INSTITUTE OF MARINE ENGINEERS

INCORPORATED.

SESSION 1898-9.

President—JOHN INGLIS, ESQ., LL.D.

WATER-TUBE BOILERS.

BY MR. G. HALLIDAY, WH. SCH., AND MR. EDWARD SEABURY (MEMBERS).

READ AT 58 ROMFORD ROAD, STRATFORD,
ON MONDAY, APRIL 25TH, 1898;

CHAIRMAN:
ALD. G. W. KIDD (VICE-PRESIDENT).

AT THE ARTS SOCIETY'S HALL, SOUTHAMPTON,
ON TUESDAY, MAY 10TH, 1898.

AT the beginning, in the days of Savery, Smeaton, Newcomen and Watt, boilers were simply closed pots containing water, which was to be converted into steam at about atmospheric pressure. As higher pressures were soon in demand, engineers had of necessity to modify the design to withstand these pressures. After the design had been adapted to the pressures, Watt at once began to arrange for fuel economy and high efficiency. For present-day marine engineers, lightness and rapidity of evaporation are the *alpha* and *omega* of boiler design. For a long time the struggle for the first place has been going on between makers of the cylindrical type and of the water-tube boiler.

Mr. Goschen, First Lord of the Admiralty, announced the other day in the House of Commons that "all expert evidence was now wholly in favour of the water-tube type"; and, if there were nothing else, the mere fact that, a few years ago, the weight of boiler with water in it to give an indicated horse-power was 200 lbs. as against 40 lbs. with an express boiler of the present day, points to the adoption of the water-tube boiler.

The behaviour of the plate which transmits the heat from the flame to the water is now of great interest, and especially so where the transmission is forced. But little was known of the temperatures of the sides of the plate even, until the late Mr. A. C. Kirk and Sir John Durston made experiments to ascertain the facts.

The method adopted by both to obtain temperatures was the same, namely, by means of fusible plugs inserted in the bottoms of the vessels with which the experiments were made. It was assumed that the temperature of the metal on the water side was the same as the temperature of the water. Sir John made some of his experiments with an open dish 10 in. diameter, 3 in. deep, and $\frac{1}{4}$ in. thick. He placed this dish containing water over a flame at a temperature of 1,500° F. Fusible pieces of solder, ranging in melting point from 220° to 250° F., were fixed on the bottom. With these he ascertained the temperature to be 240° F. The water was open to the atmosphere, and was at a temperature of 212°. A layer of grease obtained from the interior of a ship's boiler was put on the inside bottom of the vessel, $\frac{1}{32}$nd of an inch thick, and this caused the temperature of the vessel's bottom next the fire to rise to 330° F.

A flanged plate with a tube expanded into it showed a temperature at the middle of its thickness of between 290° F. and 336° F., the temperature of the fire being about 2,000° F. With a vessel of flat ends and through tubes of steel, brass, and iron, placed vertically on a fire so that the tube plate was subject to a heat of about 1,400° F. and the pressure of steam inside the vessel 100 lbs., it was found after being overheated and then allowed to cool that the tubes leaked so badly that no pressure could be obtained; no difference was observed in the behaviour of the tubes. The same experiment was made with lead plugs inserted in the plate, and as soon as the plugs—with a melting point of 617° F.—had melted, the vessel was taken from the fire and tested to 200 lbs. pressure, and found to be quite tight. A similar result was obtained after fusing some plugs of zinc, with a melting point of 770° F. It was concluded that up to a temperature of 770° F. no damage was done to the boiler. It was further found by a series of experiments that the loss of transmitting efficiency in an iron tube due to a thin coating of grease was eleven per cent. With an open dish partly filled with fresh water and placed horizontally over a fire urged by a moderate blast, the temperature of the plates was 240° F.; with a higher blast the temperature rose to 280° F. When the surfaces of the plate were practically clean the difference in temperature between the water side and the fire side of the plate did not exceed 100° F., even with high steam pressures, whilst the addition of 5 per cent. of linseed oil raised the difference by about 30° F.; and a greasy deposit of $\frac{1}{16}$ in. thick made the temperature on the fire side of the plate rise to about 300° F. above the temperature of the water side, the temperature of the fire varying from about 2,300° F. to 2,500° F.

Variations in the pressure did not alter the relative temperatures of the two sides of the plate. In this connection marine engineers will have experienced the great difficulty of keeping the back tube plates of marine boilers in a good condition even with ordinary natural draught, and it is our belief that the very bad tube and tube plate failures experienced in the Navy decided our naval authorities to look to the water-tube type of boiler as a means of avoiding the defects experienced in other types.

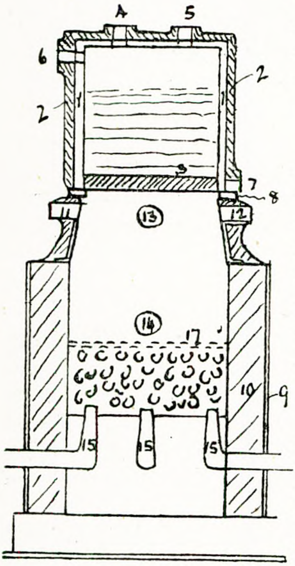


Fig. 1.

We will now consider some experiments made by the late Mr. Blechynden to determine the effects of varying differences of temperature and varying thickness of plate. The apparatus employed by Mr. Blechynden for this purpose is shown (Fig. 1). There is a boiler on the top 10 in. diameter and 12 in. high, made of tinned iron plate about 24 W.G. thick. It is surrounded by a jacket leaving a 1 in. space on sides and top, and this jacket was covered with asbestos fibre $\frac{3}{8}$ in. in thickness to prevent radiation. Steam could be passed through the jacket by the inlet and outlet pipes. The plate subjected to the experiment was soldered into the bottom, and water could be admitted and steam allowed to escape by the openings marked 4 and 5. The furnace was beneath; its walls were made of firebrick inside an iron casing; five gas jets (15) supplied the flame, and these played on asbestos lumps placed above them to equalise the heat; there is a hole marked 14 and another 13 through which the temperatures can be taken, and 11 and 12 are passages for the escape of the hot gases.

Siemens-Martins steel was used for the plates, each plate being machined on one side only to make it the required thickness; five plates were used of different carbon values ranging from ·25 to ·21 per cent., and having specific gravities varying from 7·742 to 7·84. The results obtained are seen in the table appended:

	Temperature of furnace	Difference of temperature	Total units of Evaporation	$\frac{\text{Temp. 2}}{\text{Temp. 1}}$	$\frac{\text{Evap. 2}}{\text{Evap. 1}}$	$\left(\frac{\text{Temp.2}}{\text{Temp.1}}\right)^2$
	1	2	3	4	5	6
1	838°	626°	6·820	1·9	3·97	3·87
2	1,445°	1,233°	27·100			
1	775°	563°	6·705	2	4·4	4
2	1,360°	1,148°	29·550			
1	625°	413°	4·270	3·0	9·13	9
2	1,465°	1,253°	38·950			
1	850°	638°	9·175	1·9	3·84	3 86
2	1,465°	1,253°	38·950			

Each of these four groups consists of two readings of experiments made with the same plate; the fourth column gives the second reading of temperature divided by the first of each pair, the fifth column gives the evaporation from the plate of the second of each pair divided by the first, and the sixth column gives the square of the second temperature divided by the first. It will be seen that the numbers in the columns five and six are nearly equal, and that the evaporation from the plate is proportional to the difference between the flame and the water squared; this is given graphically in the accompanying curves (Fig. 2) for the different thicknesses of plate.

It was found that the machined surface made a difference in the transmitting power of the plate; this was tested by machining one plate on both sides, and, comparing it with two other plates not machined, the differences were as ·0148 to ·0225. The following table

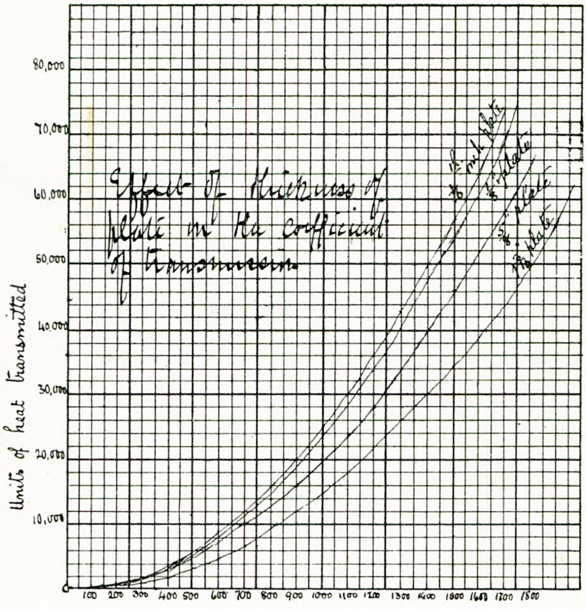


FIG. 2.

gives the carbon percentages and gravities of the plates used :

Carbon.	Specific gravities.
·21	7·8176
·22	7·8032
·23	7·8401
·25	7·7420

It was found that the lowest in carbon was also the lowest in conductivity, so that steel plates should have an advantage over iron ones, whilst it was also apparent that the best evaporative results would be obtained by using thin plates and a hot furnace; these conditions can of course be much more readily obtained, and with greater safety, in the water-tube boiler than in that of any other type.

Professor Ser, of the College of Arts and Manufactures, Paris, made a series of experiments to determine the influence of rapid motion of water over the heating surface. The apparatus he used consisted of a thin copper tube, a foot in length and four inches internal diameter. The water was made to enter at

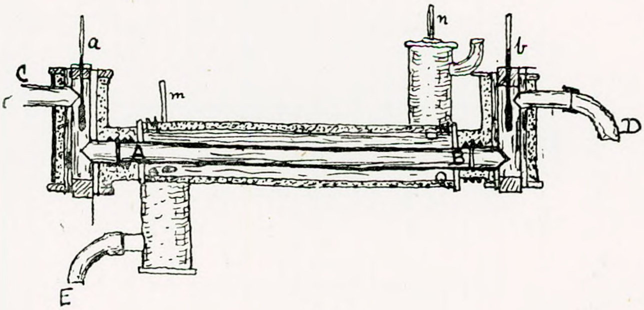


FIG. 3.

the pipe C, pass through the tube AB, and flow out again at D (Fig. 3). The temperature of the water to be heated was shown by a thermometer at *a*, and, after heating, at *b*; a casing or muff, MNPQ, made of copper, surrounded the tube AB. Steam was passed through this muff by the connection shown at E, and its temperature was shown by the thermometers *n* and *m*. All the surfaces of the casing or muff were covered with wadding to prevent radiation. The principal object which the Professor had in view was to find the transmission coefficient at different given velocities of water in the tube AB, the temperature of the heating medium being constant, and the results of his experiments are given in the following table:

Speed of water through the tube	Co-efficient	Speed of water through the tube	Co-efficient
·1	1,400	·7	3,180
·2	2,230	·8	3,330
·3	2,550	·9	3,480
·4	2,710	1·0	3,640
·5	2,860	1·1	3,800
·6	3,020		

From the above tables it will be seen what a great

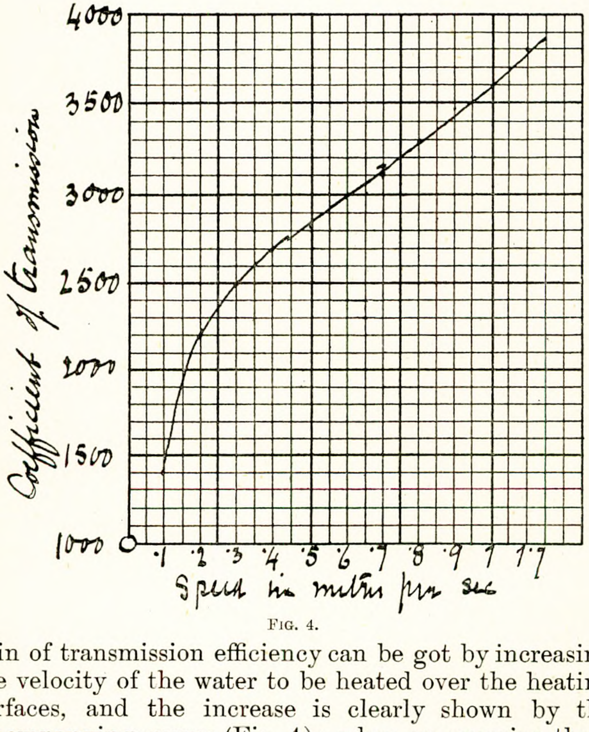


FIG. 4.

gain of transmission efficiency can be got by increasing the velocity of the water to be heated over the heating surfaces, and the increase is clearly shown by the accompanying curves (Fig. 4); when we examine these carefully we see that the rate of increase of transmission rises very rapidly between the velocities ·1 and ·3 metres per second; from ·3 to 1·1 the transmission of efficiency does not rise so rapidly, still there is a rise proportional to the speed. From this part of the curve the co-efficient of transmission Q works out to be,

$$Q = 2{,}080 + 156 \times \text{velocity of water.}$$

Here, then, we have a law based on Professor Ser's experiments which proves that the quicker water passes over the heating surfaces the better the transmission of heat from the heating medium to the water; in other words, the more rapid the movement of the water over the heating surfaces the greater the evaporation. This is undoubtedly very favourable to water-tube boilers, as it is possible with them to arrange the tubes in such a manner that there is little or no obstruction to the circulation of the water in them, a condition not attainable in the old marine type. If you will consider the construction of this latter boiler you will observe that the part of the boiler immediately over the furnaces is filled with tubes more or less closely pitched; now, as the greater part of the evaporation in proportion to the surface takes place on the furnaces, it follows that the circulation there in this type of boiler is not at all what could be desired, as it is so difficult for the stream of water and steam bubbles to ascend to the surface when obstructed by the tubes immediately over the furnace. Imagine a ball, say, of india-rubber, to be substituted for a steam bubble, and to be driven by any mechanical force from the furnace to the water level, striking first against one tube and then the other; it will at once be apparent to us that the tubes in the Scotch boiler must have a retarding effect of considerable amount on the escaping steam bubbles formed on the furnaces.

Having now looked at what takes place on the steam and water side of a boiler, let us consider the fire side.

There is practically no limit to the size of fire grate we may employ, and we are not troubled with either the Board of Trade or Lloyd's rules for plain or corrugated flues, whilst the space necessary in all boilers for the combustion of the gases is, in the water-tube boiler, easy to arrange. We can also avoid the cooling effect that a large flat-sided combustion chamber has on the gases, being able to split them up into currents of flame, without partly extinguishing them. The circulation which we have seen is so very necessary in the case of the water is just as important for the flames on the fire side if good results are to be obtained.

Taking also into consideration the strides that artificial draught is making, the water-tube boiler, being so much better adapted for high evaporation, is bound to come to the front, as no one will maintain that flat vertical plates, such as are necessary in the combustion chambers of ordinary marine boilers, are either efficient or safe with high evaporation or when subjected to high temperatures.

Before turning to the boilers which we have the pleasure of bringing before your notice, may we point out one or two features which go to the sum of a good marine boiler. Of course the first consideration is that the materials used, and the construction, not only of the boiler proper but of all its fittings and connections, must be such that there is no risk of explosion or failure under any conditions that can obtain in ordinary working. Next, the heating surfaces must be so arranged and of such area that as little as possible of the heat produced on the fire side is lost, and the water to be evaporated should be split up into comparatively small sections and guided as easily as possible through the hot gases, the form of tubes being such that little or no obstruction is offered to the free escape of the steam produced. The boiler and all its parts should be readily accessible for cleaning and repairs, and the parts liable to most wear should be so designed that replace ones can be obtained in any part of the globe to which the ship is likely to go.

Turning now to the boilers which have been selected as types, the following illustrations and results of trials have been obtained from the makers themselves or from the published results in the engineering papers.

The first we call your attention to is made by the Babcock and Wilcox Company. This firm have made hundreds of their boilers for land purposes and fitted some to a number of American steamers, and latterly to other ships, both British and foreign. The illustration (Fig. 5) will explain the construction and arrangement of this boiler. The makers claim the following advantages over other types of water-tube boilers: The tubes are all straight, therefore easy to clean or replace; no screwed joints are used to fix them, they are expanded into the headers with an ordinary expander; the steam and water collector or drum is of such ample dimensions as to ensure perfect steadiness of water level and dry steam; the circulation is continuous and no overheating of tubes can take place.

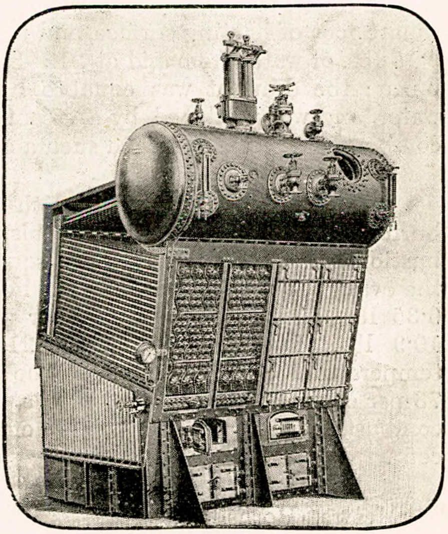


FIG. 5.

A boiler of this type was fitted some few years ago into Messrs. T. Wilson's *Nero*, and we believe gives satisfaction, but we have no results of its working.

A very complete set of tests has lately been made with one of these boilers of an improved type, for H.M.S. *Sheldrake*, before it was fitted on board.

With a combustion of 40 lbs. of coal per square foot of grate, the evaporation was 8·3 lbs. of water per square foot of heating surface, and the evaporation was 9·15 lbs. of water from and at 212° F. per pound of coal burnt; the draught was equal to half inch column of water, and was produced by a steam jet. The rate of combustion seems high with such a draught.

On the efficiency trials with the same boiler burning Powell Duffryn steam coals, the rate of combustion being 26 lbs. of coal per square foot of grate, the evaporation per square foot of heating surface was 6·35 lbs. and the evaporation per pound of coal was 10·9 lbs. of water from and at 212° F., the funnel temperature being 600° and the boiler efficiency 73 per cent. Some further trials at a slower rate of combustion increased the boiler efficiency to 80 per cent.

Messrs. Hornsby & Sons, of Grantham, make a somewhat similar boiler, which, although it has never been fitted for marine purposes, has a good reputation at electric light stations and elsewhere. Its construction is shown (Fig. 6), and the general design scarcely differs from the original, or land type of the Babcock and Wilcox boiler.

Messrs. Hornsby very kindly made some tests for this paper on a water-tube boiler, which has been in use in their own works for about four years. This boiler has a total heating surface of 893 square feet,

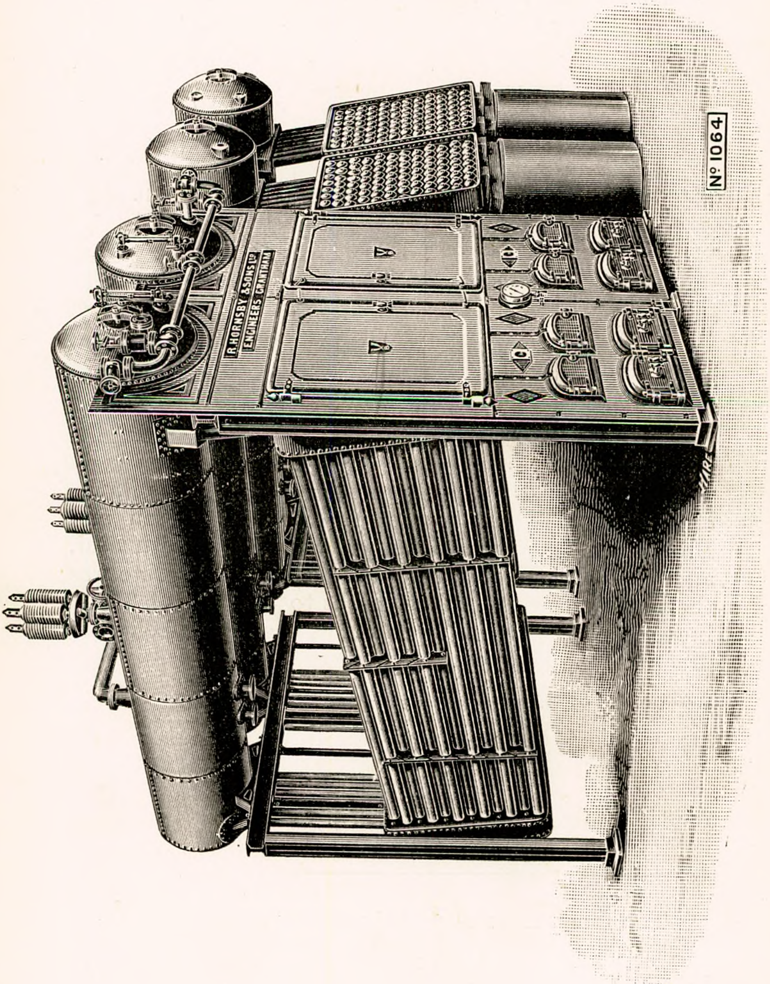


FIG. 6.

and a grate area of $14\frac{1}{4}$ square feet. The heating surfaces had not been cleaned for some time, and after the trial there was a scale of quite $\frac{1}{8}$ inch thick in places. The results obtained were as follows :

Quality of Coal	Coal burnt per square foot of grate	Water evaporated per square foot of surface	Water evaporated per pound of Coal from and at 212° F.	Water evaporated per pound of Combustible from and at 212° F.
Welsh ...	21·7	3·38	10·62	10·76
Newstead best hard steam in lump ...	26·3	3·16	8·21	9·20
Watnall slack with steam jet under bars to assist draught ...	43·0	4·09	6·43	7·33

Some further trials were made with Astatke oil, the oil being sprayed on to the grate with a Holden and Brooks injector, the fire being started first with coal, and steam got up to work the injector. The grate was then covered with broken bricks to a depth of 3 to 4 inches, and a series of trials made, the results being all practically alike and as follows:

Fuel used	Fuel per square foot of grate	Water evaporated per square foot of heating surface	Water evaporated per pound of fuel from and at 212° F.
Russian Astatke ...	22·36 lbs.	4·48	14·03

The foregoing results are all very satisfactory ; this class of boiler is seen by the above results to be a specially good one for using liquid fuel.

The Belleville boiler (Fig. 7) has been the cause of

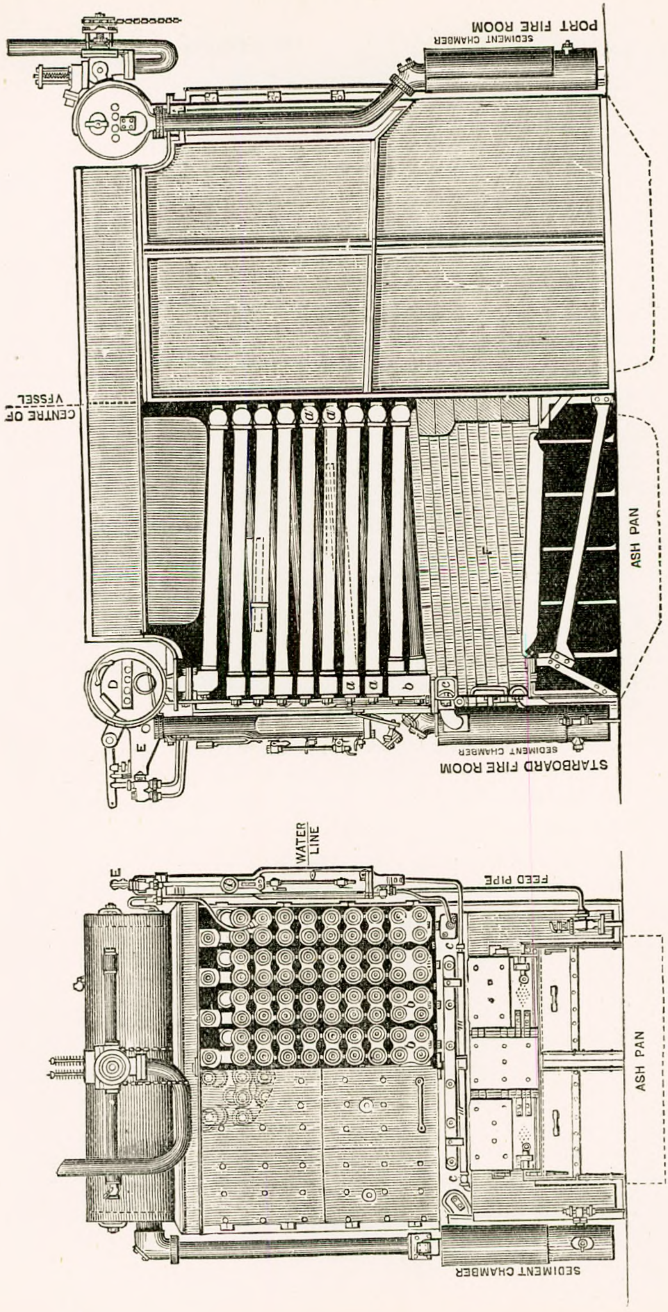

PORT FIRE ROOM
SEDIMENT CHAMBER
CENTRE OF VESSEL
ASH PAN
STARBOARD FIRE ROOM
SEDIMENT CHAMBER
WATER LINE
FEED PIPE
ASH PAN
SEDIMENT CHAMBER

FIG. 7.

much discussion in this country. In 1893 the Admiralty decided to fit it in the *Sharpshooter*. The results of the trials in this and other ships, and other information placed at the disposal of the Admiralty, have been such that up to the present moment there have been fitted, or in course of construction, Belleville boilers for twenty-one cruisers of from 10,000 to 25,000 I.H.P., seven battleships of from 13,000 to 15,000 I.H.P., besides several smaller vessels, so that it is clear that our Admiralty engineering staff think them the best for large ships at the present moment.

This boiler, then, being somewhat similar to the previous two mentioned, in that it is fitted with comparatively large tubes in nearly a horizontal position, yet its details differ considerably: it essentially consists of a large top cylinder or steam and water collector, a lower water chamber, and a series of elements made up of straight tubes coupled together in such a manner that they form a kind of flattened spiral tube of considerable length, the lower part of which is connected to the water inlet and the upper part to the top cylinder or steam collector. There are devices for regulating the feed inlet to the tubes and separating the steam and water from each other in the collecting cylinder; each of these elements consisted originally of about twenty tubes, each about 7 ft. 6 in. long and 4 in. inside diameter, screwed into malleable cast-iron couplers or boxes so as to form the returns of the flattened spiral.

The effect of this is that each particle of water to be evaporated passes through a continuous tube about 160 ft. in length, arranged practically horizontally. It is found necessary in practice to reduce the inlet for the feed water, so that each element gets its fair share of feed water, and return tubes are fitted so that the surplus water from the steam collector can return into the water chamber, and a non-return valve is fitted to prevent the water from the elements passing back up through this water chamber.

It is quite apparent from the construction of this boiler that there must be very considerable resistance to the circulation of the water and steam in these elements; the great length alone, without considering the number of bends, must cause much friction, and we can quite understand that a good many devices are necessary to get a continuous circulation. In a sea way, where the relative levels of the back and front are continually changing, one can easily imagine that there will be a great tendency for the current to change its direction, and the circulation will then be anything but continuous. Again, with such a length of tube arranged in this manner the steam bubbles must fill a very large proportion of its area, so that the danger of the tubes being overheated is great. Of course, the boiler is free to expand and contract, and in the later boilers a sort of roller bearing is fitted to facilitate this; but the experience of the merchant service is that no surface of a boiler other than a water-covered surface should be exposed to the heat of the gases, and if this is departed from the life of that part of the boiler is a very short one.

In a boiler of this type containing when cold 3,000 lbs. of water, when working at a rate of 12 lbs. of coal per square foot per hour of grate, it contained 2,400 lbs.; whilst with 20 lbs. per square foot its contents were 2,100 lbs.; and at 30 lbs. per square foot its contents were 1,600 lbs., or practically the tubes were little more than half full of water, although the water level in the boiler as shown by the glass was still the same. It is thus necessary to have a considerable amount of reserve feed at hand for boilers of this class, and the question of dealing with the surplus water in the boilers when changing from slow to full speed must cause anxiety, as it will be next to impossible to keep it all out of the engines, even with the best steam traps or separators.

The results on trials and actual working of these boilers as steam generators appear to be good and the tubes are fairly easy to replace, whilst there can be no doubt that the material and workmanship in them is of the very best. Although they have not yet been adopted for merchant service work, they are undoubtedly the most popular for naval purposes.

The results of trials on shore with two of these boilers, which were for H.M.S. *Powerful*, were as follows :

Coal per sq. foot of grate	Steam pressure	Feed temperature	Pound of water evaporated per pound of coal from and at 212° F.
18 lbs.	258	42°	10·81
24 lbs.	258	42°	10·42

And the results of the recent trials in H.M.S. *Diadem*, as given in *Engineering*, with the latest improved type of these boilers, which are fitted with a large feed heater in the uptake, show that it causes a decrease in the temperature of the escaping gases to 500° F. whilst the feed water is heated from 68° F. to about 230° F. This, of course, considerably increases the economy.

On the eight hours' emergency trial, when burning 21·14 lbs. of coal per square foot of grate, the indicated power obtained was nearly twelve I.H.P. per square foot of grate, and one I.H.P. was obtained per 2·36 square feet of heating surface, the air pressure being only 0·3 in.

On some further trials when burning 27·52 lbs. per square foot of grate, one I.H.P. was obtained per two square feet of total heating surface, and the trials, which were very lengthy, were satisfactory, the only defect noted being the blowing out of the fusible plugs, which are fitted to the elements to give warning in the event of their being overheated due to shortness of water, but this blowing out of the plugs was attributed to unsuitable material and not to any overheating.

The Thornycroft boiler—which has been, and is now being, fitted to a number of high-speed torpedo boats and torpedo-boat destroyers, has had a most successful career in this class of vessel—is shown (Fig. 8). Its principal features are the steam and water drums or cylinders which are connected together by the steam-generating tubes, the upper ends of which all terminate above the water level, whilst special return tubes of large section are fitted at the end. When these boilers are working under normal conditions, a stream of water and steam is continuously being delivered by the generating tubes into the steam drum, the surplus water falling down the return tubes to the water drum, to be again passed through the generating tubes. It is claimed for these boilers that the circulation is rapid and continuous, there being no change of direction or any fear of the tubes being partly emptied through a change of current; they are economical as steam generators, and a great saving in weight and space is obtained with them, whilst no amount of forced combustion interferes with their working—in fact the faster they are worked the better the circulation.

Messrs. Thornycroft have fitted an automatic feed regulator to these boilers, as must be necessary where a number of them are working together from one feed supply, and they are as near as possible automatic when being driven at their highest rate of working. A view of the automatic feed valve, which is of the float type, is shown (Fig. 9), and, when the boiler is working, it actually does maintain a constant water level.

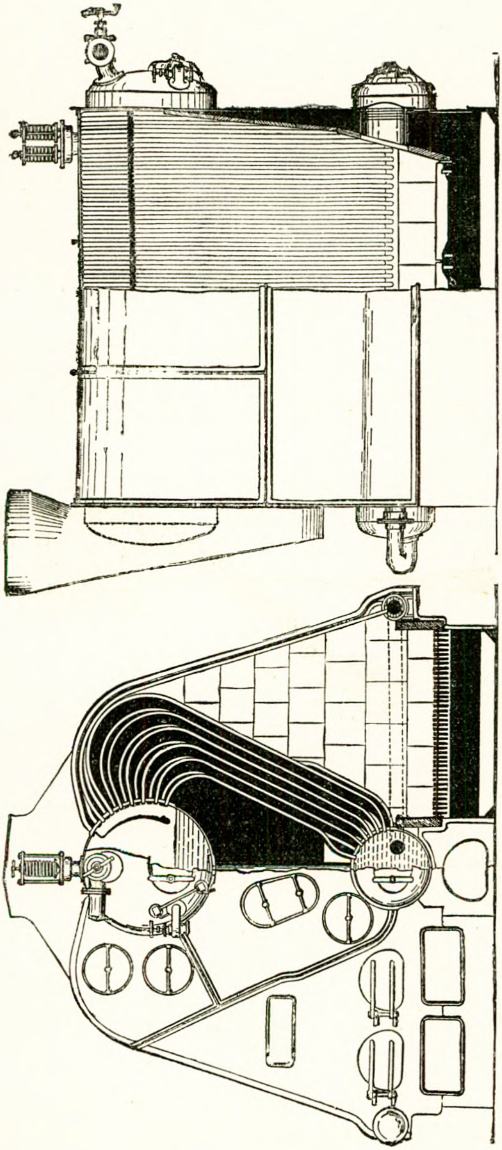


FIG. 8.

Some very extensive sea trials with these boilers made in 1892 gave the following results :

Steam pressure in Boiler	Coal Consumption per square foot of grate	Coal Consumption per I.H.P.	Funnel Temperature
170 lbs.	17·8	1·75	438° F.
176 „	25·2	1·77	482° F.
177 „	34·5	1·87	590° F.

The engines were triple expansion and doubtless fairly economical, whilst the funnel temperature shows that the losses there were not great, even at such a

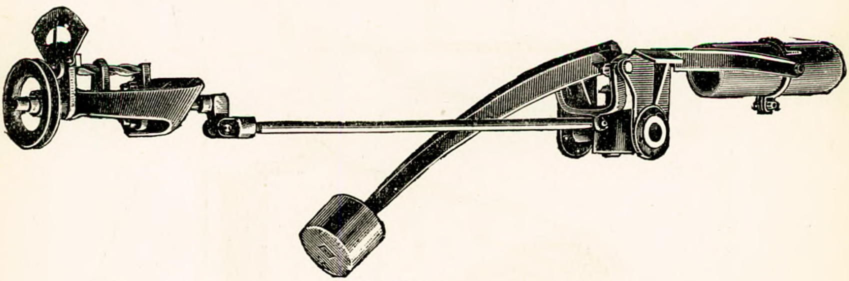


FIG. 9.

high rate of combustion as 34·5 lbs. per square foot of grate.

Mr. Thornycroft, in a paper read before the Naval Architects in 1894, stated that as the result of some experiments he made, he found that for every 1 lb. of water evaporated 105 lbs. of water circulated through the tubes, and that even at such a high evaporation as 20 lbs. per square foot of heating surface the generating tubes could not be overheated.

The *Speedy's* boilers gave 2·5 I.H.P. per foot of heating surface, and the total weight of boilers with fittings and water per I.H.P. was about 39·2 lbs., and the I.H.P. per foot of grate surface 23 I.H.P.

The Yarrow boiler shown (Fig. 10), is also fitted to a great number of high speed vessels both in

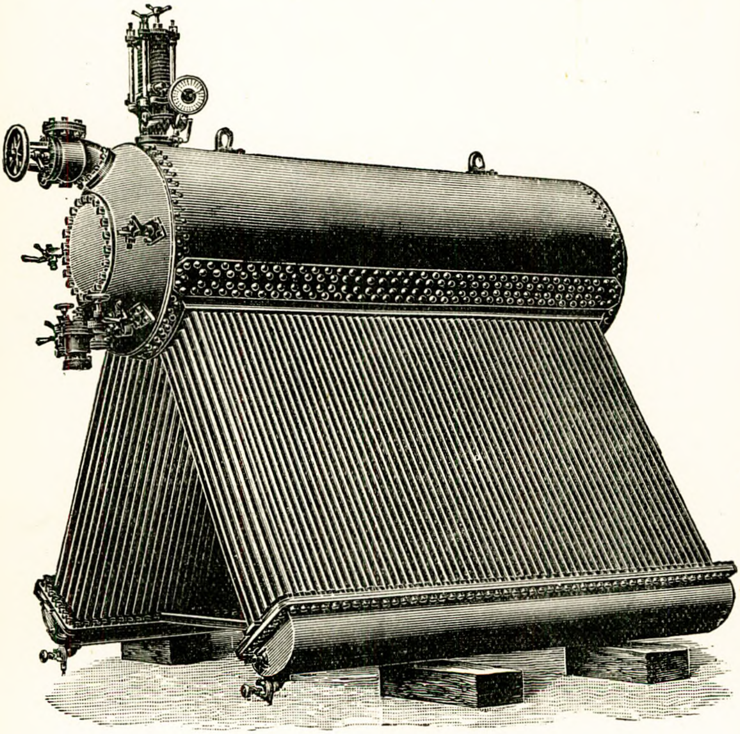


FIG. 10.

our own and foreign navies, and has been adopted by the Dutch Government for their cruisers. Its special construction is shown, and it consists essentially of a steam drum or collector, with two lower water chambers, connected together by a number of straight tubes simply expanded into them. These straight tubes, which are about 5 feet long and $1\frac{1}{8}$ inch diameter, form the steam generating surfaces, and the cross section of the boiler is therefore triangular with the grate at the base. The whole of the generating tubes have their upper ends below the water level in the steam drum, and hence they are called drowned tubes. No return tubes are fitted, as they are not considered necessary. The advantages claimed for this boiler are as follows :

1st. The tubes being straight are easily cleaned, examined, or replaced, and require no special manufacture.

2nd. The angle of the tubes is such that they offer very little frictional resistance to the ascending bubbles of steam.

The tubes in this boiler being all below the water level, their normal condition is to be full of water, and therefore they are not liable to damage by corrosion when worked at low speeds; and, when forced, it is found that a certain number of the tubes nearest the fire are the ascending or uptake ones, whilst a number of others further removed from the heat of the fire are the downcast or return tubes, and are filled with practically solid water.

Messrs. Yarrow's system of automatic feed consists practically of a separate pump for each boiler.

The economy of these boilers is very high, as when evaporating at the rate of 3 lbs. per square foot of heating surface the evaporation was 12 lbs. per 1 lb. of coal from and at 212° F., whilst with the very high evaporation of 10 lbs. of water per foot of heating surface 10 lbs. of water were evaporated per pound of coal burned.

These boilers have also been worked for days with a leaky condenser, and tried with a salt feed for some hours without the slightest injury to them, although the density was as high as $\frac{4}{32}$, and the steam pressure 150 lbs.; although through neglect one of these boilers was allowed to get so short of water that the upper ends of the tubes must have been red hot, the only result was a slight leakage, which could be easily kept under with a force pump at 150 lbs. pressure.

Some sets of these boilers made for the Dutch Government are herewith compared with some ordinary marine type boilers in the same ships.

Ship's I.H.P.	Total weight of each boiler with fittings and water	Weight per I.H.P.	I.H.P. per foot of grate	I.H.P. per foot of heating surface
1,125	60 tons	1·066		
950	11 ,,	0·234	21	·47

The Reed boiler, a view of which is shown (Fig. 11), is the invention of Mr. Reed, Engineer Manager of Palmer's Shipbuilding Co., of Jarrow.

This boiler consists of the usual cylindrical steam drum and two water drums; these are connected together by the generating tubes, the top ends of which are below the water-level—they are thus of the drowned type; the tubes are bent in a special manner to bring them over the furnace, and are fitted with an ingenious screwed connection at each end for fixing them in position, this renders them easy to replace; the tubes are $1\frac{1}{16}$ in. outside diameter, reduced at the bottom end to $\frac{7}{8}$ in., which gives a little more room to get at the bottom nuts; outside return tubes are fitted to act as downcomers for the surplus water from the steam drum; diaphragm plates are fitted to cause the gases to traverse the greater part of the heating sur-

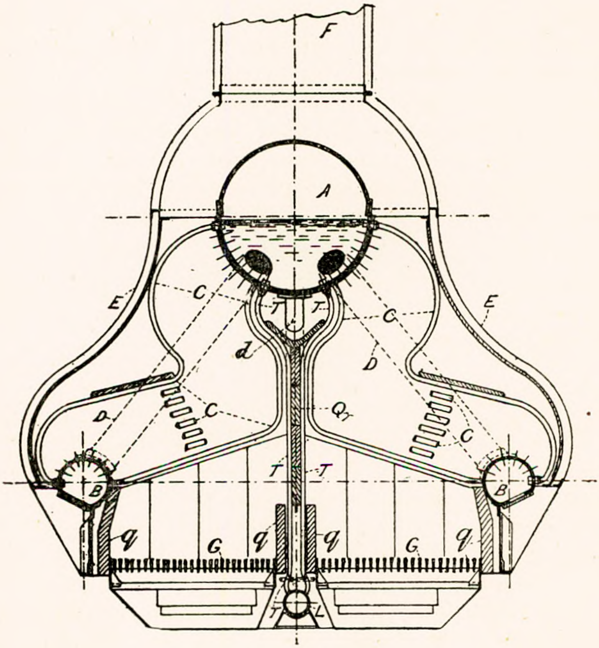


FIG. 11.

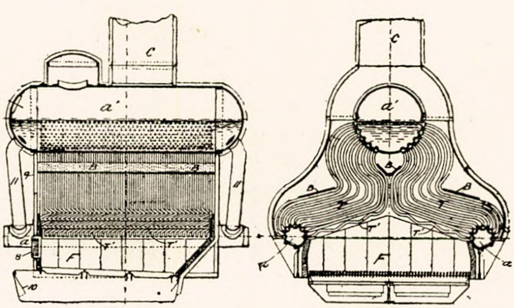


FIG. 11A.

faces, and the air casing is arranged so that the air heated by radiation is led into the ashpit, thus helping to keep the boiler-room cool and heat the supply of air to the furnace at the same time.

A number of these boilers have been fitted or are in course of construction—something like eighty for the British Admiralty alone—and not only to the torpedo-destroyer type of vessel, in which they have given great satisfaction, but they are also being fitted in our third-class cruisers. At present altogether about 110,000 I.H.P. of these boilers have been made, which, considering that the boiler has only been in use some four years, is evidence of its efficiency. It has been subjected to some severe tests: getting up steam quickly, checking the generation, and exposing the tubes to severe conditions of heating; but it has stood them remarkably well. Out of some 100,000 or more tubes there has not been a single failure of a joint, we hear.

Mr. Reed used an automatic feed regulator which is as near perfection as possible. The pressure to which these boilers are worked is from 210 lbs. to 300 lbs. per square inch, and the consumption of fuel at full power, with draught 3·2 in. of water, averages about 2·25 lbs. per I.H.P. The weight of boilers, complete with all fittings, casings, etc., water in and steam up, is 23·3 lbs. per I.H.P.

Mr. A. G. Mumford, of Colchester, has lately made a set of four boilers for H.M.S. *Salamander*, views of which are shown (Fig. 12). Their construction is somewhat different from all the others. The boiler consists of a steam drum or collector, and two water drums or cylinders, and a number of generating elements which are connected at their lower ends to the water chambers, and at their upper ends to the steam space of the steam drum. These elements are therefore not of the "drowned" type. A return tube of large diameter is fitted for improved circulation to the water cylinders. The elements in the older forms

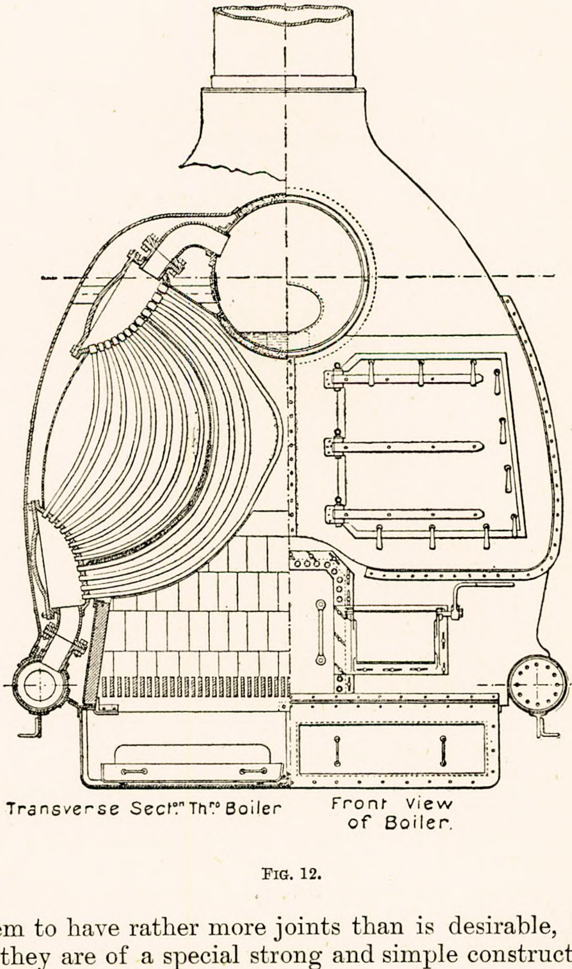
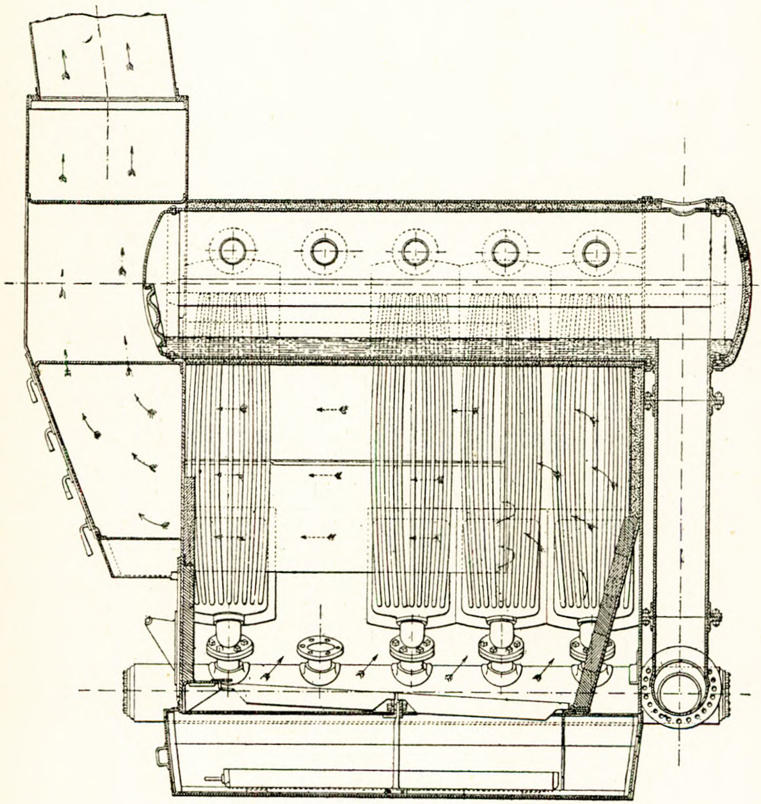


FIG. 12.

seem to have rather more joints than is desirable, but as they are of a special strong and simple construction they give no trouble. The tubes are expanded into the headers, and any of the elements can be readily removed if necessary, and another substituted, or the connections blanked if requisite. In the new type the number of joints is the same as in the Thornycroft.



Sectional Elevation Through Centre of Boiler with one Element Removed

FIG. 12A.

Baffle plates are fitted so as to compel the gases to travel the length of the boiler in the central part. They are then guided back among the tubes at each side, so that the products of combustion pass first to the back of the boiler along the centre, and are then returned along the sides. This makes the boiler a very efficient one as a steam generator ; an automatic feed regulator is fitted to maintain the water levels.

A number of these boilers have been fitted to steam pinnaces and launches, and they are giving good results.

The result of evaporation with the *Salamander* boilers was over 12 lbs. from and at 212°.

Another boiler which is making headway is the Clyde Patent Water-Tube Boiler, manufactured by

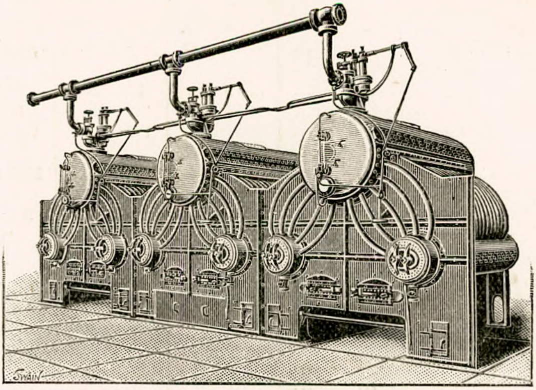


FIG. 13.

Messrs. Fleming & Ferguson, of Paisley ; this is shown (Fig 13). Its construction is similar to most of the previous boilers of the express type. It consists of an upper steam cylinder and two lower water cylinders which are connected together by curved generating tubes expanded into them. These tubes at their top ends are below the water level in the steam drum, and are, therefore, of the "drowned" type. It will also be noticed that a row of tubes is kept outside the furnace, presumably to act as down comers or feeders for the conveyance of the feed to the water legs. The upper drum is sufficiently large to enable the tubes —which are comparatively short—to be drawn into it should they require to be replaced, without disturbing the casing.

The following are some of the results of trials made with this boiler.

Tests of three Clyde Patent Water-Tube Boilers:

	No. 1	No. 2	No. 3
Grate area	$9\frac{1}{2}$ sq. ft.	20 sq. ft.	45·8 sq. ft.
Heating surface...	540 sq. ft.	630 sq. ft.	1,650 sq. ft.
Coal consumed per square foot of grate per hour	24·8 lb.	20·3 lb.	30·3 lb.
Total coal consumed per hour...	236 lb.	406 lb.	1,391 lb.
Water evaporated per hour ...	2,040 lb.	3,500 lb.	9,812 lb.
Water evaporated per hour from and at 212° F.	2,468 lb.	4,260 lb.	11,345 lb.
Water evaporated per lb. of coal from and at 212° F. ...	10·43 lb.	10·5 lb.	8·15 lb.
Water evaporated per lb. of combustible	11·15 lb.	11·25 lb.	8·7 lb.
Water evaporated per square foot of grate per hour ...	260 lb.	213 lb.	247 lb.
Water evaporated per square foot of heating surface per hour from and at 212° F....	4·5 lb.	6·7 lb.	6·8 lb.
Quality of coal used	Welsh	Welsh	Scotch
Draught natural on all trials.			

The evaporation per square foot of heating surface is very high.

Having now put before you all the boilers we propose to deal with to-night, we wish to remark that in selecting these we do not intend it to be understood that we think they are the best, but we put them forward as types of the best known boilers of the day, and we have, as far as time has permitted, pointed out their special features with a view to have you discuss their good and bad qualities and the lines on which they have been designed, as it appears to us that the time is rapidly coming when the marine engineers of the mercantile marine will be called upon to take charge of this class of boiler, and if anything in our paper helps you to more thoroughly grasp the problem of the water-tube boiler we shall be repaid for the trouble we have had.

M. Normand in 1895 astonished many of the members of the Institute of Naval Architects when he informed them that a reduction of the weight of any part of the ship allows the whole displacement to be reduced by about four-and-a-half times the weight saved. His particular argument at the time was to show that feed water heaters and everything which went to increase economy saved weight and displacement. At that time the weight of his boilers and engines came out as low as 48 lb. per I.H.P.; the Reed boiler taken alone gives us 23 lb. per I.H.P.

Taking this against 200 lb. per I.H.P. for the old Scotch boiler makes it appear as if the universal adoption of the water-tube boiler for marine purposes is simply a matter of time.