25th of February, 1859, and when the French ironclad seagoing ships were being built, how easy it was to undervalue new forces. This administration undertook the building and conversion at that time of sixty-seven wooden line-of-battle ships and frigates; and they were all in the hands of the dockyard authorities, in various stages of production, a few months afterward. But not one of them was suitable for the circumstances of the time. Many of them were never finished.

WATER-TUBE BOILERS FOR WARSHIPS.*

By J. I. THORNYCROFT.

In modern warships the weight to be carried is an ever increasing source of difficulty. The essence of a skillful design is the combination of great powers of offense and defense, of speed and coal endurance, in a limited displacement. In the ironclad of to-day, evidence may be seen in every part of the struggle of the designer to reduce the weight of his elements without impairing the efficiency of the structure as a whole. Forced to increase the thickness of his armor, he covers with it only a small portion of the hull, and he hardens the face of his plates to increase the resisting power of a given weight of material. The structure of the hull has been elaborated until the amount of material has been reduced to a minimum consistent with safety. The weight of the guns has been reduced, I am inclined to think, quite as much as is desirable when the amount of the charge is considered; and the engines, like the guns, have had their pressures and velocities increased until progress in these directions appears to have reached a limit.

In the boilers, however, there is still much room for reduction of weight, not only by economizing material, but also by economizing fuel. Mr. Sennett's paper, last year, shows how strong is the pressure brought to bear upon the engineering department with a view of saving weight in the boilers. His answer has been, reduced test pressures and reduced thickness of material. Economy of fuel in steam boilers depends greatly on the amount of heating surface that can be allowed for a given evaporation. If we can estimate the weight of a unit of heating surface in different classes of boilers, it becomes a very simple matter to calculate the comparative weight of the boilers for a given economy of fuel. On the other hand, for a given weight of boiler we can estimate the saving in fuel, or the increase of power, due to a change from one class to the other.

Some experiments were made at Portsmouth two years ago having a direct bearing on this subject. By an evaporative trial, at natural draught, of two boilers, the one locomotive, and the other water tube, the heating surfaces of which were in the ratio of 1 to 2.3, it was found that in the case of the latter boiler the rate of evaporation could be increased in the ratio of 1 to 2.36 with the same economy.

It follows that a water-tube boiler will evaporate a little more water per foot of surface than a locomotive when working equally economically, and, therefore, under these conditions, the weights of the two types will be proportioned to one another as the weights of a unit of heating surface. The weights of boiler and water and fittings per foot of heating surface of the locomotive and water-tube boilers tried at Portsmouth were 25.6 lb. and 9.61 lb. respectively. The weight, therefore, of a water-tube boiler and water, working at the same economical rate as a locomotive boiler and water, will be less than half.

In practice we prefer to make a smaller reduction in weight, and to work the boilers less hard by giving a larger allowance of heating surface for a given quantity of water to be evaporated. By this means better economy is obtained, and much less stress is put upon the boilers.

Whereas the common wind pressure for locomotive boilers in torpedo boats is from 4 in. to 5 in. of water, we do not usually exceed 1½ in. to 2 in. with the water tube, and a corresponding reduction could doubtless be made in warship practice. The following figures will show the amount of the saving in weight:

	Indicated horse power.
Indicated horse power per ton weight of water-tube boiler, including all fittings, mountings, water pipes, donkey, spare gear, and funnel...	68
Locomotive boiler of same power in a torpedo boat...	48
Locomotive boiler in latest English torpedo catcher...	43
Boilers of H.M.S. Anson...	21.3
" P. and O. steamers...	16.6

This boiler has other qualities which render it particularly suitable for warships. In addition to the saving in fuel due to the greater economy, the power of getting up steam in a short interval of time must tend to further saving, for when it takes a long time to raise steam it must be kept up continuously, if there is a possibility that it may be wanted with only a notice of an hour or two. With the power to get up steam quickly, it would be sufficient to keep steam in one boiler, for the purpose of starting auxiliary engines and warming the main engines. It has been found that steam can be raised in from 15 to 20 minutes without risk of injury, and forced firing has never caused leakage of the tubes.

The water-tube boiler consists simply of three cylinders lying parallel to each other, the smaller being at the base of the structure, and the larger one at the top. (See Fig. 1 of engravings herewith). These cylinders are connected by means of two large tubes at the fire-door end, and are stayed at the opposite end by a triangle frame. A further connection exists between the top and bottom cylinders in a great multitude of small tubes. These are the steam generating tubes. On looking carefully, it will be noticed that the inner row of tubes, forming what would be the crown of the fire-box, and the outer row, forming what would be the shell in an ordinary boiler, are, by means of a very simple alteration of their ends, made to lie quite close together, so that none of the products of combustion can pass between them (Fig. 3).

The lower part of the upper cylinder is thus protected from the direct action of the heat. The tubes are fixed in the cylinders by expanding in the ordinary

way, and an outer casing of thin steel covers the whole. In the upper half of the upper cylinder a curved baffle plate with serrated edges is fixed to protect the steam pipe and effect the separation of the water and steam. The firebars are disposed at the base of the boiler, and between the two lower cylinders. They are surrounded by firebrick slabs, which act as protectors to the lower cylinders and as bridges over which the flame must pass on its way to the chimney.

When steam is required, the boiler is filled with water up to nearly the middle of the upper cylinder, and the fire is lighted. The products of combustion pass over the side bridges and through the spaces between the lower ends of the generating tubes, into the spaces between the tubes, and along them to the upper half of the upper cylinder, whence they pass to the funnel. In addition to the heat absorbed from the gases a great amount of radiated heat is received by the tubes forming the crown of the furnace.

The heat absorbed by the tubes is at first only communicated to the small volume of water within them, so that the density of the water is rapidly reduced. At the same time the two large tubes which connect the upper and lower cylinders are filled with water of the original density, thus more than balancing the weight

18th of September last. He says: "The boiler itself is doing splendidly, and we have no difficulty in keeping up steam sufficient for 400 revolutions; in fact, quite steam enough for any purpose, and when head to wind often too much."

The next boiler was fitted in a second class torpedo boat for the British navy, and tried early in 1886. It has therefore been at work for about three years. I obtained permission from the Admiralty to remove some of the small tubes for ascertaining their condition. These specimens were cut out recently, and are exactly in the condition in which they were taken from the boiler. In examining them I was exceedingly pleased to find that the deposit in them was so very small in amount. It appeared possible that this boiler might fail, from the tubes becoming obstructed by deposit, and as it is impossible to gain access to much of their interior, this would have been a very serious drawback. I am not aware that the boiler from which these tubes are taken has been treated with any special care; the surface condenser is of the ordinary kind, and is not specially made to prevent leakage.

A few of these tubes, however, are not in such good condition as I had hoped; oxidation seems to have taken place to a slight extent within them, and the ex-

THE THORNYCROFT WATER-TUBE BOILER.

of the contents of the generating tubes, and causing rapid circulation. The discharge from the tubes into the upper cylinder is a mixture of steam and water, and these elements are separated as they flow over a curved baffle plate, which is placed immediately under the openings of the tubes, and incloses a considerable space above the water surface protected from spray, and from which the steam is taken.

The absence of leakage may be briefly explained as being due to the facts that the tubes can expand freely and that their connections with the upper and lower cylinders are not exposed to the heat of the fire, while in fire-tube boilers the part of the tube exposed to the most severe heat is its junction with the tube plate, around which there is no water to cool it.

Opinions have been expressed that this boiler will have but a short life. Opinions on such a matter are not of much value, and the author thinks that it will be of interest to the Institution to learn how the boilers of this type which are already at work have stood the test of time. The first one was made for the Congo Mission steamer Peace. The vessel was tried on the Thames in 1882, then taken to pieces, the boiler included, and re-erected in Africa by the Rev. George Grenfell, with black assistants only. She commenced work on the Congo in the spring of 1884, and has performed continual service since. The last news we had of her was contained in a letter from Mr. Grenfell dated the

ternal surface of those taken from the outer rows has been very much rusted, and seems to indicate that these tubes have been wet for a considerable period. This is corroborated by the fact that the plates forming the external casing are also decayed in places. It is most satisfactory, however, to find that the tubes in the flue, and also those forming the firebox, are in most excellent condition. The blue scale is still visible on the outside, and the parts of the tubes exposed to the most intense heat do not show the least trace of injury from the fire.

The next examples are the boilers of the Ariete and Rayo. It will be remembered that an exceedingly high speed was attained in these vessels, due largely to the lightness and steaming power of the boilers, of which each boat had two. They were delivered to the Spanish government in August, 1887. Very soon afterward, newspaper reports appeared as to defects having manifested themselves, and it was stated that the boilers were condemned, and were to be replaced by others of locomotive type. We had no communication made to us officially concerning these alleged defects.

Seeing in the newspapers an account of certain maneuvers in which these and other torpedo boats were engaged, where it was stated that one of the boilers of the Ariete was disabled, we applied to the minister of marine for permission to send an engineer over to examine the boilers, and to put right any defects which had arisen.

* Paper read at the Institution of Naval Architects.

After much delay this was granted, and our engineer reports as follows:

"The work of removing pipes, casings, etc., was commenced March 15. On removing the front and back plates of boiler casing, all the small tubes were found covered with a coating of soot from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. thick. I then caused the side casing to be removed; when this was done the lower parts of the casing (adjoining the coal bunkers) were found wasted away, caused by small coal, ashes, and soot being allowed to accumulate to a depth of about 5 in., the steam-cleaning gear pipes being embedded and partially destroyed.

"The front frame plate carrying the ashpan doors was then removed, and I found the ashpans firmly fixed in a bedding of small coal and soot which had been allowed to accumulate; this had to be dug away before the ashpans could be removed, and through this accumulation it has, to some extent, corroded the sides of the ashpans. On going inside the firebox I found the firebricks much damaged, and they have been in this condition for some time; those on the port side will have to be removed. The center firebrick on the inside of end casing, nearest the safety valve end of boiler, is missing, and from the crumpled appearance of the plate, has been in this state for some time. The inside of separator tube and collector tubes are very fair, no appearance of pitting being discernible, although the collector tubes have a deposit on the bottom of $\frac{3}{8}$ in. of lime, etc. The separator dash plates (zinc) have wasted in their thickness from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. on the part that has been in the water, while the upper parts have a great deal of sediment fixed on them. The zinc bars in the collector tubes are but slightly worn.

"I have examined the safety valves and stop valves, and these are in a very fair condition. This day I have tried the small tubes with water, and have discovered one tube in the row marked I, or the second row counting from the top center of separator, and it is the eleventh from the safety valve end of boiler; this is the only one I have discovered, and it is caused through a small hole in tube about $\frac{1}{4}$ in. in diameter. I propose to draw this tube and refit a new one, to remove all sediment from the collector tubes, clean zinc dash-plates and bars, refit new firebricks, well cleanse the outside of small tubes from the soot, and remove the damaged parts of side casings, and fit strips of plate 8 in. deep to take the place of damaged parts.

"I would add that there is nothing in these repairs, excepting the damaged tubes, but what could have and should have been done by the stokers belonging to the ship, but which, from the total neglect the boiler has received, has very seriously impaired the efficiency of the boiler, until the neglect is rectified. In reference to the damaged tube, there are a number of special plugs supplied with the boat for the purpose of putting out of use any defective tube or tubes. Had this been applied—and the application of it is very simple—no annoyance would have been experienced, except instead of 918 tubes there would have been 917. From the general appearance of the boiler and fittings, it shows it has been greatly neglected, for in addition to the steam-cleaning gear there are brushes applied to assist; these have not been used, nor have the end plates been removed for this purpose, nor for inspection, since the boat left England."

The next vessels in order were the Danish torpedo boats *Støren* and *Soloven*, delivered in 1887. Since then we have supplied water-tube boilers in all the new torpedo boats built for that government, and are

Careful experiments have recently been made by Professor Kennedy on one of these boilers, in order to ascertain the evaporative efficiency at different rates of working. The best result was with natural draught, when the evaporative duty reached 13.4 lb. of water per pound of coal, from and at 212 deg. The calorific value of the coal, as determined by analysis, was 15.41 lb. per pound of coal. The efficiency of the boiler with natural draught was therefore 87 per cent. of the theo-

line over which the machine is to travel. The ladder over which the buckets travel is hung on an axis on the back of the machine, but throws the center of gravity toward the working side, and to offset this, ballast of railroad iron is loaded on the extension on the back of the machine. The boilers are usually horizontal, giving low center of gravity, and the water tank of iron and a coal bunker of iron are placed on the boiler end of the platform. There are two styles

FIG. 12.—FRENCH EXCAVATOR, "DOWN DIGGER" TYPE.

retical evaporation, which we have reason to believe is the highest on record.

[Continued from SUPPLEMENT, No. 700, page 11179.]

PLANT AND MATERIAL OF THE PANAMA CANAL.*

By WILLIAM PLUMB WILLIAMS, Jun. Am. Soc. C. E.

EXCAVATORS (Figs. 12, 13, 14, 15, 16).—Many styles of the endless chain of bucket excavators are in use, but after a thorough examination as to machinery and

of attacking a bank, called "down diggers" and "up diggers," whether attacking material above or below level of track. A "down digger" of the above manufacture at work at Tavernilla may be described as follows, Fig. 12. The endless chain of buckets operated on "over and under" system received their motion from the square upper tumbler of the shaft, which was geared from its wheel of large circumference, connecting with a smaller gear wheel on the crank shaft. The vertical engine supplied this shaft with three pistons, giving a positive motion. The buckets were constructed with a quadrangular hemispherical face and no back,

FIG. 13.—OSGOOD AMERICAN EXCAVATOR.

now replacing the locomotive boiler in a boat $5\frac{1}{2}$ years old with two water-tube boilers.*

* Figs. 4 and 5 are diagrams illustrating the saving in space effected by the substitution of Thornycroft's water-tube boiler for a locomotive type boiler in the steam yacht *Gitana*.

	Old Boiler.	New Boiler.
Grate surface in square feet.....	16.2	22.7
Heating surface, firebox.....	51.87	75.0
" " tubes.....	653	1335
" " total.....	705	1410
Weight of boiler in tons.....	6.25	5.9
Water in boiler.....	1.87	1.35
Total weight.....	8.12	7.25

work accomplished, I consider the machines constructed by P. DeMange and Messrs. Satri & Lyons superior to any others. This machine is constructed on two trucks of four wheels each and of a 5 foot gauge, while when in working condition the working base is broadened by jacking up and throwing the weight on the working side out to a third rail 7 feet distant from the line rail. In transporting the machine from place to place the construction track of 5 foot gauge is adequate, and in working a third rail is laid up and down the

* A paper read before the American Society of Civil Engineers, July 2, 1889. From the *Transactions* of the Society.

the links being hung at the back of the bucket, and the ladder being suspended down the bank, was raised or lowered to give a slight contact to the cutting nose of the bucket, which became filled by gradually cutting a slice all of the way up the bank, carrying the material up and on to the upper tumbler shaft, and as the bucket at a slope of 45 degrees to the horizontal changed its angle by going over the upper tumbler, no support was given to the contents, which fell out and down into the hopper, and through a chute suspended over a train of dump cars on the second track and back of the machine.