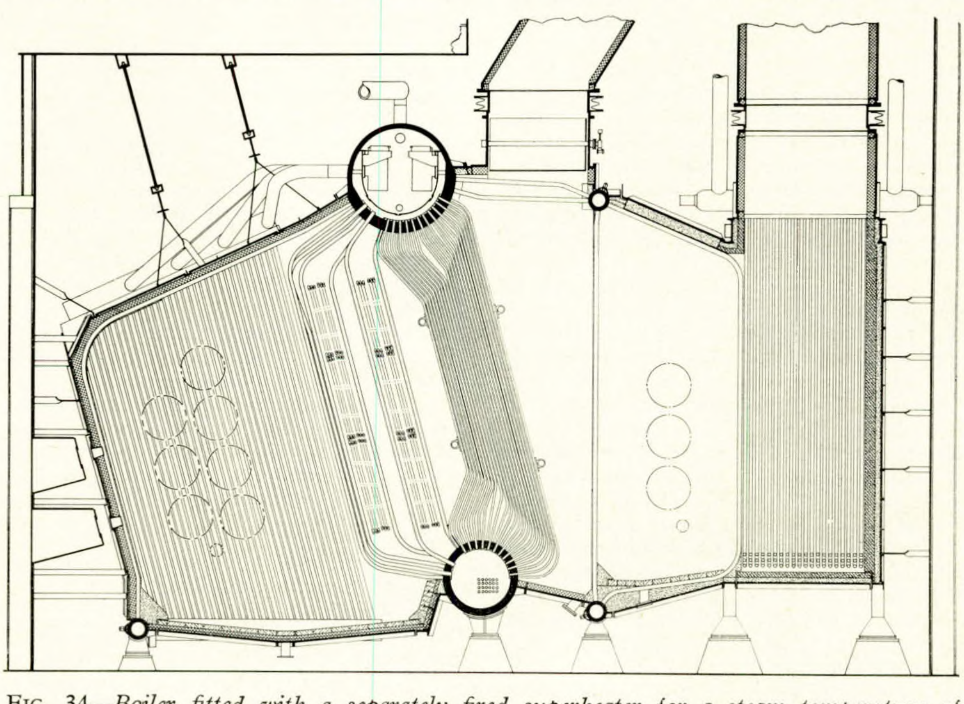


FIG. 34—*Boiler fitted with a separately fired superheater for a steam temperature of 1,200 deg. F.*

furnace only is fired, a maximum temperature of 950 deg. F. is possible and the secondary superheater can be bypassed. With this feature in mind it is possible to envisage a semi-experimental seagoing plant designed for say 1,300lb./sq. in. and 1,100 deg. F. with auxiliaries working at 600lb./sq. in. and 900 deg. F. A small turbine could be geared to the shaft through a clutch with an inlet temperature of 1,100 deg. F. and exhausting at 900 deg. F. to the auxiliaries and a conventional marine turbine. Both the high temperature turbine and the secondary superheater could be bypassed if trouble developed in this part of the plant. Although the fuel consumption would be significantly reduced, the fuel burnt in the secondary furnace would be more expensive per ton and it is doubtful whether such a scheme would be economic and could only be justified as an experiment.

Reheat

Reheat offers a way of increasing the cycle efficiency without using excessive steam temperatures but is generally avoided due to the complication involved and the difficulty of manœuvring. Although few ships have been fitted with this type of machinery, several projects have been made in the course of which the designs and control systems have been simplified. Sometimes the reheater is included in a separate boiler which is shut down when reheat is not required. Alternatively a two-furnace boiler, similar in principle to that shown in Fig. 34, is used. The reheater takes the place of the secondary superheater but the space occupied by the reheater and reheat furnace is usually less than in the illustration and the reheater is carried above its furnace instead of alongside.

Number of Boilers

It is generally appreciated that if the number of boilers is reduced then the initial cost is lower and automatic operation is simplified. Few owners have considered it prudent to use only one boiler but in certain vessels it might be attractive to have one main boiler and an auxiliary boiler. The auxiliary could act as a "get you home" boiler in an emergency.

Pressure Combustion and Gas Turbines

It is doubtful whether pressurized boilers offer any great advantage for merchant ships except that a lower fuel consumption can be obtained since the boiler acts as a waste heat recovery plant for the gas turbine so that its efficiency is very high compared with the overall efficiency of an electric fan supplied from a steam turbo-generator. There may also be fuel problems and obtaining a gas turbine with the appropriate characteristics for a particular plant may be difficult.

Gas turbine driven generators and all electric auxiliaries would appear more attractive since the heat in the exhaust gas could readily be utilized, either in the boilers or in separate heat exchangers, to assist in the generation of steam for main propulsion. This would also seem a wise first step in the path toward combined steam and gas turbine main engines for merchant ships.

CONCLUSIONS

1) Two-drum boilers can be designed to give reasonable maintenance and availability when burning low grade fuels.
2) These boilers also have "flat" steam temperature characteristics so that steam temperature control is not so important but, due to the small safety margin in terms of temperature, it is prudent to have some form of superheat control for design temperatures above 900 deg. F.
3) A general advance in steam temperature much above 950 deg. F. with low grade fuels is unlikely unless some economic method is found to prevent attack of the superheater tubes by the corrosive elements of the fuel.
4) Steam pressures may rise but this will make little difference to the basic principles of marine boiler plant design except to encourage the use of gas air-heaters. Although the air-heater corrosion problem cannot be considered as solved there are encouraging signs in this direction.
5) Boiler efficiencies of 88 per cent or more can be justified on economic grounds although the initial cost is increased.
6) A significant increase in fan pressure above that in general use today is unlikely to be economical unless the general price of fans is reduced and the efficiency of generation of electricity in a ship is increased.
7) Close collaboration between the designers and manufacturers of the various parts of a steam turbine installation is essential if the best economy is to be achieved.
8) The overall efficiency of the steam ship of the future may be improved by the wider use of reheat or by adopting a combination of steam and gas turbines.

REFERENCE

1) WALLS, W. A. and PROCTOR, W. S. 21st Oct. 1960. S.N.A.M.E., Philadelphia Sec.

Discussion

MR. J. SCOTT, D.S.C. (Member) said that during the last fifteen years watertube boiler design for merchant ships had been continuously under review and in his view it had been influenced by two major factors:

a) the effort to improve efficiency;
b) the effort to control and, if possible, to reduce maintenance cost.

Undoubtedly much progress had been made in both design and construction techniques and as improvements were made there was a tendency to accept them and to press on to the next immediate problem. It was only when the background history was reviewed, as had been done by the author in the first part of the paper, that one could see the broad outline of improvement in its correct context.

Was it not significant that, allied to development in boiler water treatment and control, these boilers might now continue in service for 24 months between opening up for survey, for Lloyd's classification requirements?

In the introduction to the paper there appeared the following sentence:

> "Throughout the paper reference is made to deterioration in the quality of boiler fuel."

He would like to point out that a very wide range of quality was available for bunker fuel, naturally at a price. It was appreciated that many boiler problems stemmed from the quality of fuel (and the amount of foreign matter contained therein) which was currently used on merchant vessels and it was also appreciated that the use of low cost fuel was dictated by economic pressures and the continuous drive for lower cost operations.

The development and use of retractable soot blowers, mentioned on page 38, was significant and he would like to confirm having very favourable experience with that type of equipment.

The boiler design shown in Fig. 20 and the arrangement of boilers and turbines in Fig. 21 were very interesting in the light of current developments in semi-automatic centralized control of propulsion machinery. However, there was some doubt in his mind as to the extent of distortion which could take place and the variation in circulation rate which could occur on the long narrow boiler, when steaming on light load with, say, one burner in operation. The author had, however, proposed an alternative which was not included in the paper and no doubt he would wish to make further comment on those points.

Developments on air-heater design were reviewed on page 47 of the paper but no mention was made of the potential for corrosion resistant alloy cast iron sectional air-heaters which might show economic advantage in relation to the cost of renewals on mild steel tubular air-heaters.

The optimization study on boiler design set out a clear cut pattern for evaluation and left the reader to draw his own conclusions, dependent upon background and experience, but it was felt that such conclusions must be influenced by operating experience on maintenance costs for gas air-heaters and economizers. That experience would vary depending upon the operating conditions for particular vessels, but Mr. Scott's firm would welcome the opportunity of supplying such information as they had, to the author, to augment that economic study.

In conclusion he wished to express to the author his appreciation for the very fine review and for an indication of what potential might be available in merchant ship watertube boiler design in the near future.

MR. R. L. J. HAYDEN, B.Sc.(Eng.) (Member) said that Mr. Hutchings' paper made a timely and welcome contribution to the published information on boilers. There was much in the paper with which all would agree. Some points, however, seemed to be controversial and there would appear to be some omissions. It was very difficult for an author to cover every phase of boiler history and development and, as most of those points were relatively minor, they were best dealt with in writing.

It was easy to agree that one approach to the problem of superheater deposits with steam temperatures of 950 deg. F. was represented by Fig. 9. It was even easier to agree with the author that improvement in that design was still desirable and it really was most gracious of him to have subsequently included Fig. 11. As the previous illustrations all followed the logical trend of boiler development it was quite natural to assume that he agreed that boilers with the superheater after the generating bank had considerable advantages when dealing with difficult fuels. According to the remarks made by the author when presenting his paper he felt that that was not so for steam temperatures above 850 deg. F.

The impression given by the author that such boilers could not be designed for steam temperatures above 850 deg. F. needed correction. The first installation of that type was in 1952 and was for a steam temperature of 950 deg. F. The gas temperature to the superheater was 1,540 deg. F. Subsequently 209 boilers of this type were in service and among them were sixteen boilers for steam temperatures of 950-960 deg. F. Many of those boilers had gas temperatures before the superheater of 1,700-1,900 deg. F. which the author suggested would give trouble from bonded deposits. Experience had shown, however, that such boilers showed considerably less tendency to fouling of superheaters and needed less maintenance than boilers with the superheater nearer the furnace.

After such close agreement, with but a few minor exceptions, it was disturbing to read the section of the paper which dealt with deposit formation on superheaters. Here the author suggested, apparently, that in order to prevent superheaters from choking due to bonded deposits, higher steam temperatures should be used and the superheater should be put in the highest possible gas temperature zone. That, he suggested, would result in the surface of the deposits on the superheater tubes being molten, which would reduce the thickness of the deposits. But in fact, Mr. Hayden asked, would not the high melting point ash particles in the gas stick to the molten surface and was that not the mechanism of bonded deposit formation? It would be interesting to learn where the molten ash eventually went to. Did it volatilize or did it finish up on the bottom drum? Perhaps the author was suggesting that if the surface of the deposit was hot enough the ash could not condense. In that he might well be right.

Figs. 12 to 16 purported to show the thickness of deposit on a superheater tube at a temperature of 800 deg. F. with ash having a nice clean cut melting point of 1,600 deg. F. The ash in fuel oils could vary widely and in addition to constituents with melting points from 600-1,600 deg. F., could contain high melting point particles. Using the author's arguments and considering steam temperatures from 700-950 deg. F. in the superheater and ash fusion temperatures from 600-1,600 deg. F., some strange conclusions might be reached. The first of those would be that the deposits would be greater on the cooler passes of the superheater. The second would be that the lower the melting point of the ash the less troublesome it would be. Neither of those conclusions would appear to be in accord with operating experience so that unfortunately, in the end, it was difficult to agree with any but one feature that the author proposed to prevent superheater deposits. It was certainly wise to have as large a gap between the tubes as space and economics permitted. In fact, it had been common practice to have a gap of $\frac{3}{4}$in. on superheaters near the furnace and a gap of $1\frac{3}{4}$in. on superheaters after the generating bank. It would seem that the time taken to block a superheater would be at least in direct proportion to the size of the gap and, when the physical strength of the deposits was considered, might be much more than in direct proportion. Apart from that point the author's recommendations would appear to be at variance with operating experience, which would seem to indicate that superheaters placed in the coolest gas zone that was practical and economic were much less susceptible to deposit formation and, if deposits did form, were much less susceptible to overheating when the gas velocities through the gaps in the deposits exceeded the designers' predictions.

To locate the superheater after the generating bank increased very slightly the cost of the boiler, but that extra cost appeared to be more than justified by the lower maintenance.

The paper contained very little about superheater supports. It would appear that the corrosion of those parts by the vanadium and sodium constituents of the ash was still not completely solved, irrespective of the situation of the superheater.

COMMANDER E. TYRRELL, R.N. (Member) said that the author was to be congratulated on the clarity with which he had outlined the development work carried out by his company in recent years. The versatility which had characterized the solution of the many problems encountered was impressive, but it was possibly not out of place to add a few more remarks to those which Mr. Hutchings had already given on the future of the marine steam turbine plant.

In the years immediately after the last war, shipowners everywhere over-estimated the demand for ships. The result of that was now to be seen in the low freight rates pertaining and in the laid-up tonnage to be found in the estuaries of the world. Shipbuilding capacity was now almost double that required to meet the demand for replacement ships and for the increase in world trade. Until the ships, at present laid up, found employment or were scrapped, the demand for new vessels was likely to be well below the yearly average, which was itself only sufficient to keep the shipyards of the world half employed.

Not only was the demand for ships over the next few years likely to be small but, as the author had so rightly said in his introduction, the use of low grade fuel, reduced maintenance costs, and the increase in power obtainable from a single direct-coupled direct-acting Diesel engine, had made it a formidable competitor to the steam turbine, except for ships requiring very large horsepowers. Today the steam turbine could only find automatic choice for warships, the very largest tankers and for large, fast passenger liners whose future was at best doubtful.

Steam engineers had concentrated on burning cheaper fuel and increasing steam temperatures and pressure in order to improve economy. Those measures, coupled with expanding Diesel engine output, had pushed the price of the steam turbine installation above that of a Diesel of the same horsepower.

Although much of what Mr. Hutchings had said was applicable to warships the main stress of his paper was directed towards the Merchant Marine, particularly that section devoted to economics, but it seemed that only seven merchant ships over 5,000 tons with steam machinery, had been ordered in Europe so far this year. Those figures did not include cross-channel vessels, where space considerations must eventually establish the gas turbine as the prime mover for that type of vessel, or ships ordered in the United States of America. Here the application of the large sums of money spent on turbine research by the U.S. Navy had been incorporated by the major United States land turbine builders in marine steam turbine sets for merchant ships. That, coupled with the special manning and maintenance problems found in U.S. ships and with the absence of a successful direct-coupled Diesel engine manufacturer in that country, had ensured that the steam turbine retained its place in U.S. ships as the most popular prime mover.

The outlook for the marine steam turbine and boiler industry was therefore not encouraging and the author had referred to many of the economic criteria involved and had indicated how the efficiency might be improved and the cost of the steam turbine installation reduced, but with the exception of the acceptance of a single-boiler installation the advantages were marginal and were unlikely to affect the overall picture. While it was appreciated that many of the troubles with steam turbine installations occurred in the boilers, the majority of shipowners were prepared to rely on a single Diesel engine and it seemed somewhat illogical to insist on boiler duplication, which possibly dated back to the days when it was not possible to build large boilers and when there were as many as eight or ten boilers in a ship, presumably with the feeling that there was safety in numbers. As Mr. Hutchings had already said, single boilers would greatly assist automation but were they quite sure that automation was the answer?

The Allis Chalmers Company of the United States recently carried out a research study for the National Maritime Administration on the methods of reducing running and first cost of turbine machinery. That investigation showed that a simple package turbine plant consisting of one boiler and a turbine set built in the factory as a unit, comprising turbines, condenser, pumps, heat-exchangers, coolers, extraction pumps, condensers and so on, with the piping manufactured ashore and ready to fit into a ship could save, over the twenty years' life of the ship, 5 million dollars in first and running costs over a conventional unit of 22,000 s.h.p. as fitted in a *Mariner* class vessel. Also the crew was reduced from 55 to 22. In that particular case automation was kept to a minimum with single-lever bridge control of all engine movements and automatic start of auxiliary generators. Savings in manpower were achieved by keeping valves and control equipment to a minimum and grouping them in convenient positions.

The methods used by other manufacturers to improve the competitive position of the steam turbine installation were to be found in standard turbine units covering a wide range of powers, the sale of complete packaged units guaranteed both for reliability and fuel rate and in extensive automation designed to reduce the engine room watch to two, or in some cases only one man. Two manufacturers at least were now offering small computers with their turbine machinery, which gave a constant fuel rate reading and also control of auxiliaries for maximum efficiency at the chosen running speed.

While it was possible that automation and other developments in steam turbine machinery would not save the steam ship from extinction it was significant that of the seven turbine ships ordered in Europe this year, three were to be engined with automated packaged units obtained from the United States of America, despite the high cost of such units, and he believed everyone present would agree that such importation of that type of unit from the United States ten years ago would have been quite unthinkable. Of the other four vessels, three would be built in Germany and one in Great Britain, with more conventional machinery.

What was certain was that there would be great changes in the methods used to design and manufacture integrated automated steam turbine units and it seemed doubtful if the engineering departments and engine shops of the shipyards had the resources and background necessary to produce that type of machinery which would probably be required in the future, machinery of which Mr. Hutchings' boilers and all the research and development described in the paper formed but a part, and the future for which was not in his hands. Perhaps the author would care to comment on that.

MR. W. C. CARTER, B.Sc. (Member) said that he had read the paper with considerable interest and found himself in so much agreement with the various points made by the author that he did not propose to comment broadly, particularly on the economics. Instead he proposed to confine his remarks to a few comments on which he had some knowledge, namely the simple engineering aspects.

Mr. Hutchings was to be congratulated on his excellent synopsis which was most factual and an indication of his competency, but further than that he had made one remark which indicated that he was also a very brave man. He had said that the only problem with burning sulphur in the oil was the amount of sulphur and the oxygen present. There were so many theories on the oxidation of SO_2 to SO_3 by catalysis, that Mr. Carter did not propose to say anything more except to draw attention to it.

In Mr. Hutchings' paper and also in his synopsis he had mentioned recent developments in the use of steam atomizing type burners and although he said that they had definite advantages he had not pinpointed those advantages and it would be interesting to know what they were. In the same connexion the author had mentioned a "turn-down" range of 10 : 1. That was all right, but it meant an air register pressure drop range of 100 : 1. What about the air control when there was a 10 : 1 range on the boiler?

With regard to the superheaters, Mr. Hutchings had mentioned that superheater tubes were often welded to the nozzles above 875 deg. F., in Mr. Carter's submission they should all be welded above that temperature.

In the criteria for boiler design three factors were mentioned and a previous speaker had already commented on them. He was a little surprised that some comment had not been made on one factor which was omitted, namely that in the view of his company the metal temperature of the superheater tubes should not be more than 1,100 deg. F., and preferably 1,080 deg. F. That was an important factor in avoiding corrosion from the sodium vanadates and it was further emphasized if one looked at Figs. 9 and 17, where the superheater tubes lay behind two rows of watertubes. Obviously there would be direct radiation on to the superheater tubes and he felt sure that the metal temperature of these tubes might well be dangerously high. Indeed he knew that fact to his cost.

He found himself very much in agreement with the author on the subject of casings. His firm had used double casings for about thirty years and on marine work for some fifteen to eighteen years but, unfortunately, they appeared to be using the double casing on a type of boiler which, due to conservatism, did not find too much favour.

Referring to Fig. 24 he felt that the methods for sealing tube holes, assuming that one had no tapered plugs for plugging the tubes, were possibly somewhat expensive. His own company had tended to revert to the use of Ermeto couplings with a simple blank and had found them very effective, avoiding the use of the flanges mentioned.

On the subject of air-heaters, his firm had considerable experience with air-heaters and air-heater coatings. In fact they had used at least fifty different varieties of tubes ranging from tungsten to glass-lined tubes and he could tell Mr. Hutchings with all confidence that they knew the solution to corrosion in the tubular air-heater, namely a fused glass lining. The trouble with all vitreous enamels was that they were not 100 per cent. perfect. If the vitreous enamel on a tube was only 99 per cent. perfect the SO_3 and H_2SO_4 would find their way through the enamel on to the tube. He had found the only solution was to use a glass lining and then to fuse the glass on to the tube, but unfortunately it cost £5 to coat a tube. Also, on the subject of the air-heater, possibly even coating the ferrules with an inert substance was effective, but he thought that an equally important point was the question of air distribution into the heater itself. Bad air distribution could nullify all the very good advice and precautions which might be taken.

He found himself in disagreement with Mr. Hutchings on the question of CO_2 with regard to the operating values in the United States of America and Europe. Possibly his plant was more of a commercial type but in the United States he found that the CO_2 values which they were operating on were appreciably lower than those in this country.

MR. G. A. WATT congratulated the author on his excellent paper. It was obvious that a great amount of work had been put into the preparation of it.

Commenting on the paper, Mr. Watt said that the author made no reference, other than in figures 1, 2 and 11, to the use of short retractable soot blowers in the furnace. As soot blower manufacturers, the company with which he was associated had found the short rectractable blower, located on the furnace walls and roof, to be highly successful in cleaning the superheaters of some 1,200 two-drum boilers. The short retractable blower had the advantage over the multi-jet blower in that it was exposed to the high furnace temperatures for only very brief periods, whereas the multi-jet elements and bearings in the superheater cavity were permanently located in one of the hottest parts of the boiler. The result was that, whereas the multi-jet elements and bearings had a life of the order of only six to nine months, the short retractable blowers lasted for many years with only minor replacements. However, with the deterioration in the quality of fuels he agreed that it was becoming more desirable to use the long stroke retractable blower in the superheater. At the wish of the owners his company had installed a long stroke blower in the superheater of each of the Babcock selectable superheat boilers in the Shell tanker *Solen* and after a year the vessel had now returned for its guarantee overhaul and it was believed that it had maintained normal steam temperatures over the whole period without recourse to water washing of the superheater tubes.

It was interesting to note that the author had referred to a two-drum boiler with an external superheater, which, as blower manufacturers, they had found to be an admirable layout for soot blowing, again with short rectractable blowers. However, it appeared from what the author had said that cleaning of the superheaters generally would in time present greater problems than at present and therefore they would be given no time to rest on their soot blowing laurels.

Under the heading of "The Future" the author had commented that a wider degree of automatic control would only be economic if it resulted in a reduction of personnel or reduced maintenance costs. He personally felt that a wider scope might be covered. One point which came to mind was the case where manually operated blowers were situated in very hot locations with high ambient temperatures. The operator might make a token blow, or might even skip it altogether. Automatic control ensured that all the blowers were operated correctly and in a proper sequence and so contributed towards the maintenance of the high boiler efficiency which the designers had striven so hard to obtain.

The optimization study was obviously a very important part of the design of the boiler and it would be interesting to hear from the author what steps, apart from very elaborate automatic controls, the boiler supplier could take to ensure that all the good work which he put into the design of the boiler was not lost on the boiler room staff.

MR. J. H. MILTON (Member of Council) said that, as one who had seen watertube boilers not so much from the design as from the survey aspect, or when in trouble, he had always been interested in what could happen to them in service. He was surprised that in the paper more emphasis was not laid on what he had always looked on as "most likely defect No. 1", namely failure of superheater supports. Many were the designs and materials that had been used to try to overcome that defect and yet they still presented a problem. The external superheater boiler shown in Fig. 11 with its superheater in a comparatively low temperature gas zone behind the boiler would appear to have distinct advantages in that direction.

Slagging of superheaters had been dealt with at length by the author and numerous graphs had been included. The inference that superheaters in high temperature zones were less susceptible to slagging than those in low temperature zones did not exactly fit in with his own experience. It would be extremely interesting to know how the all-important slag surface temperature of 1,600 deg. F. was ascertained, above and below which apparently so much happened and at which the slag was $\frac{3}{8}$ in. thick.

Fig. 14 showed the effect of gas temperature on the maximum thickness of slag which would form on a superheater tube; would it not have been more accurate to say which could form on a superheater tube?

In the section on "History" the author mentioned maintenance and also the incidence of low quality fuels. Accepting the fact that fuel quality had deteriorated, was it not true that with water cooled furnaces, backed by careful design, present day units with their relatively high steam conditions required less maintenance than their wartime predecessors?

In that section mention was also made of the fact that in the 1950's water treatment had improved, thus reducing the maintenance of water wall tubes. It would be interesting to know why water wall tubes were more susceptible to failures than the main bank generator tubes. Was it through an accumulation of deposits at mid-lengths of water wall headers, caused through using downcomers at each end, rather than floor tubes as fitted by some designers, which must surely give a better flow distribution.

The author mentioned that above 870 deg. F. handhole fittings in superheater headers were seal welded and that handhole and tube leakage in economizers had been overcome by eliminating handholes and welding tubes. Was the seal welding and elimination of handholes an admission of failure to produce a satisfactory handhole joint, or had such a stage been reached in development that so little happened inside superheaters or economizers nowadays, that surveyors no longer queried the internal condition of such parts at survey time?

Practically all the boiler designs shown in the paper had "in line" tubes except for the fire rows and the author's comments on the relative advantages, for the same linear pitch, of staggered and "in line" tubes would be appreciated.

It had often been suggested that roof firing would permit a longer flame path and better distribution and the design shown in Fig. 20 appeared to have those assets without impairing burner accessibility. It would be interesting to hear whether such a design was yet in service.

Fig. 18 showed an attemperator in the water pocket of a two-drum boiler. That meant that not content with filling up the steam drum with separators and desuperheaters, a start was now being made on the water drum and, in the event of a tube failure in the middle of the main bank at sea, the plugging operation was being made even more difficult, a time of 48 hours being envisaged for such an operation.

In conclusion, he wished to thank the author for the very interesting paper, which by its very nature was bound to produce an instructive discussion.

COMMANDER R. M. INCHES, R.N. (Member) commented that much of what he was about to say had already been said and his excuse for repeating it was that he saw things from a different angle and a picture illuminated from two sides was often clearer than one seen from one side only.

Some months previously, in the discussion on another paper* presented at the Institute, the question was asked what the boiler designers were doing to make it easier to keep boilers clean. His first reaction to the present paper was that it went a long way towards answering that question.

The steps taken to provide better access on the gas side where it was really needed, i.e. in the vicinity of the superheater, had been quite effective, even if one would have to be of an unusual construction to walk into a so-called "walk-in" superheater!

Similarly the use of "in line" tubes certainly made cleaning easier. Here the builder had to help the designer because while no one worried very much about a diagonal pitch tube being a little out of line, an "in line" tube in the same condition made a very great difference.

Soot blower development had also been substantial, and where rack type blowers could be fitted and were used regularly and frequently the deposit problem was greatly reduced. It was also interesting to see that soot blowers in the furnace roof were fitted in Figs. 1 and 2, provided for in Fig. 3 and thereafter disappeared except in Fig. 17, which showed a somewhat unusual type of boiler. He hoped that that disappearance was not just a coincidence because, although he might have been unlucky, his experience was that this particular location for a blower provided a maximum of maintenance headache and a minimum of effect.

He noted that the service experience available to the author indicated a reduction in deposits as a result of using steam for atomization. It would be interesting to know whether, in the opinion of the author, this was simply because, all other things being equal, it was easier to maintain good atomization with steam as the atomizing medium rather than, say pressure, or because the steam made a direct contribution to improved combustion.

In that connexion it was perhaps worth mentioning that the Shell tanker, which had steamed so effectively for such a long time and to which reference had been made by a previous contributors, was fitted with steam assisted atomizers.

Although he appreciated the author's motives for using multi-tube superheater elements they must bring problems in respect of steam flow distribution, which with steam temperatures of 950 deg. F. could not be disregarded, also major internal cleaning problems, even if the latter occurred but rarely. Where adequate access to the outside could not be provided he thought welding should be done from the inside rather than resorting to the expedients shown.

The analysis of the relationship between gas, metal and steam temperatures and slagging was most interesting but there were a few points on which he disagreed with the author. The first was that the temperatures quoted over-simplified the case, which bitter experience had shown him to be extremely complicated. The same applied for the chemicals quoted as contributing to the problem. Another point was that Mr. Hutchings quite rightly dismissed the use of tube metal surface temperatures above 1,600 deg. F. but, even with the temperature values which were now in practice, superheater supports suffered and that could be a completely separate and very serious problem from that of the tube.

Another point was that the author referred to a preferential slag formation in the first or leading row of superheater tubes. His own experience did not support that, neither did the curves shown in the paper. While slag formation further back in the superheater was perhaps easier to deal with because it was easier to get soot blowers in that vicinity, it was still a problem, as they had found to their cost.

The boiler shown in Fig. 17 was very good looking and he wondered if the author could say how the volume of the

* Inches, R. M. 1962. "Boiler Cleaning, with Particular Reference to Experience by, and Practice in the Royal Navy". Trans. I.Mar.E., Vol. 74, p. 289.

superheater space on a basis of pounds of steam generated compared with that which the R.N. had been able to use in the naval *County* Class design?

He had previously encountered the idea of having a superheater with vertical tubes but, in spite of the advantage of having the tubes run the same way as the generator tubes it had not really caught on. He believed one of the reasons to be trouble at the bends because of the impossibility of venting, but he would be glad to have the author's comments.

For highly rated boilers he agreed with everything the author had said about under-floor tubes. Possibly their presence in Fig. 9 was explained by the fact that there was no downcomer to the water wall.

The method shown for sealing the economizer tube holes from the gas side looked most thorough but demanded a heavy price in tube layout and the making of access arrangements, taking into account how rarely it was required. He personally had little experience of the problem but there was a much simpler plugging method, from the gas side and if the author would like to follow the matter up he would be pleased to tell him about it.

In his look into the future the author had referred to automatic controls. Commander Inches wished to endorse very firmly what had been said, and he could perhaps speak with more actual experience than the majority of people who had spoken so far. Automatic controls in the R.N. were not only enabling people to withdraw into an air conditioned space under conditions where the air outside was unpleasant for some reason or other — the principal purpose for which they were originally intended — but they were also proving more efficient watchkeepers than the human variety.

Reference had been made to the role of excess combustion air in corrosion. There also, properly set automatic controls allowed minimum margins of excess to be maintained when steady steaming. That probably did not apply under manœuvring conditions but he thought those could be looked at completely separately and would anyway only affect something like 10 per cent. of a boiler's working life.

MR. J. N. MACKENZIE (Member) said that it was a good sign for boiler users when designers and manufacturers wrote about boiler troubles. The more designers talked about troubles the less likely were operators to be worried by them.

With reference to slagging and corrosion on the fire side of the boilers it would be interesting to have Mr. Hutchings' views on whether or not there was any lesson to be learned from combustion in Diesel engines. In raising the question his remarks were not intended as evidence in support of Diesels as he would not deny that they also had their troubles. With similar ships, some Diesel and some steam, operating on the same service and burning identical fuels, it was found that a 3,500 sec. fuel with relatively high sulphur and vanadium content produced considerable slagging in boilers, calling for frequent water washing. Diesel engine cylinders opened up after two years showed almost negligible deposits and uptakes and waste-heat boiler surfaces were relatively clean. In addition, exhaust gas turbochargers on engines using that same 3,500 sec. also suffered very little from blade deposits. Was that lack of deposit associated entirely with centrifuging without water washing, or did it suggest that pressure combustion might have an advantage in that direction?

MR. J. A. BOLT expressed his appreciation at being allowed to be present as a guest and even more at having the opportunity to put forward some of his impressions on such an excellent paper.

Referring to page 39, under the heading "Steam Atomizing Burners" he wished to endorse some of the questions which had already been asked, and he would go through them briefly. According to the statement on page 39 by the utilization of the "Y-jet" steam atomizing burner the following results were achieved:

1) superheater deposits were reduced;
2) CO_2 was higher;
3) funnel gas temperatures were lower;
4) deposits were reduced throughout the plant;
5) soot blowers were not used as frequently.

With regard to those claims the following questions came to mind:

1) Were the vessels mentioned converted to steam atomizing from pressure jet burners?
2) What were the estimated gas temperatures in the superheater banks of those vessels?
3) What was the tube clearance in the superheater banks?
4) What was the CO_2 before and after?
5) What were the gas temperatures in the funnel before and after?
6) Were the deposits that were eliminated superheater slags or soot, or both?
7) What was the change in frequency in soot blowing, and was that change made on all soot blowers or just those in the economizer/air-heater banks?
8) Were the bunkers utilized from a high vanadium crude supply during the whole of the period?
9) It was stated that steam atomizing reduced superheater slagging; did the author offer any chemical explanation for that?

As stated in other parts of the paper the superheater deposits relied on the melting point of sodium/vanadium compounds.

It was understandable that the utilization of steam would have the following effects:

1) Water-gas reaction; this had been known to marine engineers for many years as a method of removing carbon rings from Scotch boiler combustion tubes. It would affect the cleanliness, as far as soot was concerned, of the fire side areas of the watertube boiler.

2) Improved atomizing if applied with pressure jet burner. That would affect the speed of combustion; it could also shorten the flame length and improve the soot deposits on fire side surfaces.

3) Increased momentum in the oil spray; this would result in a greater entrainment factor between combined spray and combustion air resulting in shorter flame lengths.

All those points combined together would allow of a higher CO_2 being actually carried without increasing the carbon burden in the combustion gases.

It was difficult to believe at this stage that any of the above effects could have very much to do with superheater deposits *per se* unless compared to poor quality pressure jet equipment which gave a generally dirty boiler at all events.

If the results claimed for utilizing the "Y" burner on page 39, had been universally accepted they would not now be carrying out long term experiments to assess the effect of varying quantities of steam applied in conjunction with pressure jet burners.

It was relevant to point out that during such prolonged tests one was always in the hands of a number of variables:

a) Were the bunkers used throughout the test of a like quality?
b) Had the combustion controls been functioning adequately?
c) Had the ship's personnel been functioning adequately?

Any one of those factors could possibly upset one's analysis of results.

To date he was not in a position to assert that outstanding results could be obtained regarding slagging. However, there were results of twelve months' operation with boilers of the type shown in Fig. 9, without any cleaning on the fire side whatsoever, on three vessels.

The *Solen* had been mentioned as being one of those vessels. In the case of two vessels it had been possible to maintain superheat temperatures without difficulty and to have continued to operate without boiler cleaning. The third vessel of that class was having difficulty with superheater temperatures; the vanadium content of the bunkers of that latter vessel had been higher than that of her sister ship, but the figures were not known to him personally. The condition of the combustion chambers, brickwork and economizer banks was almost identical in all cases, i.e. very satisfactory. That condition had been achieved by utilizing a steam consumption of approximately one-sixth of that quoted for the "Y" burner on page 39 of the paper.

If it was proved that steam was a good thing then obviously it would be utilized, but he would prefer to use a different type of burner from that illustrated. It appeared to be an internal mixer, and there were disadvantages with that type—

a) the steam/oil pressure differential had to be watched, for obvious reasons;
b) if for any reason steam was " lost ", combustion must deteriorate to a very great extent;
c) if the same burner was to be utilized as a low pressure jet the atomizer and cap nut must be changed.

He believed that there were at least three burners available which used the assistance of steam atomizing to extend the range of simplex pressure jet burners; to the best of his knowledge none of the above mentioned drawbacks applied to them.

He agreed with the statement on page 41 that the superheater deposits could be altered by the judicious placing of rack soot blowers, and also in the basic design of the superheater itself. One point he wished to make was simply this: on a drawing, a good soot blower appeared capable of blowing through six lines of tubes; after many months those tubes were no longer regimented and the blower was trying to get through something like a labyrinth gland.

From recent experience it would seem that the rack soot blower, operating in the " walk-in space ", only tended to force the deposits back between the superheat tubes into the combustion chamber side. One was tempted to ask whether the deposits, which had been re-introduced into the combustion chamber, would volatilize and join in the battle once again. In conclusion, he would appreciate the author's views on automatic viscosity control and its effect on boiler fouling.

Correspondence

Captain W. S. C. Jenks, O.B.E., R.N. (Member), in a written contribution congratulated the author on an extremely interesting paper which not only gave an insight into some of the problems with which the marine boiler designer was faced but which also contained a considerable amount of very practical information of benefit to the marine engineer who had the responsibility for operating boilers. He wrote that perhaps of the most interesting features of the paper, however, was the economic study which was given in the last section of the paper from page 48 onwards. In the first place one must be impressed by the enormous number of variables which had to be examined in a study of this kind and this was particularly the case when it was realized that the studies in this paper included only a portion of the whole machinery installation and, furthermore, that they were all based on arbitrary specified data which in itself could be subject to many variations.

It would appear that the studies had been based on the kind of performance which would be expected from a new plant in good condition and one wondered to what extent the conclusions would be altered if allowance was made for the inevitable deterioration in performance to be expected after a period in service. For instance, 14 per cent CO_2 was specified and, while this was undoubtedly attainable, one would have thought that the average figure in service was likely to prove somewhat lower and that 13 per cent might be more realistic. Similarly the heat transfer coefficients of economizers or air-heaters would undoubtedly be reduced by a certain degree of fouling in service and the air and gas resistances were bound to be increased for the same reason. It might be thought, therefore, that it would be prudent to carry out studies under two conditions:

a) with the plant as new and capable of its full performance;
b) for the plant with assumed reductions in performance of various features due to deterioration in service.

It might be that the conclusions reached would not vary significantly, but the author's comments on this aspect would be appreciated.

Another matter which was of great significance in any economic study, where fuel cost was to be related to capital charges, was the actual price per ton of fuel. Clearly the higher the price of fuel the greater was the significance of a saving in fuel cost in relation to capital cost and, in this connexion, it appeared that the price which had been assumed might well be on the high side, depending, of course, on the source of supply of the fuel and, if this were the case, the conclusions as a result of the studies might be affected.

Studying the table in Fig. 33 one could not help being impressed by the advantages which appeared to be offered by Scheme 4. This not only appeared to be the most attractive in overall cost, but resulted in a substantial saving in weight and space and considerably reduced complexity as compared with the other solutions. Weight and space factors had in themselves a capital value and, while this would vary according to the class of ship, it was felt that these factors were sometimes given insufficient weight in studies of this kind. More important, however, was the reduction in complexity. With the present difficulties of manning ships with men of the right experience and calibre, the savings to be achieved with more complex installations might often not be realized in practice, due to errors in operation, whereas a more simple installation was much more likely to be operated in accordance with the designer's intention. The simpler solution should also produce appreciably lower maintenance costs and account should be taken of this in any economic study. On the face of it, therefore, one would have thought that there would be very strong argument for the adoption of Scheme 4.

In connexion with the section of the paper under the heading of " The Future " the reference to the possibility of using a single boiler was of interest. Two of the ships operated by the writer's company in fact had only a single watertube boiler for main propulsion purposes, but provision of two Scotch auxiliary boilers had been made in these vessels and it would be possible to propel the ship at much reduced speed with these boilers in event of dire emergency. In the event, however, it had never yet been necessary to adopt emergency propulsion for either of the ships concerned during some four to five years of service. This experience would appear to support the contention that it might indeed be a reasonable proposition to equip a ship with only a single propulsion boiler. A plant which might well be worth considering was one which had a single propulsion boiler and steam turbine plant but incorporated a small low efficiency gas turbine which could be used in emergency on a " get-you-home " basis. The economics of such a plant would, it was thought, be well worth investigation and, it was felt, would be more attractive than a large main boiler *cum* small auxiliary boiler.

Another item of interest was that concerning pressure combustion. Pressure combustion boilers had been operated in various limited applications and using high grade fuel, since the 1930's and they did appear to offer the prospect of appreciable reductions in size compared with the conventional boiler having combustion at approximately atmospheric pressure. It was appreciated that there were many difficulties to be overcome with this type of boiler but it was perhaps surprising that more effort had not been devoted to development on these lines during the very long period since such units were first introduced.

It was noteworthy that the author had nowhere referred to the problems of obtaining good circulation in the boilers in question and it was therefore assumed that no problems in this respect were experienced nowadays, at least with boilers having the relatively low ratings used in the Merchant Navy. Captain Jenks recollected that in earlier days with highly rated naval boilers, problems of water circulation were a major issue.

MR. R. A. LINDÉN (Member) found the paper very interesting and wrote that he would like to congratulate the author on the presentation of this very informative review of marine boilers and marine boiler problems. For many engineers, experience of marine boilers was limited to their own work and their own installations and therefore it was of the greatest value when somebody, who was dealing with the problems raised by several shipowners and shipyards and who was working in the midst of the activity, spent some time in summing up where the industry was standing and what the trend was for the future.

Personally he wished to thank Mr. Hutchings very much for the excellent way in which he had done so. Going into detail, Mr. Lindén had found the author's statements and investigations regarding slagging on superheater tubes very interesting and also his discussion of economics and optimization. It was obvious that the time had now passed when a boiler could be designed according to only a little steam data. Today full information must be obtained regarding the complete machine installation, to be able to put forward the most economic design and he thought that this was the way to go to meet requirements and competition. It might be that this would make the installation more complicated but then it had to be borne in mind that reliability was still the main thing.

The two-drum boiler shown in Fig. 20 and arranged for side firing looked very attractive to him, especially the arrangement of the oil burners in a very low refractory side wall. All the other walls were water cooled and the gas flow was much better than in conventional boilers. He thought that this scheme would be a real improvement and would be suitable for many different types of installation.

In this connexion he wished to express a hope regarding oil firing registers. He thought that especially now, when fully automatic manœuvring of ship machinery was being talked about, it was essential that the numbers of oil burners be limited to a maximum of five or six and where possible decreased to two or three. If necessary each boiler could be equipped with two different sizes of burners.

COMMANDER E. B. GOOD, O.B.E., R.N. (Member) wrote that the author had rightly highlighted at the very beginning of this paper the very dominant aspect which was played in marine merchant boiler practice by the necessity to burn relatively low grade residual fuel. Thus the tube spacing in the high temperature parts of the boiler, the gas and steam temperatures at various points, the choice of steam assisted burners were all mainly decided on their ability to deal with residual fuel. Fortunately it was naval practice to use, under normal conditions, a fuel roughly equivalent to Bunker B, while making provision for burning residual fuel should the necessity arise. In addition, a greater percentage outage period during the ship's operational life was accepted for boiler cleaning by the Navy. The prevention of fouling, though extremely important in the detailed design of naval boilers, did not therefore dominate the overall arrangement as was the case with merchant practice. This factor thus contributed to the navy's ability to use boilers about a quarter the size and weight of corresponding merchant marine boilers without maintenance becoming unacceptable.

Although it was appreciated that the poorer specific fuel consumption of a steam installation must inevitably demand the use of a cheaper fuel than that used in a corresponding Diesel engine installation, one wondered what gains might become apparent by installing more compact boilers using better grades of fuel. Had a detailed investigation been carried out to see whether the higher fuel costs could not in fact be offset by capitalizing on the space and weight saved and by the decreased maintenance cost arising from the use of a better grade of fuel?

The optimization given in the paper was a little restrictive in that the proportions of the furnace, generator and superheater were fixed from the considerations of maintenance, again dominated by the residual fuel aspect. It would be instructive if the author could give very briefly, the reasons for the choice of furnace size and boiler and superheater draught loss. If the fouling and maintenance problems could be eased then some room for manœuvre might be available in these fields. Obviously these basic parameters could not be decided without considering the overall machinery installation including the type of blower, prime mover and feed system, etc.

Although the author stated that optimization was time consuming and was only carried out for certain projects, it must be observed that even the restricted optimization given in this paper dealt in units of £1,000 per annum. Presumably the inference was that an experienced designer could save a great deal of effort in making intelligent estimates of the probable optimum conditions for comparable designs without undertaking a detailed optimization study. Nevertheless the value of such studies should not be under-estimated as they often threw up surprising facts and disproved popularly held misconceptions.

On the subject of gas turbines and pressure combustion raised by the author, these again are dependent on fuel policy. Neither, at present, would appear to be a practical proposition using residual or even Bunker B types of fuel. Whether a case could be made for burning distillate fuel commercially in boilers, even when associated with gas turbines as blower prime movers or in a pressure combustion installation, seemed unlikely under present price conditions. On the other hand a well designed pressure-fired boiler installation, burning distillate fuel, could drastically reduce the boiler maintenance load, and at the same time give a unit of a fraction of the size of a conventional boiler. Again the economics of this type of plant could only be determined by a study of a complete installation.

MR. M. HARPER (Member) wrote that the author was to be congratulated on the scope of the paper and its concise and easily understandable presentation. It was obvious that a great deal of time and effort had gone into this work.

The author's remarks on corrosion problems due to low power steaming were of interest, since on most tankers the boilers were sized for service power with cargo heating or tank cleaning, with frequently a further margin of about 10 per cent. This meant that for a large part of the tanker's life the boilers were being steamed far below the designed evaporation, which aggravated the corrosion problems. This would be difficult to overcome, as this was a necessary evil connected with tankers, unless owners could be persuaded to fit boilers more in line with service power requirements and accept a slight loss in speed when cargo heating or tank cleaning.

It was gratifying to learn that some progress had been made on the adoption of vitreous enamel for gas air-heaters and showed promise for the solution of this most vexing problem.

The section dealing with economics must have involved the author in a great deal of work, but it was perhaps unfortunate that no account had been taken of the remainder of the cycle efficiency, as the conclusions arrived at could be misleading if the reader did not appreciate this point. It must also be remembered that the boilers considered in schemes 2 and 3, with large gas air-heaters, would probably present difficulties in arrangement in the boiler room casings, with consequent problems in positioning the forced draught fans and trunking. This was a point which would have to be considered at the same time as the economics.

The side-fired boilers, pictured on page 45, outboard of the turbines and gearing looked attractive but, with the present trend of the naval architect progressively to fine down the ship lines aft, it would frequently be impossible to arrange the boilers in this position and a return to the conventional boiler room would have to be made. Under these circumstances the advantages would be nullified. The position of the burners under a shelf might also present a problem in ventilation and in keeping the firing platform at a reasonable comfort level.

MR. A. BELL, B.Sc. (Associate Member) wrote that Mr. Hutchings had given in his paper a useful and authoritative study of the economics of different feed systems and economizer or air-heater arrangements. In this he had come to the same conclusion as a number of other authors, namely, that up to about 600lb./sq. in. boiler pressure, air-heater and economizer schemes were equally attractive but that at higher boiler pressures the air-heater had a distinct advantage, particularly if corrosion difficulties could be overcome.

The paper mentioned promising results from vitreous enamelled tubes but did not emphasize the economic possibilities of the considerable reduction in gas outlet temperature which this development would permit.

Regenerative air preheaters had been operated successfully in America with vitreous enamelled element sheets on high sulphur coal and with a gas outlet temperature as low as 219 deg. F. Element life in excess of two years had been obtained.

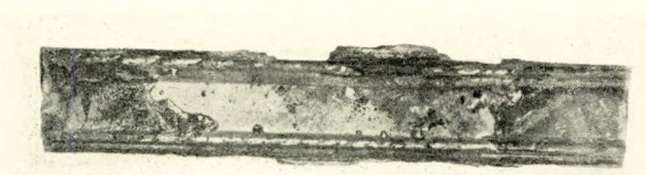
Eight sets of similar vitreous enamelled elements had been installed in regenerative air preheaters in six ships operating from the United Kingdom and France within the past eighteen months. It was too early to estimate the life of the elements, some of which were operating with gas outlet temperatures in normal service of 230 deg. F., but preliminary reports said that the vitreous enamelled elements were remaining clean in these conditions where plain elements fouled quite rapidly.

The unrestrained sheet elements of regenerative air preheaters when coated with vitreous enamel did not tend to crack due to expansion in the same way as the paper indicated could be experienced with coated tubes; so that this method of protection was particularly applicable to regenerative air preheaters both as a protection against corrosion and from fire risk.

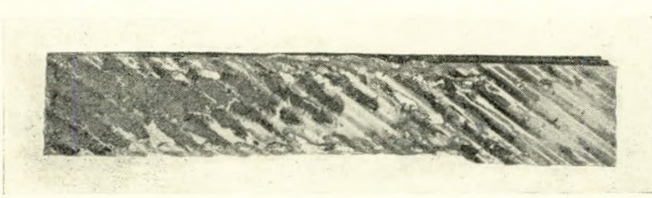
Fig. (35) showed sections of a test pack consisting of five plain and five vitreous enamelled element sheets. These test elements were coated with a mixture of oil and soot. The pack was then placed in an insulated duct and hot air at 400-500 deg. F. blown through it until the oil and soot ignited. The plain elements ignited and were badly holed, but the vitreous enamelled elements were only damaged where they were in contact with the plain elements. Since the vitreous enamelled elements had been subjected to the intense heat generated by the burning of the plain elements this was a very severe test.

To test the fire resistance of the vitreous enamelled elements under more realistic conditions, and to investigate whether they would still give protection after a soot fire, a similar experiment was carried out with separate packs of vitreous enamelled and plain elements. In this test the plain elements were completely burnt out after one fire, but after two fires the enamelled coating remained intact except for damage along the peak of the undulations—(see Fig. 36). This damage

Plain elements partially destroyed and fused to first vitreous enamelled element.

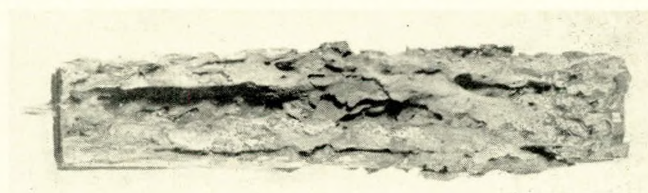


Reverse of above showing first vitreous enamelled element fused to burnt-out plain element but not even holed.

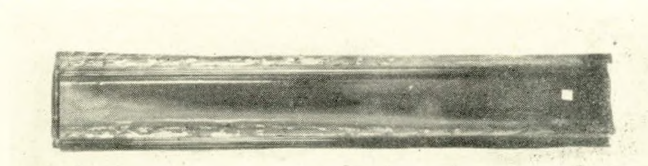


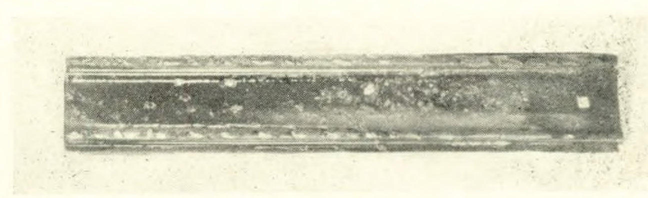
Second and subsequent vitreous enamelled elements undamaged (vitreous enamel damaged where fused to adjacent elements).

FIG. 35—*Ignition tests on soot-fouled elements*



All plain elements destroyed in first soot deposit fire.





Two examples of vitreous enamelled elements undamaged after two soot deposit fires (vitreous enamel only damaged where it had been fused to adjacent elements).

FIG. 36—*Ignition tests on soot-fouled elements*

was caused by separating the sheets for inspection thus breaking the enamel where it had fused together at the peaks of adjacent sheets. In an actual air-heater the elements would remain undisturbed and the enamel would remain intact, the fusing together of the peaks of the undulations being if anything an advantage.

The elements would therefore still be protected even after a number of soot fires.

During these tests the burning deposits rose to a temperature of 1,800-1,900 deg. F., but once the deposit had burned off the temperature quickly dropped back to that of the hot air supply.

The temperature of the burning plain elements rose to 2,500-2,700 deg. F. and they continued to burn as long as the air supply continued.

The results of these tests indicated that vitreous enamelled elements could be used both to obtain low gas outlet temperatures with consequent improvement in the boiler efficiency with little risk of corrosion; and to afford excellent protection of the air preheater against damage from soot fires.

Author's Reply

The author replied that he was delighted at the interesting discussion which the paper had evoked. The items which had caused most comment appeared to be Figs. 12 to 16 and the interpretation thereof. He thought that he had made it quite clear in the paper that the curves did not pretend to represent an exact theory of the mechanism of slagging. The curves showed the probable effect of gas temperature, steam temperature and superheater tube pitch on the problem in a design of boiler in which the superheater was prone to slagging when certain low quality fuels were burnt. These curves could be useful in assessing whether a proposed modification to such a design would be beneficial or not. For current steam temperatures there were two approaches to superheater design namely:

a) The superheater could be placed in a low temperature gas zone and be relatively free from slagging, but would suffer several other disadvantages as indicated in the paper.

b) The superheater could be placed in a high temperature gas zone and be near the ideal from most points of view, except that with certain fuels it would be susceptible to slagging.

If the first course were followed the designer must be quite confident that the inlet gas temperature to the superheater was in fact low enough to avoid slagging. This became more difficult as steam temperatures rose, particularly if a superheater gas bypass was included for steam temperature control. When a sufficiently low inlet gas temperature could be obtained, Figs. 12 to 16 had little relevance. If the second course were adopted in order to obtain the advantages of a stable and "flat" superheater characteristic reducing the necessity for steam temperature control to a minimum, then the curves indicated that, from the point of view of slagging, there was an advantage in using the widest gaps between the superheater tubes and the highest gas temperatures permitted by considerations of space, cost and metal temperature. This coupled with the use of rack soot blowers had proved an effective answer to the slag problem.

The author then made comment, on certain specific points raised, as follows.

He was pleased to have Mr. Scott's confirmation that over a long period rack soot blowers had proved effective in combatting slag on superheaters when burning difficult fuels. He also assured Mr. Scott that the circulation rates in the side-fired boiler were adequate to avoid undue distortion at any load. In fact the distortion would be less since, by having water walls at both front and rear, the casing temperatures in these two areas would be more nearly equal than was the case with current designs where the front wall was of uncooled refractory.

He agreed with Mr. Scott that the cast iron air-heater was another promising solution to the problem of air-heater corrosion and that time alone would tell whether or not it was superior to a vitreous enamelled tubular air-heater. Since this was largely a question of maintenance cost it was difficult for a boiler maker to assess the relative merits with accuracy. He therefore thanked Mr. Scott for his offer of assistance in this respect. The author also took this opportunity to say that Mr. Scott and his company had already given his own company considerable assistance in their design work and this was very greatly appreciated.

He could not agree with Mr. Hayden that boilers with superheaters after the generating bank had "considerable advantages". As far as he could see the only real advantage in this design was the possibility of avoiding slagging with moderate steam temperatures against which there were several disadvantages. It was hoped that the paper had shown that superheaters in high temperature gas zones could also be designed to be relatively free of slag formation. He was not impressed by the statement that 16 boilers of the type shown in Fig. 11 were in service without slagging troubles although designed for a steam temperature of 950 deg. F. These 16 boilers probably represented no more than six ships and it was also probable that these particular ships were not burning the most troublesome fuels. Against this he could name well over a hundred ships with close pitched superheaters in high temperature gas zones which were having no serious slagging problems due either to the type of fuel that they were burning or the use of rack soot blowers. While mentioning rack soot blowers it was perhaps advisable to point out that there were various makes of rack soot blowers available and these were not necessarily equally effective. He was convinced that if the poorest fuels were burned and the gas temperature entering the superheater was as high as 1,900 deg. F., as suggested by Mr. Hayden, then slagging would become a problem even with the superheater after the generating bank. The use of the term "generating bank" in this context although correct, could be misleading since, for a steam temperature of 950 deg. F., it might only be some six rows of tubes whereas many boilers at sea with lower steam temperatures were experiencing slagging with four rows of screen tubes and lower rated furnaces so that the inlet gas temperature to the superheater would be similar.

Mr. Hayden was quite correct in saying that the author was suggesting that, if the surface of a superheater deposit was hot enough, no further ash could condense thereon. He thanked Mr. Hayden for clarifying this point and was pleased to see that he agreed with him.

Commander Tyrrell raised the question of whether or not steam turbine machinery was on the way out for marine propulsion. Perhaps the best answer to this was that Mr. Lindén, with his well known connexion with the Götaverken Diesel engine, had considered the paper worthy of comment. Commander Tyrrell was of course quite correct in pointing out that the solution to this question did not rest with the author alone. The author was aware of and applauded, the efforts made by American turbine designers to improve steam machinery and hoped that his paper had shown that boiler makers were also making their contribution. He felt bound to state quite strongly that the study of integrated, simplified and automated steam machinery was not confined to the United States and similar studies were being made in Europe which in some ways were even more encouraging.

The parallel drawn by Commander Tyrrell between a single Diesel engine and a single boiler was not entirely true since a Diesel had a multiplicity of cylinders and the usual troubles associated with Diesel engines did not affect all cylinders and therefore resulted in a reduction in power and not a complete loss of power.

Commander Tyrrell had thrown down a gauntlet in asking the author to comment on the resources and background of engineering departments and shops of the shipyards. Although this question was to his mind quite irrelevant to the paper he felt morally obliged to pick it up—perhaps a little gingerly! As far as he could see the fundamental requirements for producing equipment of the type and quality to which Commander Tyrrell referred were as follows:

1) A considerable technical staff capable of integrating and optimizing a plant throughout in order to obtain the best balance between initial and running costs and to reduce installation costs and operating staff.
2) A research and development facility and programme to improve availability and/or efficiency and/or cost of individual parts of the plant.
3) An economic shop production and inspection method giving the quality required to take full advantage of items 1) and 2).

He agreed that few shipyards in the world possessed all these qualifications in full but would also point out that very few shipyards designed their own boilers and turbines. He saw no real reason why, providing the shipyards confined their work to that which they could carry out economically to the required quality, they should not, by virtue of licence agreements with co-operative boiler and turbine designers, produce a set of machinery as good as in the "package deals". Several shipyards already had the necessary licences. By working through licensees, it was probable that a better overall ship would be produced since, while the shipyards might not have the technical staff and background to produce the best turbine and boiler design and steam cycle, their knowledge of shipbuilding, of the overall picture, of the domestic installation problems and several contributing factors was superior to that of the boiler or turbine designer. The author also pointed out that the turbine designers who had received orders for "package machinery" sometimes manufactured less than half of the total order in their own factories and the rest was "bought in". It would seem more economical for the shipyards at least to purchase the "bought in" items from the original manufacturer which was virtually what usually happened now. Perhaps some shipyards could be criticized for trying to integrate the whole design with inadequate staff but the answer to this problem was a closer marriage of machinery designers and marine engine builders not a divorce, each partner contributing that share for which he was best suited at the time, bearing in mind sociological and economic problems as well as those of engineering.

He could find no place in the paper where he had stated that the only problem with burning a sulphur bearing oil was the amount of sulphur and oxygen present as suggested by Mr. Carter. Perhaps the author had misunderstood Mr. Carter's implication, but the point he had tried to make was that if the oxygen content of the flue gases was reduced then, all other things being equal, the amount of SO_3 and consequently the rate of corrosion would also be reduced.

In further reply to Mr. Carter, the advantages of the "Y-jet" burner were clearly stated on page 39 of the paper. To the standards required for marine work he had found no difficulty in operating the "Y-jet" burner over a 10:1 range without any adjustment to the air register normally employed with this type of burner.

He would respectfully point out to Mr. Carter that the three criteria for "boiler design" were in fact clearly stated as being only those required to avoid superheater slagging. He agreed with Mr. Carter that superheater metal temperatures should be kept below 1,140 deg. F. when burning a vanadium bearing fuel. Two-drum boilers had been in service with only two rows of screen tubes for many years, particularly in the United States, without any trouble from overheating of superheater tubes. He therefore suggested that the overheating experienced by Mr. Carter was basically due to some other factor.

There were cheaper ways of plugging economizer elements than shown in Fig. 24 but, unless one anticipated that this would be a frequent occurrence, cost, within reason, was hardly relevant. The techniques of vitreous enamelling which Mr. Carter had used might not have been successful but there were ways of providing a 100 per cent coating and they were considerably cheaper than fusing glass onto the tube.

The author did not think that there was much difference between the CO_2 values obtained in practice in the United States and Europe and the comparison drawn in the paper was between the figures used for design purposes on either side of the Atlantic.

For the right application the author shared Mr. Watt's enthusiasm for short retractable soot blowers but he was convinced from his own experience that it was not wise to locate this type of blower in the furnace walls of a marine boiler. Other speakers also shared this view. He agreed that automatic operation of soot blowers was desirable. This could be effected with simple equipment and in many cases would reduce maintenance costs and improve overall efficiency for the reasons stated by Mr. Watt.

Mr. Milton, along with others, questioned the maintenance of superheater supports. The author was aware that this trouble had been severe in many boilers designed by other firms but for some reason, of which he was not aware, only isolated cases had occurred in his own company's boilers. The only difference which he could see between their product and others was the mechanical design of the supports. He would like to think that this was the reason for their apparent success but he was not convinced that this was so.

He agreed with Mr. Milton that present day boilers required less maintenance than earlier designs due mainly to the efforts of his predecessors. It was quite true that, apart from the troubles emphasized in the paper, maintenance of other parts had been reduced and the initial cost had also been reduced.

The water wall tube failures referred to were due entirely to scale formed on the inside of the tubes. The influence of under-floor tubes did not affect the answer, in fact he would think that they created a further maintenance hazard. Under-floor tubes were shown in several of the designs illustrated in the paper in an attempt to show the different practices employed by various boiler designers.

With regard to the relative advantages of the in-line and staggered tubes, a subject raised by both Mr. Milton and Commander Inches, he would first say that this depended upon the particular problem. In the case of the close pitched rear bank tubes ($1\frac{1}{4}$-in. o.d. on $1\frac{3}{4}$-in. pitch, i.e. pitch $= 1{\cdot}4$ diameters) the coefficient of heat transfer in a given tube bank was from 5 per cent to 15 per cent higher with staggered tubes, but the gas resistance would also be between 25 per cent and 50 per cent higher depending upon the Reynolds number. If the two banks were arranged to have the same heating surface and gas resistance, the in-line bank would have a smaller gas area and be deeper, but the heat transfer coefficients would be virtually the same in each case. With a pitch, perpendicular to the direction of gas flow, equal to twice the tube diameter similar heat transfer coefficients could be obtained with both arrangements, providing the total heating surface and gas resistance were the same in both cases. However, except at high Reynolds numbers, this could only be achieved by increasing the pitch of the in-line tubes, in a direction parallel to the gas flow, by an amount up to 50 per cent, depending upon the Reynolds number. The performance of an in-line tube bank was no more sensitive to the accuracy of the pitching of the tubes than was a staggered arrangement except with tube pitches of two diameters or more and even then only at very low Reynolds numbers.

The author replied to Commander Inches, that he thought the most important feature of the "Y-jet" atomizer was the superior atomization which was obtained and maintained in service, but possibly the mere presence of the steam also contributed to the reduction in deposits experienced.

Commander Inches would appreciate the difficulty of comparing the superheater in Fig. 17 with the *County* Class design since the latter was a selectable superheat boiler. If the *County* Class boilers were redesigned to have similar superheater tube pitches and access spaces to those shown in Fig. 17, then the boilers would be some 18-in. wider and the steam temperature control range would be reduced to about 100 deg. F. A longer superheater withdrawal space would also be required.

The economizer sealing arrangement shown in Fig. 9 was only used when the economizer tube arrangement was suitable. In other cases more simple but less reliable, methods were employed and the author would be interested in the particular design to which Commander Inches referred.

The point raised by Mr. Mackenzie in comparing combustion and deposits in Diesel engines and boilers was interesting and, while centrifuging alone might be the answer, the author would not care to make a definite comment in this direction. It could of course be that the atomization achieved by a Diesel injector was superior to that of the normal marine oil burner and ample comment on the superiority of "Y-jet" burners, probably for the same reason, had been made elsewhere in the author's reply.

In reply to Mr. Bolt, the author pointed out that oil burners, as such, were not the subject of the paper and the "Y-jet" burner had been mentioned solely because, over several years, it had shown a very marked degree of success. To answer Mr. Bolt completely would require an additional paper and he hoped that the following remarks would give sufficient information on the subject.

The author's company had used all types of oil burners, including the "external-mix" steam assisted type referred to by Mr. Bolt, in marine installations for many years and the combined weight of experience was the prime justification for the claims made for the "Y-jet" atomizer. To be more specific, "Y-jet" burners had been installed in several new ships built in Europe over the last ten years. The average CO_2 recorded on the trials of these ships was higher than that usually recorded with any other type or make of burner. The majority of vessels fitted with "Y-jet" burners maintained their high CO_2 in service (automatic combustion control was fitted to all these vessels). The general impression of operators and service engineers was that the boilers in these ships were cleaner than other boilers in the same fleets and air-heater or economizer corrosion was less. A specific trial was carried out in two German-built sister ships trading between Germany and New York. These vessels had been in service for between four and five years. The first vessel was originally fitted with pressure atomizers and the other with "Y-jet" burners. It was necessary to water wash the superheaters of the first vessel at two to three monthly intervals in order to keep the general slag thickness below a quarter of an inch and the slag was difficult to remove. After seven months service without water washing, the second vessel had only about one tenth of an inch deposit and this was friable and easily removed. The marked difference was maintained for a further period and then "Y-jet" atomizers were fitted to both vessels and near identical performance was obtained in each. In the first ship, air-heater tubes had corroded through in less than twelve months, but with "Y-jet" burners a longer life was obtained. An analysis of deposits on the superheaters showed that there was a much smaller proportion of sulphates in the deposits on the boilers fitted with "Y-jet" atomizers.

Other ships built in Europe for American owners had shown similar results. In one class of six ships which had been in service for six years, the owners ran for a period on "Y-jet" burners then for a similar period on pressure atomizers, finally returning to "Y-jet" burners. The owners were convinced, by the results, of the advantages of the "Y-jet" burner. In the last twenty years 135 steam ships had been equipped with "Y-jet" burners.

The author regretted that he was not expert in the chemistry of combustion and it was possible that the steam played a part in this but he was sure that the method of atomization by steam instead of relying on an accurate and delicate sharp edged orifice in any form was an important factor. It had been shown that this type of atomizer gave a considerably smaller S.M.D. (Sauter mean diameter) than any mechanical type and this was far more likely to be maintained in service.

The point made by Captain Jenks, that the economic study was based on certain controversial assumptions for cleanliness, CO_2, fuel cost and steaming days per year was a very real one, also, as stated in the paper, certain other factors had been disregarded. If a different CO_2 was chosen as a basis then there was a change in the optimum fan pressure and efficiency, but the arrangement and size of the heating surfaces required for an optimum design did not alter appreciably. With 13 per cent CO_2 as a basis, the optimum fan pressure for the plant studied in the paper would be increased by about 10 per cent from 11·7-in. w.g. and 19·5-in. w.g. to 13-in. w.g. and 21·5-in. w.g. at normal power and design fan rating respectively. Similarly the optimum boiler efficiency would be between 0·5 per cent and 0·6 per cent lower.

A variation in fuel cost or steaming hours however could have a significant effect. For example, if the price per ton of fuel was doubled the optimum efficiency increased by 0·45 per cent and the cost of the corresponding plant was nearly £18,000 higher. Conversely, if the steaming days per year were reduced from 270 to 135 then the optimum design indicated by a similar study would be cheaper by £11,500 and the efficiency would be 0·7 per cent lower. This was also only part of the story since as the number of steaming days was reduced the shape of the curve became less sharp near the optimum. If the design was chosen to have the lowest possible efficiency without incurring a penalty of more than £300 per year on combined capital charges and fuel cost then the relative costs and optimum efficiency would be as shown in Table II.

TABLE II

Fuel cost per ton.	*Steaming days per year.*	*Chosen Efficiency per cent.*	*Capital cost.*
£15	270	89·5	£19,000
£7 10s.	270	88·8	Basis
£7 10s.	135	87·15	£15,000

The author was in complete agreement with Captain Jenks on the advantages of Scheme 4 when all points were considered. He also thought that Captain Jenks' suggestion of a plant with a single boiler and a "get-you-home" gas turbine deserved consideration. Subsequent to writing the paper the author had also had second thoughts on pressure combustion and although he still doubted whether this had any future for merchant ships he was perhaps not so doubtful as he was six months ago.

Mr. Lindén's kind remarks were greatly appreciated and the author was glad to receive his approval of the design shown in Fig. 20. The author was also pleased to hear from a leading ship and marine engine builder that co-ordination of design was essential. He was in sympathy with Mr. Lindén's desire to reduce the number of burners but in doing so one must be sure that combustion efficiency was not impaired.

The query raised by Commander Good, with regard to the economics of operating with and designing for a better grade of fuel was interesting. Although the author was not aware of the detailed results of any such investigation he doubted whether this would prove attractive except perhaps for cross-channel ships or for a very high steam temperature experimental installation as suggested in the section of the paper headed "THE FUTURE".

The furnace dimensions in the basic design were chosen to give the greatest residence time for the combustion balanced against space occupied and price. The design in Fig. 20 was advantageous in this respect since one of the features was that, for a given furnace volume, the residence time was increased. With such a design therefore, experience might justify higher ratings. The heating surfaces of the boiler had been chosen mainly to give reasonable access for water washing and once again experience with a boiler, such as that shown in Fig. 20, with rack soot blowers, "Y-jet" burners, improved combustion chamber and wide superheater tube pitches might show that economies could be made in this direction even with the poorer quality fuels.

He agreed with Commander Good that optimization studies were important and sometimes revealed surprising facts. He thought however it was worth pointing out that the main value of such studies was in showing whether in fact there was any point in departing from current practice and, if so, in which way one should go, i.e. in the case of fan pressure to higher or lower figures.

The necessity for maintenance with pressure combustion boilers burning Diesel fuel, might well be less than with conventional units but with the designs so far produced he doubted whether the cost would be less, since any single problem encountered would be more difficult and hence more expensive than the same problem, such as replacing a tube, would be in a conventional boiler.

Mr. Harper's remarks upon the relationship between the actual normal operating load of a boiler and the maximum specified output were greatly appreciated and anything which could be done to cut out unnecessary margins on boilers would, the author thought, reduce not only the initial costs but also the maintenance cost, particularly for air-heaters and economizers.

Subsequent to writing the paper further evidence had become available in the story of vitreous enamelled air-heater tubes. In a particular vessel two classes of enamelled tubes had been installed together with plain mild steel tubes, in such a manner that their performance could be directly compared. After twelve months continuous service the plain tubes had suffered serious corrosion and some were holed. The enamel had started to flake off one type of vitreous enamelled tube, but the mild steel tube underneath was near perfect. The second type of enamelled tube was still in perfect condition as originally installed.

The author agreed with Mr. Harper that in a fine hull the side-fired boiler gave little advantage but he submitted that the improved furnace shape was in itself sufficient justification for the design. He also agreed that attention must be paid to the ventilation of the tunnel formed when two such boilers were placed side by side in the conventionel manner, but fortunately it was possible to design the boilers so that a space of more than two feet could be provided between the boiler side casings without exceeding the overall width which would be occupied by two conventional boilers similarly arranged. He entirely agreed that the results of the economic analysis of the boiler plant given in the paper could be misleading unless the consequent effects on the rest of the plant and the practical problems of accommodating the various schemes were considered. The gas air-heater occupied a large volume and the cast iron economizer was heavy and had to be supported separately.

The author agreed with Mr. Bell that if vitreous enamelled air-heater tubes continued to show success then higher boiler efficiencies could be considered with gas air-heaters which might well outweigh the space and weight disadvantages of this type of plant. It was admittedly easier to provide corrosion resistant elements in regenerative air-heaters and also easier to replace regenerative air-heater elements. The author had only two things against regenerative air-heaters. Firstly, practical experience and academic analysis revealed that this type of heat exchanger was many times more prone to fire than the tubular air-heater, in fact the fire risk in a regenerative air-heater was very real, while a fire in a tubular air-heater was a rare occurrence, bearing in mind the several thousand tubular air-heaters which were in marine service. The emphasis which Mr. Bell had put on the relative merits of different types of elements from the point of view of fire resistance only served to highlight this point. His second objection to the regenerative heater was the leakage which in practice occurred from the air to the gas side, thus increasing the fan power required and reducing the overall efficiency. The significance of this last point was reduced as the unit power was increased, but it was still quite an important factor in the powers at present used in the average marine installation.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at The Memorial Building on Tuesday, 13th November 1962

An Ordinary Meeting was held by the Institute on Tuesday, 13th November 1962 at 5.30 p.m., when a paper entitled "The Design and Development of Two-drum Marine Boilers" by E. G. Hutchings, B.Sc. (Member), was presented by the author and discussed.

Vice-Admiral Sir Frank Mason, K.C.B. (Chairman of Council) presided at the meeting which was attended by 153 members and guests.

In the discussion which followed nine speakers took part.

A vote of thanks to the author, proposed by the Chairman, was enthusiastically received.

The meeting ended at 7.25 p.m.

Section Meetings

South Wales

A junior meeting of the Section was held on Monday, 21st January 1963, at the Welsh College of Advanced Technology, Cardiff, at 6.0 p.m., when a paper entitled "Watchkeeping in a Motorship" by S. Speed (Member) was presented by the author to an appreciative audience of fifty-three members, students and guests.

Owing to the indisposition of Dr. Harvey, Principal of the College, Mr. R. A. Simpson (Chairman of the Section) presided at the meeting.

Mr. Simpson welcomed all those who were present and expressed his pleasure that so many had turned up, despite the adverse weather and he made particular reference to the party that had travelled from Swansea. He then introduced the speaker.

Mr. Speed's very absorbing and illuminating lecture, which was much appreciated by all present, was followed by an active and interesting discussion period, in which the author dealt ably with the numerous questions presented to him.

At the conclusion of the lecture Mr. Simpson proposed a vote of thanks to the guest speaker and the meeting terminated following a vote of thanks to the Chairman, proposed by Mr. H. S. W. Jones (Member).

West Midlands

A meeting was held on Thursday, 24th January 1963, at the Engineering and Building Centre, Broad Street, Birmingham, at 7.0 p.m. when a lecture entitled "Bristol Siddeley Olympus Turbo Generator Sets" was presented by Mr. W. H. Lindsey, M.A., F.R.Ae.S., M.I.Mech.E.

Mr. H. E. Upton, O.B.E. (Chairman of the Section) presided at the meeting which was attended by 56 members and visitors.

With the aid of slides, Mr. Lindsey described the arrangement of the gas turbine generator set with particular emphasis on the advantages in using as prime mover, a gas turbine where the set would only be required to meet peak load conditions at very short notice. Mr. Lindsey mentioned that similar gas turbines were also being used for marine installations where high powers were required and space was very limited.

Following the lecture a very interesting discussion took place in which all questions were ably dealt with by the speaker.

On behalf of the members and guests present, the Chairman thanked the speaker for a most interesting lecture.

The meeting closed at approximately 9.0 p.m.

Election of Members

Elected on the 11th February 1963

MEMBERS

Henri Louis Beliard
William Crowley
Alexander Leo Donnelly
William Mayers Hedley
Knud Møller
Desmond Wright, Lt. Cdr., R.N.

ASSOCIATE MEMBERS

Robert Ernest Brand
Wilfred Kenneth Bright
Keith Brownlie, B.Sc. (Bristol)
Maurice Brunton
David Morrison Campbell
James Candy
George Hunter Crowe
Eric William Deans
John Flynn
Moshe E. Elias, B.Sc. (Glasgow)
Brian Green
Richard Meyrick Hewlett, T.D.
George Thomas Hindmarsh
Roland Lavoie
Ian Lennox, Lt. Cdr., R.N.
Richard Ernest Lovell
M. D. Neal
Harold Orford
H. T. Pavri
Anthony John Smith
Gordon Frederick Smith, Lieut., R.C.N.
John Derek Smith
Lester Montague Vanderzeil
Alan Edward Walton
Geoffery Watson Wayman

ASSOCIATES

Thomas F. Brennan
Ernest Sydney Garvey
Henry Joseph Hardy
Ronald Carstairs Hawksford

GRADUATES

Francis James McClemens
Keith Victor Robbins
Robert Stuart Salt
John Raymond Williams

STUDENTS

Emanuel Argyros

Jonathan Gordon Clark
Iain Hamilton Colquhoun
Robin Corlett
K. R. Day
Brynmor Michael George
Richard Charles Hingley
Donald Stuart Munro
Mark Sebastian Rainey
Hamish Charles Fraser Sutherland
Brian John Taylor
Michael Wells
Richard Geoffrey White

PROBATIONER STUDENTS
Kenneth Fidler
James Edward Green
Martyn Scott Jones
Anthony Edward Lindars
Keith Norman Ralfs
Anthony Clifford Richards
Robert Smyth
Anthony Paul Sneesby
David Alfred Tuffen
Douglas Vallance

TRANSFERRED FROM ASSOCIATE MEMBER TO MEMBER
Colin Stewart Curtis
Donald Alexander Gillies
David Sampson

TRANSFERRED FROM ASSOCIATE TO MEMBER
Louis Krygsman
Lewis McKay

TRANSFERRED FROM GRADUATE TO ASSOCIATE MEMBER
John Laurence Hutchinson
William Patrick Lawler
John Thompson Murray
Joseph William Perkins
Ian Philip Wall

TRANSFERRED FROM STUDENT TO GRADUATE
John Gabriel Green
Paul David Kyle
Ian Bernard Poole

TRANSFERRED FROM PROBATIONER STUDENT TO ASSOCIATE MEMBER
Derek Ian Rowan
Robert Stanley Symon

TRANSFERRED FROM PROBATIONER STUDENT TO GRADUATE
Malcolm Kenneth Gilbert

TRANSFERRED FROM PROBATIONER STUDENT TO STUDENT
Allan Smith Blackwood
Roger Anthony Booth

OBITUARY

JOHN CHALMERS LOWRIE

An appreciation by W. Lynn Nelson, O.B.E. (Vice-President)

With the passing of John Lowrie the Institute of Marine Engineers loses a marine engineer whose active participation in the affairs of the Institute covered many years during which period he conscientiously served three terms as a Member of Council and three terms as a Vice-President, London. In 1935 he was elected an Honorary Vice-President in recognition of his most valued services to the Institute.

As a Member of Council and later as a Vice-President, John Lowrie gave unreservedly of his valued time and effort to the Advisory Committee of Superintendent Engineers, the General Purposes Committee and the Appeal and General Committees of the Marine Engineers National War Memorial. He also served on the Committee of the Guild of Benevolence.

The career of John Lowrie is typical and exemplifies the system developed as from the advent of steam, by which the British Mercantile Marine has been furnished with marine engineers of sterling quality. Born on the 2nd of April 1881, he commenced serving his apprenticeship with W. Philip of Kirkcaldy in 1897, on the completion of which he commenced his seagoing career in 1902, as a fourth engineer with the Bank Line, owners Andrew Weir and Co. Ltd. He served in various Bank Line steamers for fifteen years, ten of which, as Chief Engineer. The remainder of his career was served as Assistant Superintendent and later as Chief Superintendent of the Bank Line vessels. In 1951 he retired having spent the whole of his career, apart from his apprenticeship, with Andrew Weir and Co. Ltd., during which period of 49 years he undoubtedly gave loyal and devoted service to the company.

John Lowrie was a quiet spoken, unassuming man, but one had not to know him long before realizing his ability and stolid forthright character. He was, above all, a kindly man as was always evident during his many years unstinted service on the Committee of the Guild of Benevolence. We of the Guild Committee were also sorry to lose his services on his retiring and leaving the London area.

JOHN HENRY ANDERSON (Member 14204), a Member of this Institute since 2nd March 1953, died suddenly at sea on 27th September 1962 at the age of 48 years. He served his apprenticeship, from October 1930 to October 1935, with Swan, Hunter and Wigham Richardson Ltd. of Wallsend-on-Tyne. He first went to sea as fifth engineer with the Anglo-Saxon Petroleum Co. Ltd., now the Shell Petroleum Co. Ltd. and remained in the service of that company as a seagoing engineer up to the time of his death.

Mr. Anderson obtained his First Class Motor Certificate on 10th March 1941 and his First Class Steam Endorsement on 12th August 1954. He became a chief engineer with Shell on 15th March 1947. He was serving aboard s.s. *Vibex* in the Persian Gulf when he suffered the heart attack which was responsible for his death. He was buried at sea on the following day.

Mr. Anderson leaves a widow and young son.

LIEUTENANT ALAN ROY ARMSTRONG, R.N. (Associate Member 23578) died in August 1962, at the age of 24 years. He was educated at Eltham College, Mottingham and the Royal Naval College, Dartmouth, passing out from the latter establishment as Acting Sub-Lieutenant, in July 1957.

From that time he underwent engineering training in H.M.S. *Sheffield* until January 1959, when he gained his Engineer Officer's Watchkeeping Certificate. For the next three months he was a watchkeeping officer in the *Sheffield* and was attached to the Reserve Fleet, Portsmouth for the purpose of placing that vessel into reserve. At that time he acted as Assistant to the Commander (E) in charge. In March 1959 he commenced a six-month tour of duty as watchkeeping officer in H.M.S. *Vanguard,* on completion of which he proceeded to the Royal Naval Engineering College, Manadon to begin a three year engineering course. He was still engaged on that course at the time of his death.

Lieutenant Armstrong was elected an Associate Member of the Institute on 10th April 1961. He leaves a widow.

LIEUTENANT REGINALD WALTER BLATCHFORD, M.B.E., R.N. (Member 11290) who died on 23rd September 1962, was born on 2nd December 1901. He served his apprenticeship from 1917-1922 at the Royal Naval Training Establishment, H.M.S. *Indus*, at the end of which he successfully passed the Admiralty examination, being awarded six months seniority on that result. In 1922 he began his service with the Royal Navy as an engine room artificer, receiving warrant rank eight years later. In 1932 he commenced a period of service, as engineer officer in operational submarines, which continued until 1945. During that period, he served in H.M. Submarines *Trident* and *Tempest*, among others, and was in the latter vessel when she was torpedoed in 1942. A Commissioned Engineer at the time, he was taken a prisoner of war and spent the next thirteen months as such in Italy.

He was repatriated in 1943 and, with the rank of Lieutenant, R.N., took charge of the building of H.M. Submarine *Thorough*, on completion of which he took her to the Far East. There he was transferred to submarine repair duties in Australia. He returned to the United Kingdom in 1945, after an accident in which he fractured his skull.

His next appointment in the R.N. was as Engineer Officer of H.M.S. *Roebuck*, a Fleet Destroyer of 40,000 h.p. He served in that vessel from 1946-1949, when he went to H.M.S. *Hornet*, Gosport to take up duties concerned with "E" Boats. Lieutenant Blatchford held that appointment until his retirement from the Royal Navy in December 1951.

He accepted an appointment, in 1952, with D. Napier and Son Ltd. to work on Deltic engines. However, he left that company in 1953 to join the staff of the Plymouth College of Technology, where he lectured on marine engineering until ill health compelled his final retirement in April 1961.

Lieutenant Blatchford was awarded the M.B.E. in the New Year Honours List in 1949; he was elected an Associate of the Institute in 1947, transferring to full membership on 18th October 1948 and will be particularly remembered for his services with the Committee of the Devon and Cornwall Section to which he was first elected in July 1960.

He leaves a widow and daughter.

LIEUTENANT-COMMANDER THOMAS ARTHUR BRANTON, R.N. (Member 12911) died on 2nd January 1963 at the age of 63 years. At the age of 16 he joined the Royal Navy as a boy artificer and trained for four years in H.M.S. *Fisgard*, Mechanical Training Establishment, where he studied applied mechanics, magnetism and electricity, machine drawing and marine engineering..

In 1919 he commenced sea service as an engine room artificer in H.M.S. *Castor*, being engaged on watchkeeping duties and maintenance of machinery. During the next nine years he served in the same capacity in H.M.S. *Coventry*, *Enchantress*, *Diomede*, *Vernon* and *Renown*. He was promoted Warrant Engineer in July 1928 and served as Engineer Officer of the Watch in H.M.S. *London*, *Concord* and *Kent* until October 1935 when he became Chief Engineer in H.M.S. *Niger*. In June 1937 he became Assistant to the Admiralty Engineer Overseer, Southampton and held that appointment until the outbreak of the Second World War. He had been promoted Commissioned Engineer in July 1938.

From September 1939 he served as Chief Engineer in H.M.S. *Highlander* and *Raider* until, in March 1943, he became Assistant to the Engineer Officer, Greenock, where his duties entailed carrying out repairs to vessels of the Clyde Escort Force. He was promoted to Lieutenant(E) in April 1946 and a month later was appointed to H.M.S. *President* as Assistant to the Admiralty Engineer Overseer, South and South Western District. He continued in this appointment until his retirement from the Royal Navy with the rank of Lieutenant-Commander in 1957, after 42 years service.

He joined D. Napier and Son Ltd. in the same year and became engaged in work concerned with the application of large turbo-blowers to main propulsion Diesel engines. He travelled widely for the company and played an important part in supervising installations in the Royal Mail Lines cruise ships *Amazon*, *Aragon* and *Arianza*.

Lieutenant-Commander Branton held a Service Certificate as First Class Engineer and was elected a Member of this Institute on 10th July 1950.

He leaves a widow and daughter.

WILLIAM CORSIE (Member 5125), who was elected to membership of the Institute on 26th May 1924, died on 15th December 1962. Born on 17th June 1888, he received his early education at the City of London School and later went on to serve an apprenticeship with John I. Thornycroft and Co. Ltd. and John Readhead and Sons Ltd.

He first went to sea in 1910 as an engineer in the Merchant Navy, subsequently obtaining his First Class Board of Trade Certificate. For two years during the First World War he served in the Royal Naval Reserve as Engineer Sub-Lieutenant.

In 1919 he left the sea and accepted a post as engineer with the Central Electric Supply Co., which later became the London Power Co. In 1939 he was appointed a charge engineer to the company, a position he held until his retirement in 1952.

Mr. Corsie leaves a widow.

GEORGE ALEXANDER DAY (Member 5648) was born on 23rd June 1895. He spent a total of seven years as an apprentice, two years with Fullerton-Hodgart and Barclay Ltd. and five with Gleniffer Marine Motors Ltd.

During the 1914-1918 war he served at sea with the Royal Navy, but on the cessation of hostilities he left the sea to take up an engineering appointment ashore. Subsequently he became assistant manager to J. Russell and Co. Ltd. of Canning Town, London, a position he held for the next nine years. In 1936 he became foreman engineer with the Downs Engineering Co. at Acton, however he left that company during the Second World War, in 1942, to take up the position of general manager to Injectodent Ltd. of Stanmore. He later became marine engineer and ship surveyor with S. A. Magoulas and Co., naval architects of London, until 1950 when he joined the James and Stone Shipyard at Brightlingsea as engineer assistant manager.

Mr. Day, who had been retired from business for a little over a year, passed away suddenly at his home in Brightlingsea, on 31st December 1962. He was elected an Associate of the Institute on 10th January 1927 and transferred to full membership on 6th February 1931.

He leaves a widow.

ERNEST JAMES DOIG (Honorary Life Member 1914), a member of this Institute since 6th December 1906, when he was elected a Graduate, died on 11th September 1962. Born on 20th December 1885, at Ilford, Essex, he was educated at the East London Technical College and later served an apprenticeship with Caird and Rayner Ltd.

In 1906 he went to sea as a junior engineer in a vessel owned by the British India Steam Navigation Co. Ltd., trading on the Indian coast. He remained with the company until 1909, in which year he obtained his First Class Board of Trade Certificate. In 1910 he joined the New Zealand Shipping Co. and worked his passage to Australia, where he joined the Ship Construction Section of the Royal Australian Navy. On the outbreak of the First World War, he became engaged in supervising the conversion of merchant vessels, for trooping duties until, in 1915, he was seconded to the Royal Navy. Holding an Engineer Commission, he served in light cruisers for the duration of the war. He was officer in charge of the boarding party from H.M.S. *Yarmouth* at the surrender of the German Fleet.

He returned to Australia in 1919 and, after spending one year in the Navy Office, joined Walker Bros. Ltd., engineers and shipbuilders of Queensland, serving that company in various capacities. He was engaged for some time in the commissioning of sugar milling equipment in several Queensland mills, but was sent to the United Kingdom for a year in 1929, to study the manufacture of Diesel engines, which Walker's intended to build under licence. Also during the inter-war period he was concerned in the construction of several merchant vessels. With the advent of the Second World War he became closely associated with the construction of minesweepers and frigates. However, most of his time was spent in the drawing office, of which he was the head when he retired at the end of 1949. After retirement Mr. Doig continued to do some design and draughting work for as long as his health permitted and he retained his keen interest in the profession and in the sea until his death.

Mr. Doig had transferred to full membership of the Institute on 18th September 1910.

DONALD CRAWFORD FLETCHER (Member 10921) died suddenly on 30th October 1962. He was born on 9th January 1913 and served his apprenticeship, from 1929-1934 with J. G. Kincaid and Co. Ltd., Greenock, being engaged in the erection and repair of marine steam and Diesel engines. Whilst indentured he attended evening classes at Greenock Technical School, where he studied marine engineering, mathematics, engineering science, engineering drawing and marine practice, for three years.

He commenced his sea service in August 1934, when he joined Clan Line Steamers Ltd., serving with that company for eight years as fourth and third engineer and carrying out full watchkeeping duties in main engine and boiler rooms.

During the Second World War, in May 1942, Mr. Fletcher was seconded to the Royal Naval Reserve and served as second engineer with the rank of Lieutenant(E). For almost a year, December 1942 to September 1943, he was on the staff of the Ministry of War Transport in the Middle East, where he was engaged, as inspecting officer, in merchant ship repair control. He was promoted to Lieutenant-Commander(E) in December 1945 and held that rank until his release from the R.N.R. in July 1946.

Following his war service, he spent a short period as second engineer with London, Midland and Scottish Railway Steamers, but subsequently became a power station superintendent with the North of Scotland Hydro-electric Board at the Glen Affric Scheme, a position he held until 1948.

Very early in 1949, Mr. Fletcher joined Wilson, Sons and Co. Ltd. and went to Brazil, where he was in charge of marine engineering workshops at Santos and Rio de Janeiro. He remained in that employment until 1952, being appointed, in November of that year, an engineer surveyor to Lloyd's Register of Shipping, in Liverpool. He subsequently acted for Lloyd's in Rio de Janiero and Bombay and transferred to the Manchester office in 1956, an appointment which he held at the time of his death.

Mr. Fletcher was elected a Member of the Institute on 3rd September 1946. He was a very active surveyor with a wide range of interests and had many friends in the engineering industry. His early death was a great shock and a loss to his colleagues and friends.

He leaves a widow, also a son of 17 years.

ANDREW EDWARD CARR GLASS (Member 13946) was born on 4th March 1904. From 1918 to 1923 he served an apprenticeship as a fitter and turner with G. Barker and Sons. Ltd., with whom he was engaged in general engineering repairs and manufacture. Whilst indentured he attended evening classes at the Dundee Technical College, where he took the first, second and third year courses in motive power engineering, engineering drawing, mathematics and mechanics.

In August 1924 he joined the Indo China Steam Navigation Co. Ltd. as a seagoing engineer and served with that company for the next seven years, in various capacities from fifth to chief engineer. His last appointment with the company was as recording engineer in the service analysis section. He had obtained his First Class Board of Trade Certificate in 1929.

In 1937, Mr. Glass joined the Shanghai Waterworks Co. as a shift engineer and remained with that company for fifteen years until 1952, serving in various grades up to station engineer. He spent the war years in an internment camp. For the last part of his service with the company, as station engineer, he held an executive position in full charge of the pumping stations and was directly responsible to the engineer-in-chief and the company directors. This appointment also covered the rather difficult period when the Chinese Communist government took over Shanghai.

Mr. Glass was elected a Member of this Institute on 13th October 1952, some months after his return to the United Kingdom. At the time of his death, which occurred on 9th September 1962, he held an appointment on the staff of the Garrison Works Officer, Norton Manor Camp at Taunton.

NATHANIEL MCFARLANE KISSELL (Member 10290) was born on 22nd May 1903. He received his early education at Ayr Newton Park Higher Grade School and Ayr Grammar School. In 1919 he commenced an apprenticeship with Ailsa Shipbuilding Co. Ltd. but in 1922 his indentures were transferred to Sir Wm. Arrol and Co. Ltd. with whom he completed his training. Concurrently with his apprenticeship he studied general engineering at Ayr Academy and higher mathematics at Glasgow High School.

In 1924 he began his sea service as junior watchkeeper with Clan Line Steamers Ltd. and served with that company until 1928 when he became a senior watchkeeper with the Donaldson Line Ltd. Gaining his First Class Steam Certificate in 1931 and a First Class Motor Endorsement the following year, he became chief engineer with the company in 1938. During his employment with the Donaldson Line, he acted for about a year as owner's representative during the building of m.v. *Salacia*, a fully refrigerated fast cargo liner.

Mr. Kissell joined Lloyd's Register of Shipping, Glasgow, as a ship and engineer surveyor in 1939 and subsequently acted for the society in Belfast, Copenhagen and Cadiz before returning to Scotland to become senior ship and engineer surveyor in charge of the society's office in Leith, a position he still held at the time of his death on 6th November 1962.

Mr. Kissell was elected a Member of the Institute on 5th April 1945 and a member of the Scottish Section Committee in 1962. He was also a Member of the Institution of Engineers and Shipbuilders in Scotland.

He leaves a widow.

FRANCISCUS LEONARDUS RABAEY (Member 2314), who was born on 6th October 1880, died on 25th October 1962 at Wijnegem, Belgium. From 1896 to 1901 he served an apprenticeship at C. Baxter's Britannia Engine Works in Antwerp and subsequently worked as a fitter with the North Eastern Marine Engineering Co., Wallsend for nine months. Returning to the employment of C. Baxter, he was engaged for six months in ship and engine repair work. He followed this with about 12 years service as a seagoing engineer with various companies, during which time he gained his First Class Board of Trade Certificate and the Belgian Government First Class Certificate.

In April 1914 he was appointed a ship and engineer surveyor to Lloyd's Register of Shipping and commenced his duties in May of that year at Düsseldorf, in order to familiarize himself with steel testing work before proceeding to Antwerp, where he assumed duty in June.

On the outbreak of the First World War, Mr. Rabaey came to England and was assigned to a position in Manchester, where he remained until March 1919, after which he returned to Antwerp. During the German occupation of Belgium in the Second World War, he carried out whatever duties were possible on behalf of Lloyd's Register and his appointment to the Society was re-affirmed in December 1944.

Mr. Rabaey, who had retired in June 1946, leaves a widow. He was elected a Member of this Institute on 6th January 1910.

RICHARD REDWOOD, M.B.E. (Associate 10869) was born on 4th August 1913 and received his early education at Hillhead High School in Glasgow, from which establishment he gained his School Leaving Certificate. In 1928 he commenced a five year apprenticeship with Gleniffer Engines Ltd. where he obtained experience in the foundry, machine shop, fitting and engine assembly shops and the engine testing shop. His experience also covered engine installation and ship trials. Whilst indentured he attended the Royal Technical College, Glasgow, gaining Engineering Course Certificates, Groups III and IV.

In November 1933 he joined Scottish Oils and Shell-Mex Ltd., Glasgow, as Special Representative (Marine) to deal with combustion problems in petrol/paraffin and high speed Diesel engines installed in fishing craft of all types. He was transferred to Shell-Mex and B.P. Ltd., Birmingham, as General Oils Supervisor for the same company in 1938. There he was employed in a technical capacity to advise on lubricants for machinery and plant in engineering and other industries. He also handled cutting, quenching, soluble and other processing lubricants of various types.

On the outbreak of the Second World War, Mr. Redwood joined the Royal Navy as an engine room artificer and subsequently was put in charge of the engine room of a 3,400 h.p. motor torpedo boat. He was promoted to Sub-Lieutenant (E) in August 1941 and became Flotilla Engineer Officer responsible for engine and hull repairs and maintenance for motor torpedo boats and motor launches, fitted with supercharged petrol and high speed Diesel engines. He was promoted to Lieutenant (E) in August 1942. A year later he became Coastal Forces Base Engineer Officer at H.M.S. *Defiance* and later held similar appointments at H.M.S. *Black Bat* and *Wildfire III*. At these establishments he was responsible for the engineering organization of workshops, stores, repair and maintenance of all attached craft and Base machinery. He was also responsible for the shipping and re-fitting of craft and machinery. 20 to 60 vessels were involved, ranging from 1,500 to 5,000 h.p. For his services at H.M.S. *Black Bat* he was awarded the M.B.E. In December 1945 he was transferred to Sheerness where he became responsible to the Base Engineer Officer for the fitting, maintenance and repair of 53 vessels. Whilst holding this appointment, Mr. Redwood was elected an Associate of this Institute on 4th June 1946.

On his demobilization from the R.N. in April 1947 he rejoined Shell-Mex and B.P. as Lubricants Supervisor at Birmingham and, six years later, transferred to Glasgow, where he became Assistant to the Lubricants Manager. He followed this by becoming Lubricants Manager of the company's Western Division at Bristol, from 1956-1962. In January 1962 he was appointed Senior Technical Assistant at head office, a position he still held at the time of his death on 28th November 1962.

Mr. Redwood leaves a widow.

HORACE URBAN WADLEY (Member 6143) was born in Wivenhoe in February 1900. He was educated locally and later became one of the first pupils at Colchester Technical College. From 1916-1921 he was indentured to Rennie, Ritchie and Newport Ltd. as an engineer and draughtsman and, on completion of this apprenticeship remained with the firm for a further three years as a draughtsman, until the company closed down. In August 1924 he commenced sea service with the Monarch Steam Ship Co. Ltd., with whom he remained for two years before transferring to Bullard King and Co. Ltd. with whom he also served for two years. During this period he gained both his Second and First Class Board of Trade Certificates.

Marrying in 1929, he left the sea and joined Insurance Engineers Ltd. After training in their Nottingham office for two years he returned to his native Wivenhoe to become Engineer Surveyor, the area of his duties covering the counties of Essex and Suffolk. He later became District Surveyor for the same two counties, a position he held until his sudden death on 25th October 1962.

Mr. Wadley had many interests. Before the Second World War he converted two ex-lifeboats into cabin cruisers and owned a hydroplane. Throughout the war he was a deputy head warden, A.R.P. and was a lecturer for anti-gas training for the county of Essex.

In his spare time he built a steam locomotive, making, turning and machining each part in his well equipped workshop. This locomotive was disposed of to a light railway running in Kent, where it is still in use. He was a committee member of the Nottage Institute, Wivenhoe, sometimes lecturing there. This unique foundation, by the late Captain C. G. Nottage, offers facilities for the training of those who wish to take up a seafaring career. Mr. Wadley was also a reader in the parish church and took an active part in the life of the parish. At the time of his death he had just completed the installation of a marine motor in a Trinity House lifeboat and was looking forward to his retirement in 1965.

Mr. Wadley was elected a Member of this Institute on 4th March 1929. In the same year he was married to Marjorie Olive Doubleday who, with two daughters, survives him.

JOHN DUNCAN WALKER (Member 5739), who died on 21st October 1962, completed his apprenticeship with the Mersey Docks and Harbour Board in 1911 and spent the next three years as a draughtsman. He made his first sea voyage in May 1914, as fourth engineer in s.s. *Hylas,* however on the outbreak of the First World War, he left the sea to enlist in the Army. He served in France with the Liverpool Scottish Regiment until the end of hostilities.

In 1919, Mr. Walker returned to the sea as fourth engineer in s.s. *Muncaster Castle,* a vessel owned by the Lancashire Shipping Co. Ltd. At a later date he transferred to the employment of Houlder Brothers and Co. Ltd., with whom he remained until 1927. In that year he joined Ellerman Lines Ltd. as seagoing second engineer, holding a First Class Board of Trade Certificate.

During the Second World War, Mr. Walker was interned in Beirut when France capitulated in 1940, however he was released after six weeks and thenceforth was employed in the Mediterranean and in North Africa by the Ministry of War Transport. From 1944-1945 he was seconded to and served with the Canadian Merchant Navy. Reference was made to some of Mr. Walker's wartime experiences in a book, entitled *And They Came Home,* which was published at the time.

After the war he rejoined Ellerman Lines and remained in the service of that company until his retirement in December 1953.

Mr. Walker was elected a Member of the Institute on 2nd May 1927.