STEAM & HOT WATER BOILERS
1840-1930

Steam Boilers

STEAM-BOILERS.

BY

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FIRST EDITION.

FIRST THOUSAND.

NEW YORK:
JOHN WILEY & SONS.
LONDON: CHAPMAN & HALL, LIMITED.
1897.

PEABODY & MILLER BOOK 1897

STEAM-BOILERS.

CHAPTER I.

TYPES OF BOILERS.

STEAM-BOILERS may be classified according to their form and construction or according to their use. Thus we have horizontal and vertical boilers, internally and externally fired boilers, shell-boilers and sectional boilers, fire-tube and water-tube boilers: the several features mentioned may be combined in various ways so as to give rise to a large number of kinds and forms of boilers. Again, we have stationary, locomotive, and marine boilers, together with a variety of portable and semi-portable boilers. Locomotive boilers are always shell-boilers, internally fired, and with fire-tubes; and the restrictions of the service have developed a form that has changed little from the beginning, except in the direction of increased size and power. Marine boilers present a much larger variety of form and construction, depending on the steam-pressure used and the size and service of the vessel to which they are supplied. The Scotch or drum boiler is more widely used than any other form at present, but the tendency to use high-pressure steam has led to the introduction of various forms of water-tube boilers for marine work. The variety of forms and methods of construction of stationary boilers is very wide: each country and section of a country is likely to have its own favorite type. Thus in New England, where the water is good, cylindrical tubular boilers are largely used; in some of the Western States, where water contains mineral impurities, flue-boilers are preferred; and in England, the Lancashire and Galloway boilers are favored; and again, various forms of sectional and water-tube boilers are now widely used.

Cylindrical Tubular Boiler.—This type of boiler is shown by Fig. 1 and by Plate I. It consists essentially of a cylindrical shell closed at the ends by two flat *tube-plates*, and of numerous *fire-tubes*, commonly having a diameter of three or four inches. About two thirds of the volume of the boiler is filled with water, the other third being reserved for steam. The water-line is six or eight inches above the top row of tubes. The tube-plates below the water-line are sufficiently stayed by the tubes; above the water-line the flat plates are stayed by *through rods* or *stays* as in Plate I, by diagonal stays like those shown by Fig. 52, page 154, or otherwise. A pair of cylindrical boilers in brick setting are shown by Figs. 36 and 37, on pages 92 and 93, with the furnaces under the front (right-hand) end. The products of combustion pass back over a *bridge-wall*, limiting the furnace, to the *back end*, then forward through the *tubes* and up the *uptake* to the flue which leads to the chimney.

The shell commonly extends beyond the front tube-plate, as shown at the right in Fig. 1, and is cut away to facilitate the arrangement of the uptake. The boiler is usually supported by cast-iron brackets riveted to the shell; the front brackets may rest on or be fixed to the supporting side walls, but the rear brackets should be given some freedom to avoid unduly straining the boiler by expansion. Thus the rear brackets may rest on rollers, which in turn bear on a horizontal iron plate. The expansion takes place toward the back end of the boiler, and to allow for this expansion a space is left between the back tube-sheet, and the arch of fire-brick back of the boiler.

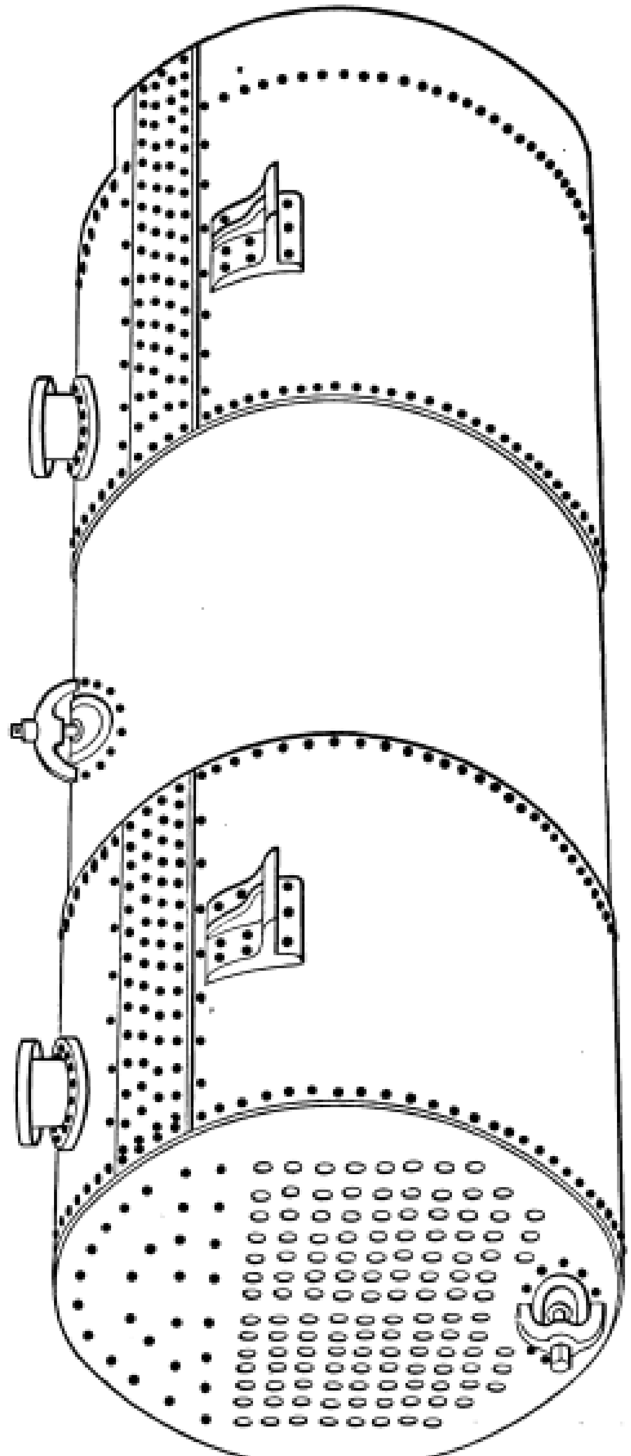


FIG. 1.

The boilers shown by Fig. 1 and by Plate I each have two steam-nozzles, one near each end. The safety-valve is usually attached to the front nozzle, which is above the furnace. The steam-pipe leading steam from the boiler is attached to the rear nozzle, which is over the back end of the boiler, where ebullition is less violent, and consequently there is less danger that water will be thrown into the steam-pipe.

Boilers of this type commonly have a *manhole* on top near the middle, and a *hand-hole* near the bottom of each tube-sheet, as shown on Plate I, to give access to the interior of the boiler and to facilitate washing out. Many boilers are now made with a manhole near the bottom of the front tube-sheet, in addition to the one on top. All parts of the boiler can then be cleaned and inspected whenever desirable. Some of the lower tubes must be left out when there is a manhole in the tube-sheet, but this is of small consequence, as the lower tubes are not efficient, and enough heating-surface can be provided elsewhere. The omission of the lower tubes requires also special stays for the portion of the tube-sheet left unsupported.

The *feed-pipe* for the boiler shown by Plate I enters the front head at the left, below the water-line, and runs toward the back end of the boiler, where it may end in a perforated pipe leading across the boiler. The feed-pipe may enter the top of the boiler, near the back end, and terminate in a similar perforated transverse pipe below the water-line.

A *blow-off pipe* leads from the bottom of the shell near the back tube-sheet. On the blow-off pipe there is a plug or valve which may be opened when steam is up, to blow out mud and soft scale that may collect in the boiler. The boiler is commonly set with a slight inclination toward the rear so that mud may collect near the blow-off pipe. The boiler may be emptied by allowing the water to run out at the blow-off pipe.

About half of the shell, two thirds of the back tube-sheet, and all the inside surface of the tubes come in contact with the products of combustion and form the *heating-surface;* all the heating-surface is below the water-line.

The boiler-setting, shown by Figs. 36 and 37 on pages 92 and 93, is made of brick laid in cement or mortar; all parts that are directly exposed to the fire are lined with fire-brick. The walls have confined air-spaces to reduce transmission of heat. The *boiler front* is commonly made of cast iron, and has *fire-doors* leading to the furnace, and *ash-pit doors* opening from the *ash-pit*, or space below the grate; there are also large doors giving access to the tubes through the *smoke-box* at the front end of the boiler. The furnace is formed by the side walls, the bridge, and the lower part of the boiler front, which latter is lined with fire-brick above the grate. Doors through the rear wall give access to the space back of the bridge. The top of the boiler is covered by a brick arch or by non-conducting material.

Two-flue Boiler.—The cylindrical flue-boiler differs from the tubular boiler mainly in replacing the fire-tubes by one or more large flues. Fig. 2 shows such a boiler with two

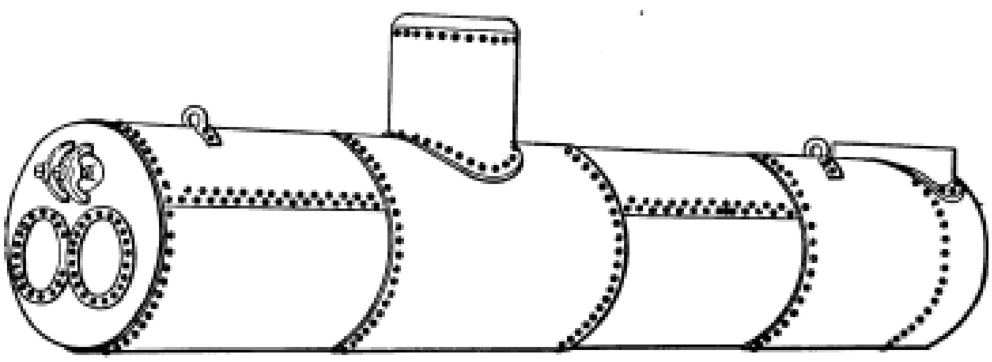


FIG. 2.

flues. This type of boiler is usually longer than a tubular boiler, but even so it has less heating-surface and is less efficient in the use of coal. Nevertheless the greater simplicity and accessibility for cleaning recommend it where feed-water is bad.

The setting of a flue-boiler resembles that for the cylindrical tubular-boiler. The figure shows two loops at the top of the shell for hanging the boiler; a crude method of supporting, suitable only for small and short boilers.

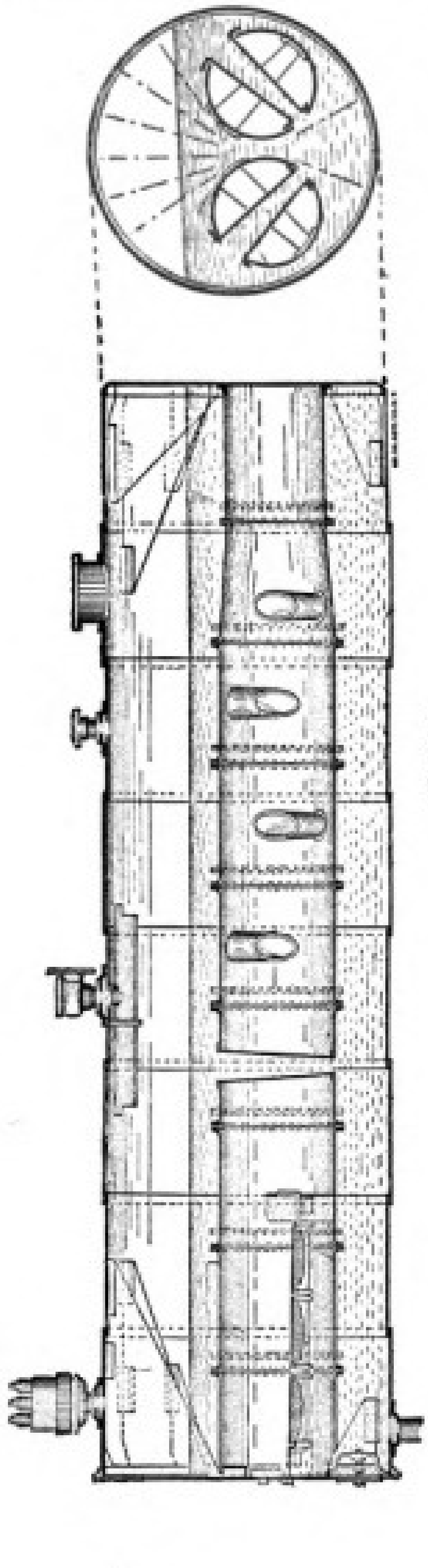


FIG. 3.

Plain Cylindrical Boiler.—In places where fuel is very cheap, especially where it is a waste product, as at sawmills, the plain cylindrical boiler is frequently used. Its external appearance is similar to that of the two-flue boiler (Fig. 2), except that there are no flues and the ends are commonly hemispherical or else curved to a radius equal to the diameter of the shell. Such plain cylindrical boilers are also employed to utilize the waste gases from blast-furnaces. They are commonly 30 to 42 inches in diameter and from 20 to 40 feet long. They have been made 70 feet long. With such extreme lengths special care must be taken to insure equal distribution of the weight to the supports and to provide for expansion.

Lancashire Boiler. — This boiler, shown by Fig. 3, is a two-flue shell-boiler with furnaces in the tubes; it is therefore an internally-fired boiler, in which it differs from the two preceding types, which are externally-fired. The chief difficulty in the design of these boilers is to provide sufficiently large furnaces without making the external shell too large. As compared with the cylindrical tubular boiler, this boiler will be sure to have long, narrow grates, with a shallow ash-pit and a low furnace-crown: the boiler also appears to be deficient in heating-surface. In compensation, radiation and loss of heat from the furnace are almost entirely done away with, and the thick outside shell, with its riveted joints, is not exposed to the fire, as with the tubular boiler. The flues are made in short sections riveted together at the ends, thus forming a series of stiffening rings that add very much to the strength of the flues against collapsing. Conical through-tubes, vertical or inclined, give increased heating-surface, break up the currents of the hot gases, improve the circulation of the water, and strengthen the flues. These tubes are small enough at the lower end to pass through the hole cut in the flue for the upper end, and thus are readily put in or taken out for repairs.

The flat plates at the ends of the shell are stayed by *gusset-stays* or triangular flat plates to the shell of the boiler. The boiler is provided with a manhole near the back end and a safety-valve near the front end. Steam is taken through a horizontal dry-pipe, perforated on the top.

Galloway Boiler.—This boiler has two furnace-flues at the front end, like the Lancashire boiler. Beyond the furnace the two flues merge into one broad flue, having the upper and lower surfaces stayed by numerous conical through-tubes, like those shown in Fig. 3 for the Lancashire boiler.

Cornish Boiler.—This boiler was developed in conjunction with the Cornish engine, and both boiler and engine long had a reputation for high efficiency. It differed from the Lancashire boiler in that it had but one flue; it formerly did not have cross-tubes. The one furnace of the Cornish boiler, with a given diameter of shell, can have better proportions than the two furnaces of the Lancashire boiler, but there is even greater difficulty to get sufficient grate-area and heating-surface. The high economy shown by these boilers when used with the Cornish pumping-engine was due to a slow rate of combustion, and to the skill and care of the attendant, who was usually both engineer and fireman, and who was stimulated by a system of competition and awards, maintained by the mine-owners in that district.

The Lancashire and the Cornish boilers are set in brickwork which forms flues leading around the outside shell, thus making the shell act as heating-surface. Fig. 4 gives a cross-section of the Lancashire boiler and its setting. After the gases

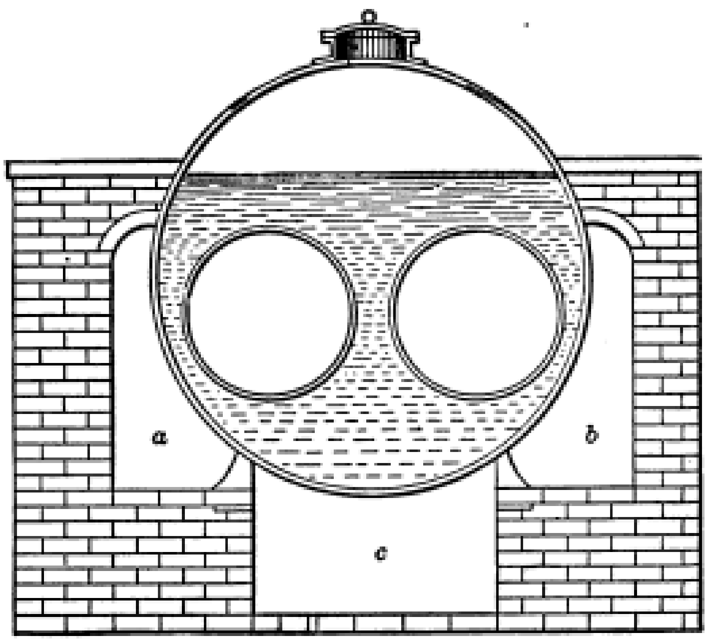


FIG. 4.

from the fires leave the internal flues they are directed into the flue *a* and come forward; then they are transferred to the flue *b* and pass backward; finally they come forward in the flue *c*, and are then allowed to pass to the chimney. This forms what is known as a *wheel-draught*. In some cases the gases divide at the rear and come forward through both side flues *a* and *b*, and uniting pass back through *c* and thence to the chimney, forming a *split-draught*.

Vertical Boilers.—Boilers of this type have a cylindrical shell with a fire-box in the lower end, and with fire-tubes running from the furnace to the top of the boiler. Large vertical boilers have a masonry foundation and a brick ash-pit; small vertical boilers have a cast-iron ash-pit that serves as foundation. Vertical boilers require little floor-space; if properly designed they give good economy, or they may be made light and powerful for their size, when economy is not important.

Fig. 5 shows a large vertical boiler designed by Mr. Manning. It is made 20 to 30 feet high, so that there is a large heating-surface in the tubes. The shell is enlarged at the fire-box to provide a larger furnace and more area on the grate. The internal shell which forms the fire-box is joined to the external shell by a welded iron ring called the foundation-ring. This internal shell should be made of moderate thickness to avoid burning or wasting away under the action of the fire. Being under external pressure, the shell of the fire-box must be stayed to avoid collapsing. For this purpose it is tied to the outside shell at intervals of four or five inches each way, by bolts that are screwed through both shells and riveted over cold, on both ends. The stays near the bottom have each a hole drilled from the outside nearly through to the inside end. Should any stay break or become cracked, steam will escape and give warning to the fireman.

The tubes are arranged in concentric circles, leaving a space about ten inches in diameter at the middle of the crown-sheet; the corresponding space in the upper tube-sheet provides for the attachment of the nozzle for the steam outlet.

There are numerous hand-holes in the shell outside of the fire-box, some near the crown-sheet, and some near the foundation-ring, and these are the only provision for cleaning the

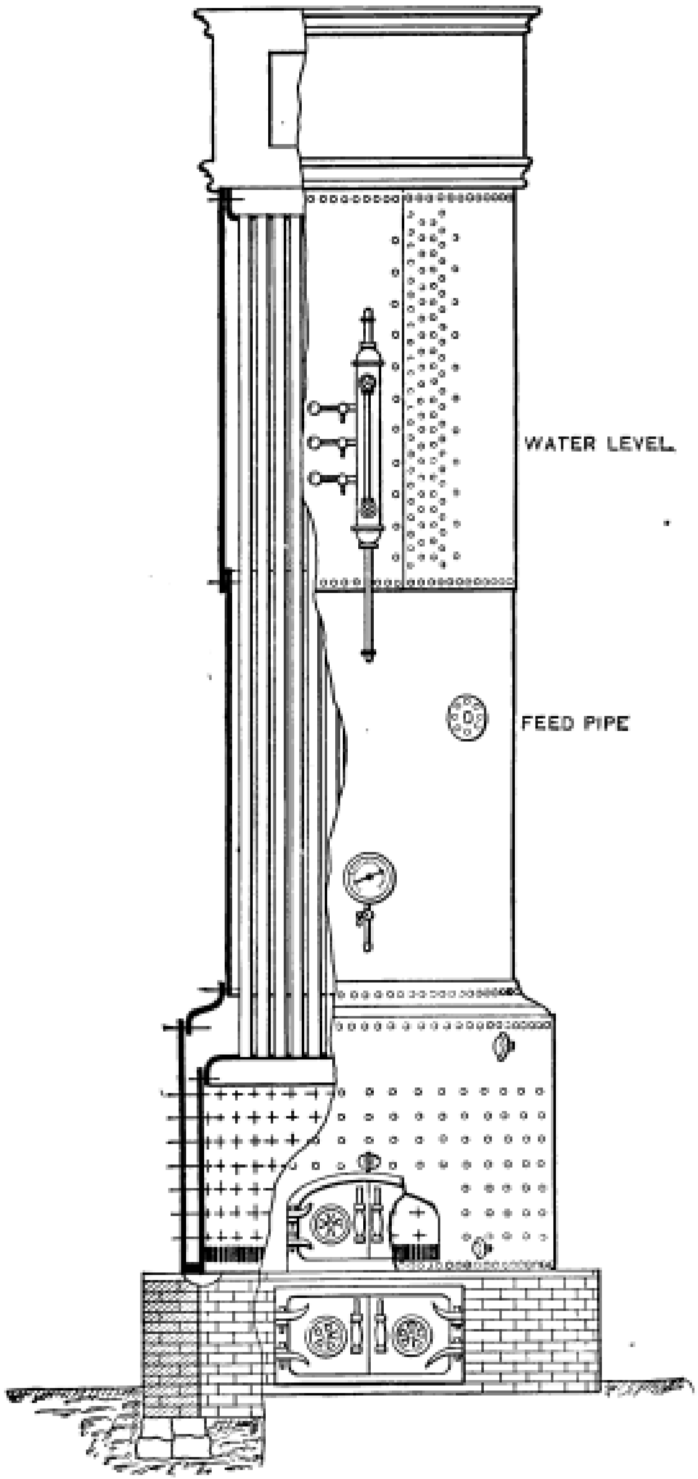


FIG. 5.

boiler, which consequently is adapted for the use of good feed-water only. The feed-pipe enters the shell at one side and extends across the boiler; it is perforated to distribute the feed-water.

The sides of the fire-box, the remaining surface of the tube-sheet allowing for the holes for the tubes, and the inside

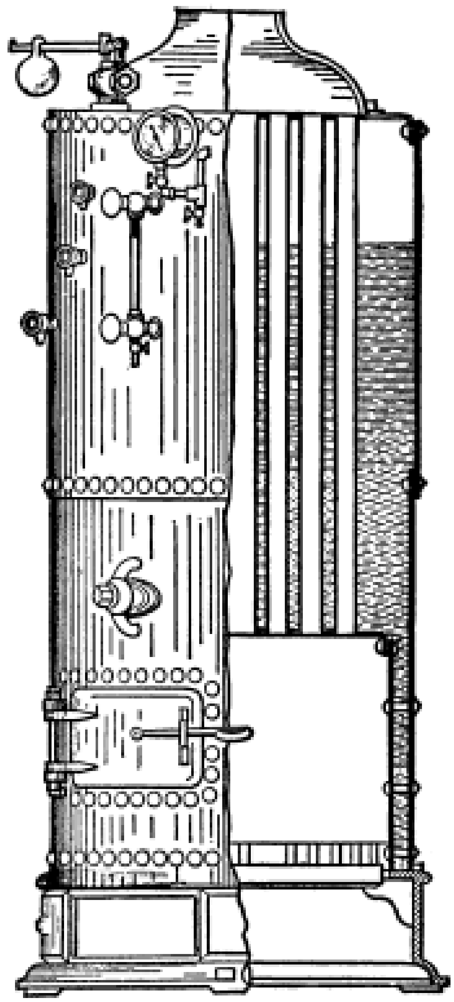


FIG. 6.

of the tubes up to the water-line form the heating-surface: the inside of the tubes above the water-line form the *super-*

heating-surface, since it transmits heat from the gases to the steam and superheats it.

This type of boiler has found favor at factories where floor-space is valuable, since a powerful battery of boilers may be placed in a small fire-room.

A small vertical boiler adapted for hoisting, pile-driving, and other light work is shown by Fig. 6. It commonly has a short smoke-pipe, into which the exhaust steam from the engine is turned to form a forced draught and give rapid combustion. Under this treatment the upper ends of the tubes frequently give trouble by leaking. To avoid this difficulty the tubes are sometimes ended in a sunken or submerged tube-sheet which is kept below the water-line, as shown by Fig. 7. The space between the edge of the tube-sheet

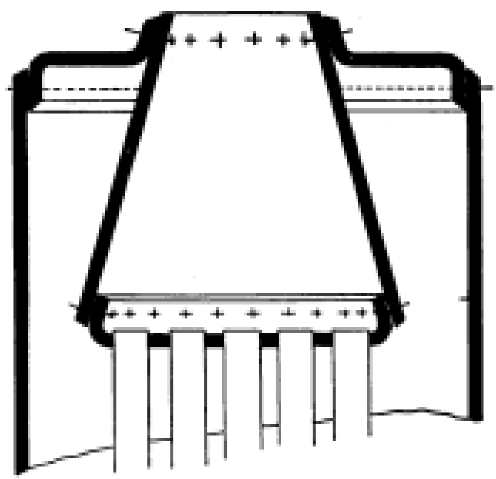


FIG. 7.

and the outside shell is likely to be contracted, and not to give proper exit for the steam formed on the tubes and crown-sheet. Furthermore, the cone forming the smoke-chamber above the tube-sheet is subjected to external pressure and is likely to be weak.

A form of vertical boiler having a sunken tube-plate is shown by Fig. 8. It was at one time much used for steam fire-engines, but to save weight it was so crowded with tubes and the water-spaces were so contracted that it gave much trouble when forced, as at a fire.

Fire-engine Boiler.—A boiler for a steam fire-engine should be light and compact, able to make steam quickly and

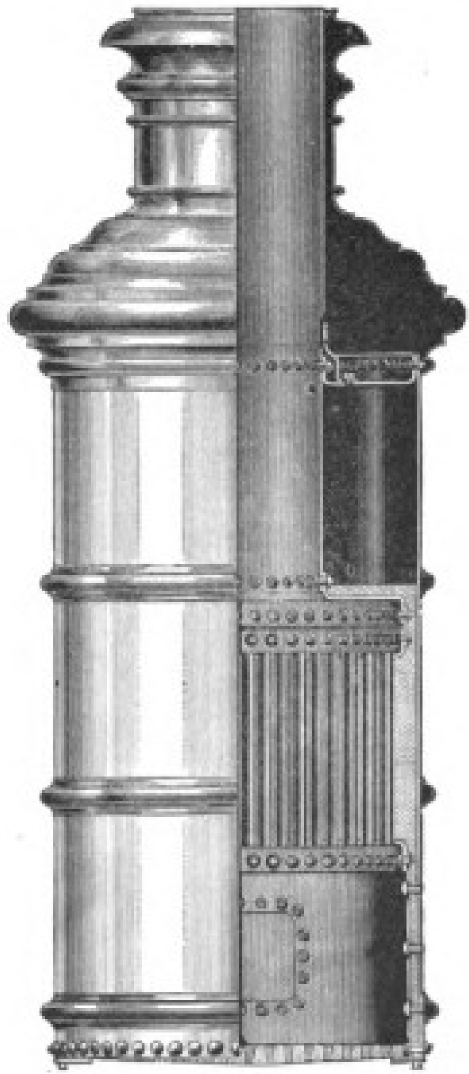


FIG. 8.

to steam freely when urged. They have small water-space and large heating-surface for their size, but are not economical in the use of fuel. It is customary to use cannel-coal for fire-engines, as it burns freely without clogging. A forced draught is obtained by exhausting steam up the smoke-pipe. When standing in the engine-house ready for duty the boilers are kept hot by connecting them to a heating-boiler in the basement. The connection is so made with snap-valves that it is broken by pulling the fire-engine out of position.

Figs. 9 and 10 show a vertical section and two half-horizontal sections of the Clapp fire-engine boiler. The boiler has a cylindrical shell and a deep internal fire-box. From the crown-sheet a number of fire-tubes lead through the water and steam space to the upper tube-sheet. In the upper part of the fire-box there are a number of water-tubes that start from the side of the fire-box, make several helical coils, and then open into the water-space above the crown-sheet.

There are three concentric sets of these helical coils, leaving a cylindrical space in the centre, which is occupied by a series of castings, shown in perspective and partly in section by Fig. 11. The casting is formed of an annular torus with a cross-tube, and an inverted U tube above. Water enters at the middle of the cross-tube, passes into the torus, and then up and out at the top of the U.

The left half of Fig. 10 shows the helical tubes from above; the right half shows the arrangement of the fire-tubes and the openings of the water-tubes.

Marine Boilers.—A single-ended three-furnace Scotch marine boiler is shown in perspective by Fig. 12; Fig. 13 gives the working drawings of a similar boiler with two furnaces. The arrangement of the furnaces in the flues, is similar to that for the Lancashire boiler, shown, by Fig. 3. The furnace-flue leads into a combustion-chamber, from which the products of combustion pass through fire-tubes to the uptake, which is bolted onto the front end of the boiler.

The flues are from three and a half to four and a half feet in diameter; the size of the boiler depends on the number and size of the flues. Large boilers have as many

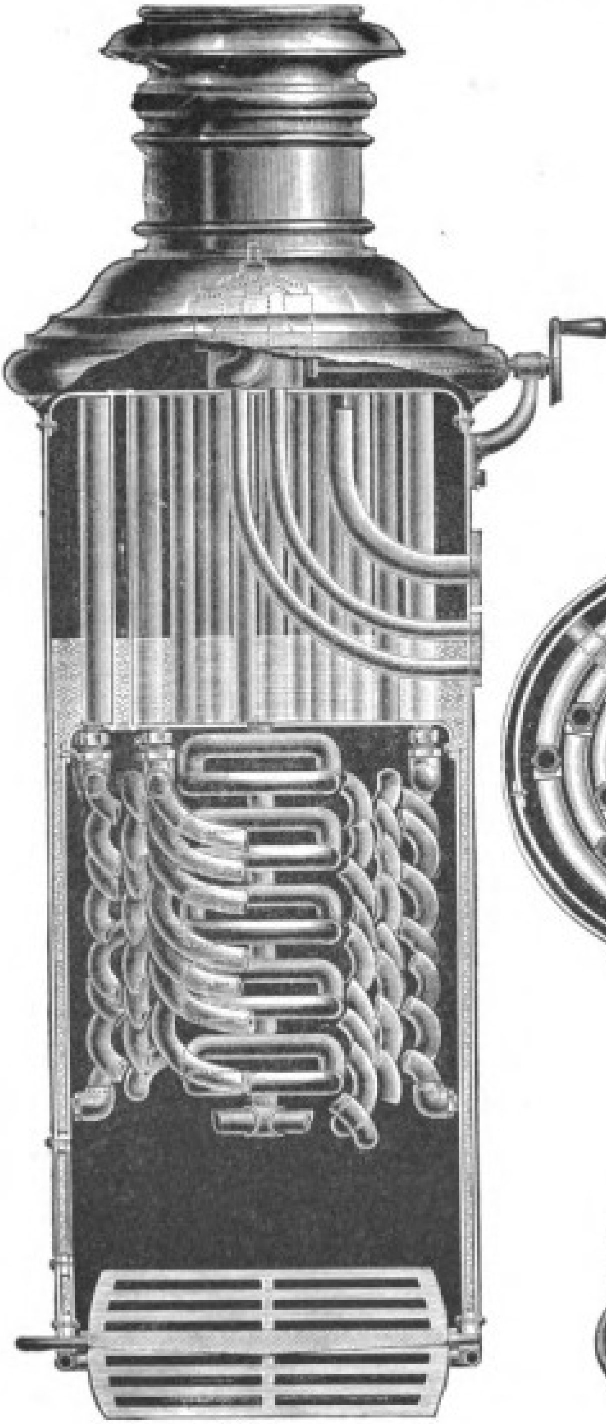


FIG 9.

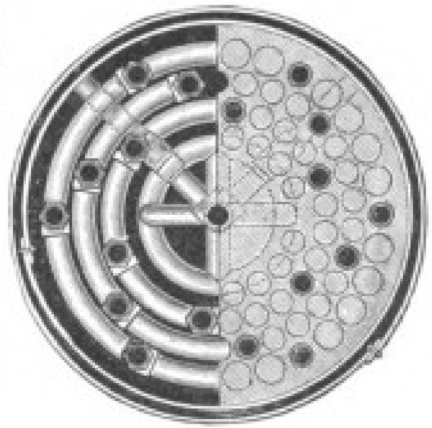


FIG. 10.

FIG. 11

as four flues. A three-furnace boiler commonly has three combustion-chambers, while a four-furnace boiler may have two, into each one of which two furnaces lead. Double-ended boilers have furnaces at each end, and resemble two single-ended boilers placed back to back. A double-ended boiler is lighter, cheaper, and occupies less space than

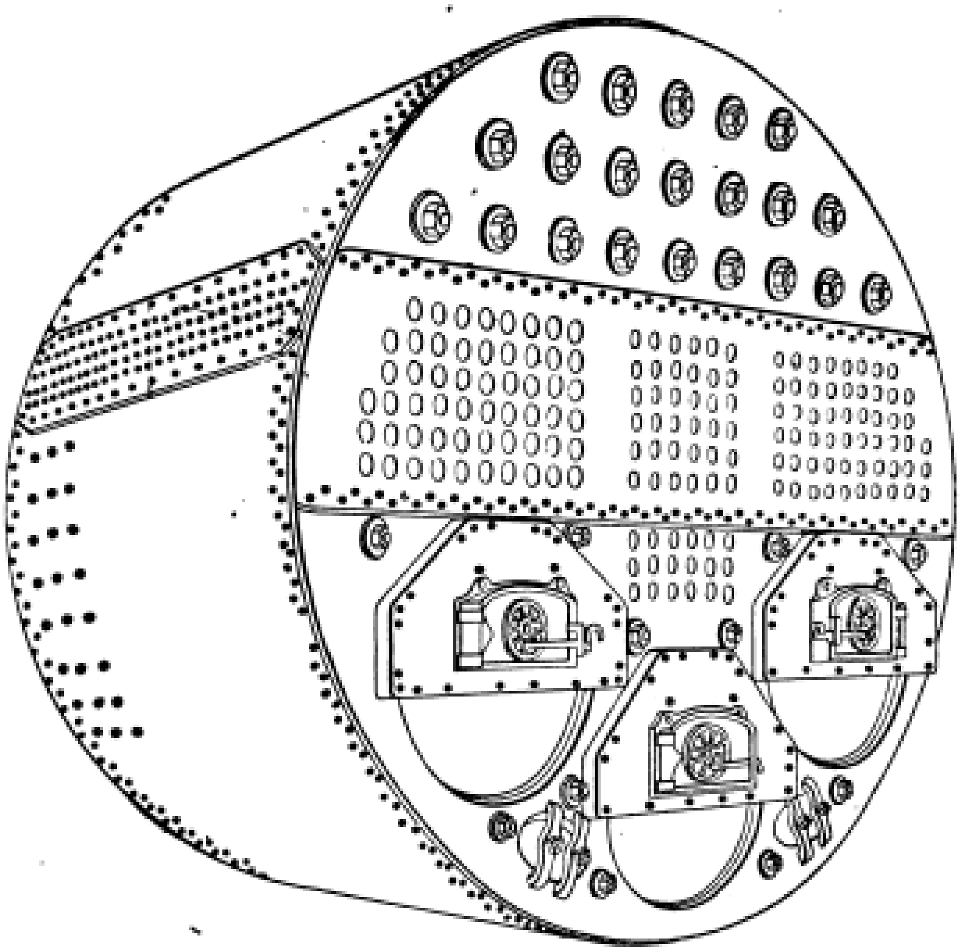


FIG. 12.

two single-ended boilers. In the best practice there are two distinct sets of combustion-chambers for the two sets of furnaces. To still further lighten double-ended boilers, common combustion-chambers for corresponding furnaces at the two ends have been used. The results from such boilers have not been satisfactory, more especially when

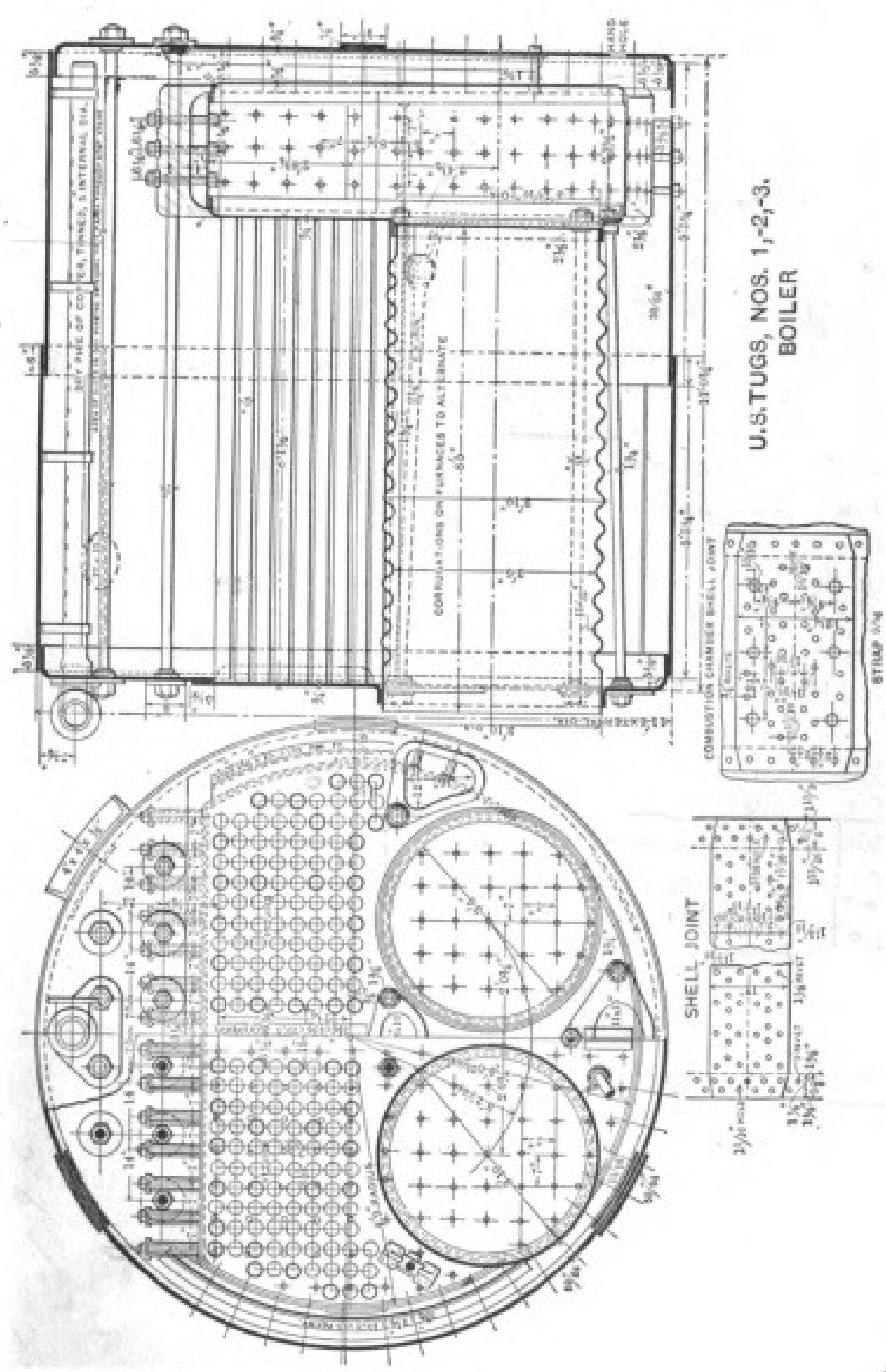

U.S.TUGS, NOS. 1,-2,-3.
BOILER
CORRUGATIONS ON FURNACES TO ALTERNATE
COMBUSTION CHAMBER SHELL JOINT
SHELL JOINT
STRAP

FIG. 13.

used under forced draught in the closed stoke-holes of war-ships; there has been so much trouble from leaky tubes under such conditions that forced draught has been abandoned in many cases, and ships have consequently failed to make the speed anticipated.

The circulation of water is defective in all Scotch boilers, and more especially in double-ended boilers. Considerable time—three or four hours—is always allowed for raising steam. Frequently some arrangement is made for drawing cold water from the bottom of the boiler and returning it near the water-line, while steam is raised. Haste and lack of care are liable to cause leakage from unequal expansion. The flue has the highest temperature of any part of the boiler and consequently expands the most, so that some allowance for expansion must be made or it will strain the tube-sheets and cause leaks. The methods of providing for expansion and at the same time stiffening the flues against collapsing under external pressure are shown on pages 210 to 216, and will be described in detail later on.

Gunboat Boilers.—Some gunboats and other small naval vessels have not room under the deck for Scotch boilers. The form shown by Fig. 14 has been used on such vessels; it has two furnace-flues, leading to a common combustion-chamber, from which fire-tubes lead to the back end of the boiler.

Locomotive-boilers.—The typical American locomotive-boiler is shown by Plate II. Fig. 15 gives a perspective view of a boiler of the locomotive type used for small factories, or where steam is required temporarily; it has no permanent foundation, but is supported on brackets at the fire-box and by a pedestal-bearing on rollers near the back end.

The locomotive-boiler consists essentially of a rectangular fire-box and a cylindrical barrel through which numerous tubes pass from the fire-box to the smoke-box, which forms a continuation of the barrel, and from which the products of combustion pass up the smoke-stack.

The fire-box is joined to the outer shell at the bottom by a forged rectangular foundation-ring, similar (except in shape)

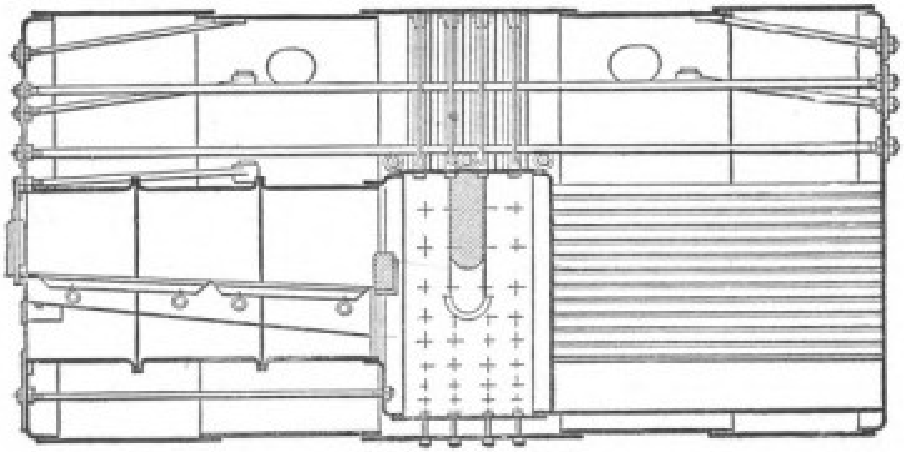


FIG. 14.

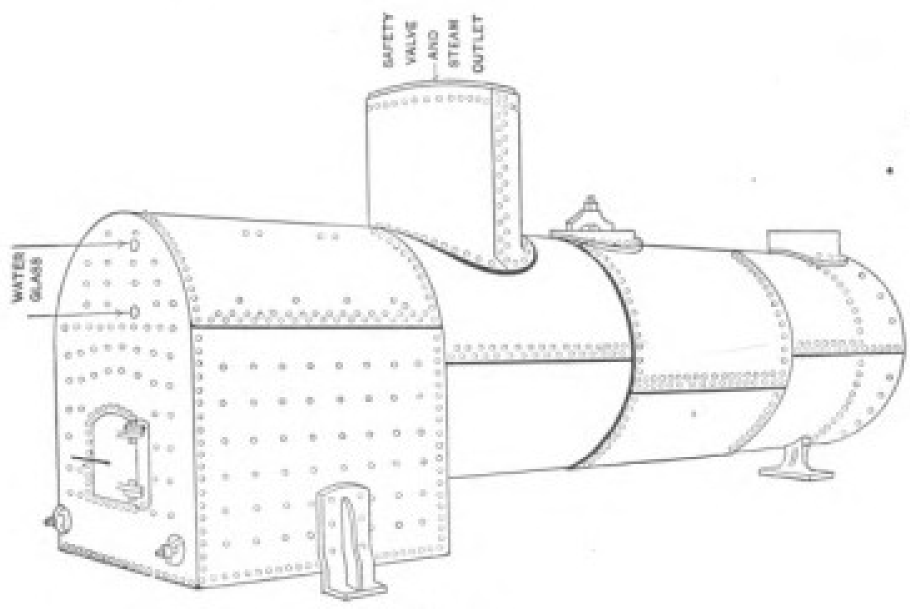


FIG. 15.

to the foundation-ring of a vertical boiler. Near this ring are several hand-holes for clearing out the space between the fire-box and the shell, commonly called the *water-leg*. The boiler also has a manhole at the top of the barrel. The water-leg is stayed by screwed stay-bolts riveted cold at the ends.

The flat crown-sheet is stayed to a system of *crown-bars* which rest on the side sheets of the fire-box and are also slung from the shell. Plate III shows a locomotive-boiler with a flattened top over the fire-box, to which the crown-sheet is stayed by through-bolts. Other methods and details of staying crown-sheets will be given later.

The tubes for a locomotive-boiler are smaller than for stationary boilers (about two inches in diameter) and are spaced much more closely. This is to obtain a large heating-surface required by the high rate of combustion, which often exceeds one hundred pounds of coal per square foot of grate-surface per hour. The boiler works under a strong forced draught, produced by throwing the exhaust up the smoke-stack.

The boiler is fastened rigidly to the frame of the locomotive at the smoke-box end; a small longitudinal motion on the frame at the fire-box end is provided by *expansion-pads*, shown by Fig. 4, Plate II.

Locomotive Type of Boiler —Reference has already been made in connection with Fig. 15 to a boiler of locomotive type used for stationary purposes. Plate IV shows a modification of the locomotive type designed by Mr. E. D. Leavitt to give high evaporative efficiency. The boiler represented has a barrel 90 inches in diameter, and it is 34 feet 4 inches long over all. It supplies steam at 185 pounds pressure to the square inch to the high-duty pumping-engine at Chestnut Hill Reservoir, Boston.

The fire-box of this boiler is spread at the bottom to give increased grate-area, and contains two separate furnaces, shown by the section *AA* on Plate IV. The products of combustion pass through openings, shown by section *BB*, into a combustion-chamber, which has the section shown at *CC*. From the combustion-chamber, the gases pass through tubes to the smoke-box and uptake. As far as the combustion-chamber the top of the boiler is flattened to facilitate the staying of the crown-sheets of the furnace, passages, and combustion-chamber; the barrel of the boiler beyond the combustion-chamber is cylindrical.

The boiler is somewhat complicated in construction and staying, and must be handled with care, especially in starting, to avoid straining from unequal expansion. It is adapted for the use of good feed-water only.

Boilers of the locomotive type were at one time used for torpedo-boats. The fire-box was made shallower than for locomotive-boilers, and forced draught in a closed stoke-hole was used, the rate of combustion being even higher than on locomotives. Whatever may have been the reasons, it was a fact that this type of boiler, which is very reliable on locomotives, gave much trouble in torpedo-boats.

Water-Tube Boilers.—The boilers thus far considered have an external shell containing a large body of water. Heat is communicated to the water through the shells or through the sides of internal furnaces, and also by carrying the gases through tubes or flues. The boilers and water contained, are heavy and cumbersome, and the shells under high pressure must be made very thick. If the boiler fails either through some defect or through carelessness of attendants, a disastrous explosion is likely to take place. If properly designed and made and if cared for by competent and careful attendants they are safe, reliable, and durable. The large mass of hot water tends to keep a steady pressure, though at the expense of rapidity of raising steam or of meeting a sudden demand for more steam.

A large number of water-tube boilers of all sorts of shapes and methods of construction has been devised to overcome the admitted defects of shell-boilers. They all have the larger part of their heating-surface made up of tubes of moderate size filled with water. They all have some form of separators, drum, or reservoir in which the steam is separated from the water; some of these boilers have a shell of considerable size, thus securing a store of hot water and a good free-water surface for disengagement of steam. Such shell, drum, or reservoir is either kept away from the fire or is reached only by gases that have already passed over the surface of water-tubes.

The tubes are of moderate or small diameter, and so can be abundantly strong even when made of thin metal. Even if a tube fails through defect in manufacture or through wasting during service, it will not cause a true explosion; and yet the failure of a tube in a confined boiler or fire-room has frequently caused death by scalding.

Water-tube boilers may be made light, powerful, and compact, and are well adapted for use with forced draught. Steam may be raised rapidly from cold water, but pressure falls as rapidly if the fire loses intensity, and fluctuations in pressure are likely to occur. The two greatest difficulties are to secure a proper circulation of water through the tubes and to properly separate the steam from the water. There are many joints that may give trouble by leaking, and some types have numerous hand-holes for cleaning the tubes, which may further increase the chances of petty leaks.

A few water-tube boilers will be described as illustrations; many others equally good will be passed by, since it will be impossible to describe all.

Babcock and Wilcox Boiler.—This boiler, which is shown by Figs. 16 and 17, is a water-tube boiler having a cylindrical shell to furnish steam-space, and in which is the free-water surface for the disengagement of steam. The tubes are expanded into vertical headers at each end; the front-end headers open into a cross-connection in communication with the cylindrical shell, while the back-end headers are connected with a similar cross-connection by slightly inclined pipes. The tubes in each section are staggered so that the tubes taken as a whole are in horizontal rows, but not in vertical rows—an arrangement that gives a better spreading of the products of combustion among the tubes. At each end of each tube are hand-holes that give access to the inside of .

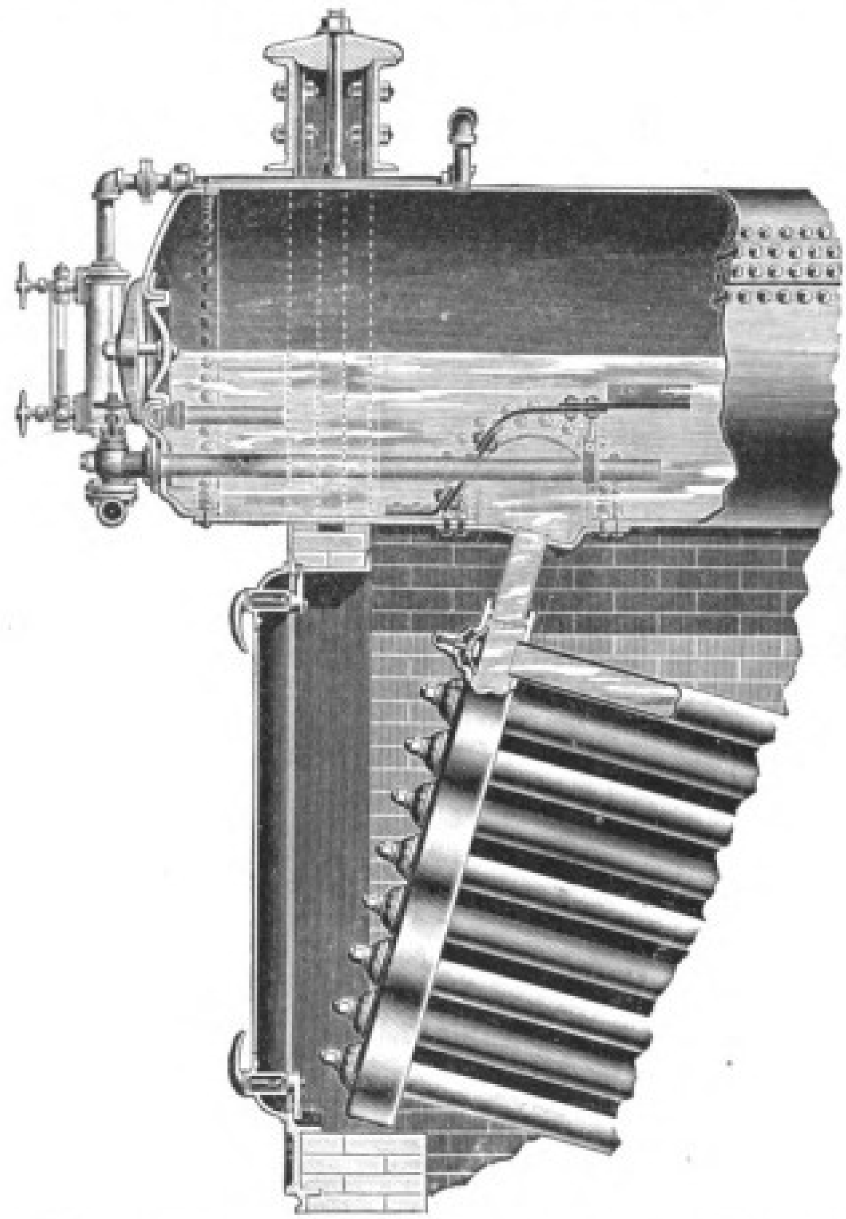


FIG. 16.

the tube when it needs cleaning or scaling. By the aid of a brick bridge-wall at the end of the furnace and a continuation of this wall formed of special tiles through the tubes, tog-ther

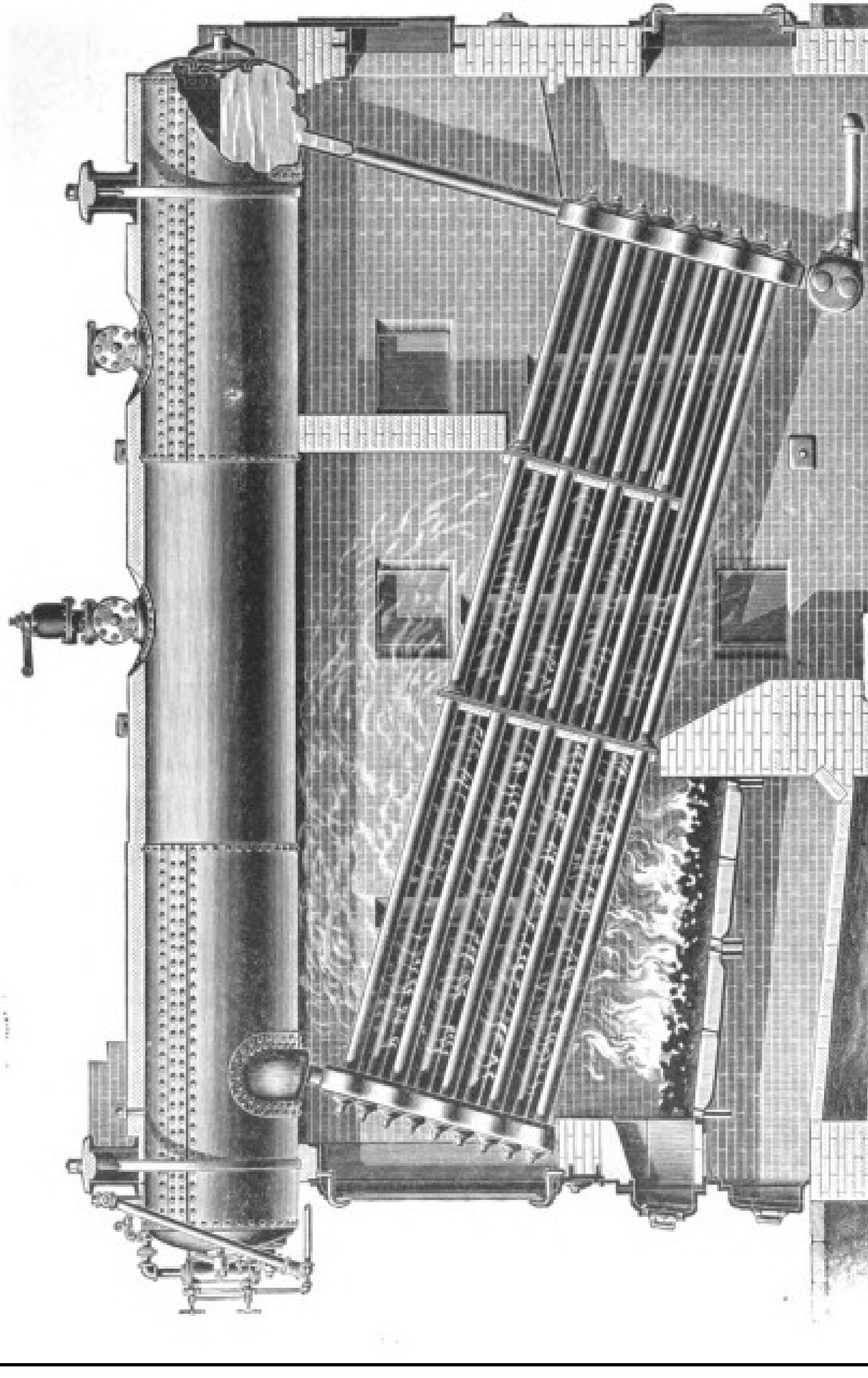


FIG. 17.

with a hanging bridge-wall similarly continued through the tubes, the products of combustion pass over the tubes three times on the way to the uptake at the back end of the boiler. The lower half of the cylindrical shell serves as heating-surface, but it is at such a height above the fire and is so shielded by the water-tubes that it is not liable to be overheated. The boiler is hung from cross-girders front and back, which in turn are supported on iron columns, and the brick setting is only a screen to retain the heat.

The circulation of the water in the boiler is down from the shell at the rear to the water-tubes, forward and upward through the tubes, in which course it is partially vaporized and consequently has a less average density, then up into the shell, at the front where the steam and water separate; the water in the shell flows continually from the front to the rear to supply the current through the tubes.

The Heine Boiler, shown by Fig. 42, page 106, resembles the Babcock and Wilcox boiler in general arrangement, but differs in that the tubes are expanded into one large header at each end, made of plate, properly stayed and provided with hand-holes. Again, the gases from the fire are constrained to pass along the tubes instead of across them, for which purpose there are floors or nearly horizontal bridges of tiles, laid on two or three layers of tubes, instead of the nearly vertical bridges of tiles used in the Babcock and Wilcox boiler.

The Root Boiler.—The general appearance of the Root boiler is shown by Fig. 18, and details of construction are shown by Fig. 19. Pairs of tubes are first expanded into headers at the end, as shown by 1, Fig. 19; then several pairs are assembled, as shown by 2, to form a vertical *section*, by the aid of bends, of which 3 gives further details. The joints between the bends and headers are made tight by aid of a metallic packing-ring shown by 4. The conical bearing on the bend shown by 5 expands the ring into a recess in the header, shown by 6, thus making a steam-tight joint. Each

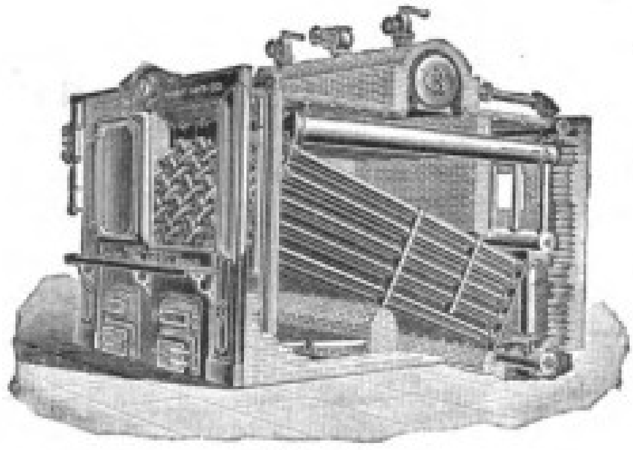


FIG. 18.

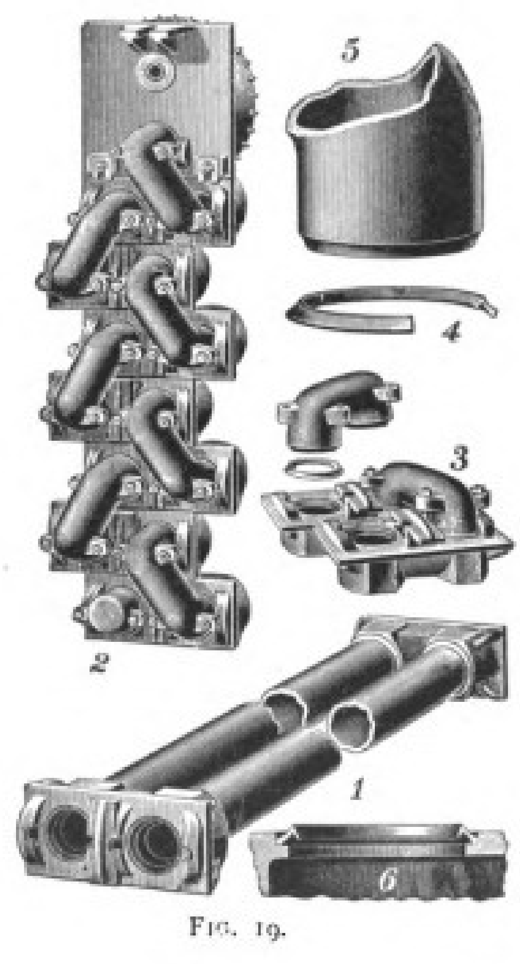


FIG. 19.

section has a steam-drum at the top, as shown in Fig. 18, and at the back end of the steam-drum are pipes leading up into the transverse steam-drum, and downward into a transverse water-pipe at mid-height of the boiler. Near each end of the mid-height water-pipe are vertical pipes communicating with the ends of a transverse mud drum, from which a series of pipes lead to the sections of the boiler. The water circulation is down from the back ends to the mud-drums, then forward through the tubes to the front ends of the steam-drums, in which the steam and water separate, the steam passing into the transverse steam-drum, and the water returning through the back connections to the sections. The products of combustion pass over the tubes three times before escaping to the chimney.

The Stirling Boiler.—This boiler, shown by Fig. 20, has three cylindrical drums at the top and a larger drum at the bottom, connected by tubes having a slight curvature at the ends. The two forward drums at the top have also a connection below the water-line through pipes not indicated. All three upper drums have their steam-spaces connected by piping. The water-line is indicated by a dotted line.

The feed-water is introduced into the rear upper drum, from which it passes down through the rear system of pipes, which act mainly as a feed-water heater, and enter the lower drum, where the water deposits any lime compound that it may contain, from whence it may be blown out at intervals. Fire-brick bridges cause the products of combustion to pass in succession through the three systems of water-tubes as shown by the arrows.

The Cahall Boiler is a vertical water-tube boiler, shown by Fig. 21. It has an annular drum at the top and a cylindrical drum at the bottom, connected by tubes and also by two large circulating pipes outside of the brick setting, one of which is drawn in the figure. The fire is in a brick furnace at one side of the boiler, from which the products of combustion pass back and forth across the tubes to and from the central space between the tubes. For this purpose there are two iron baffle-plates in the central space, as indicated in the figure.

The water-line is carried at about one third the height of the upper drum, and steam is drawn from a nozzle at the top.

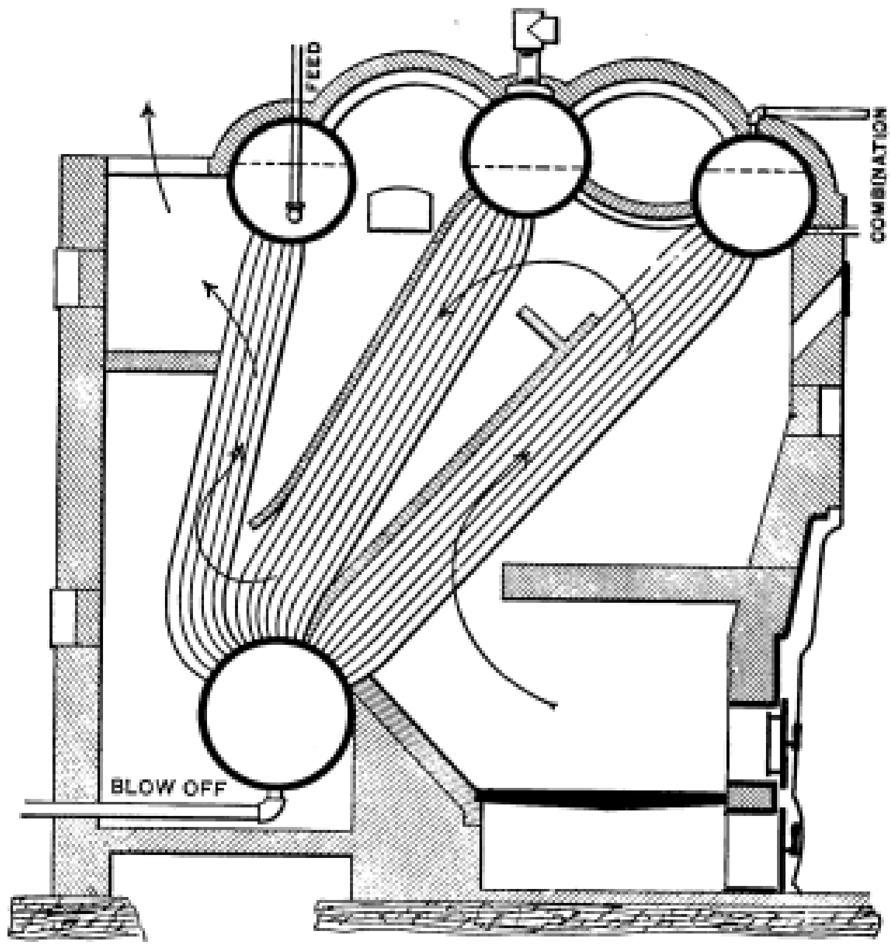


FIG. 20.

The circulation is down the large exterior pipes to the lower drum, and then up the water-tubes to the upper drum. Manholes give access to both drums, and in addition there are eight hand-holes in the top of the upper drum, so that any tube may be cut out and replaced without disturbing the others.

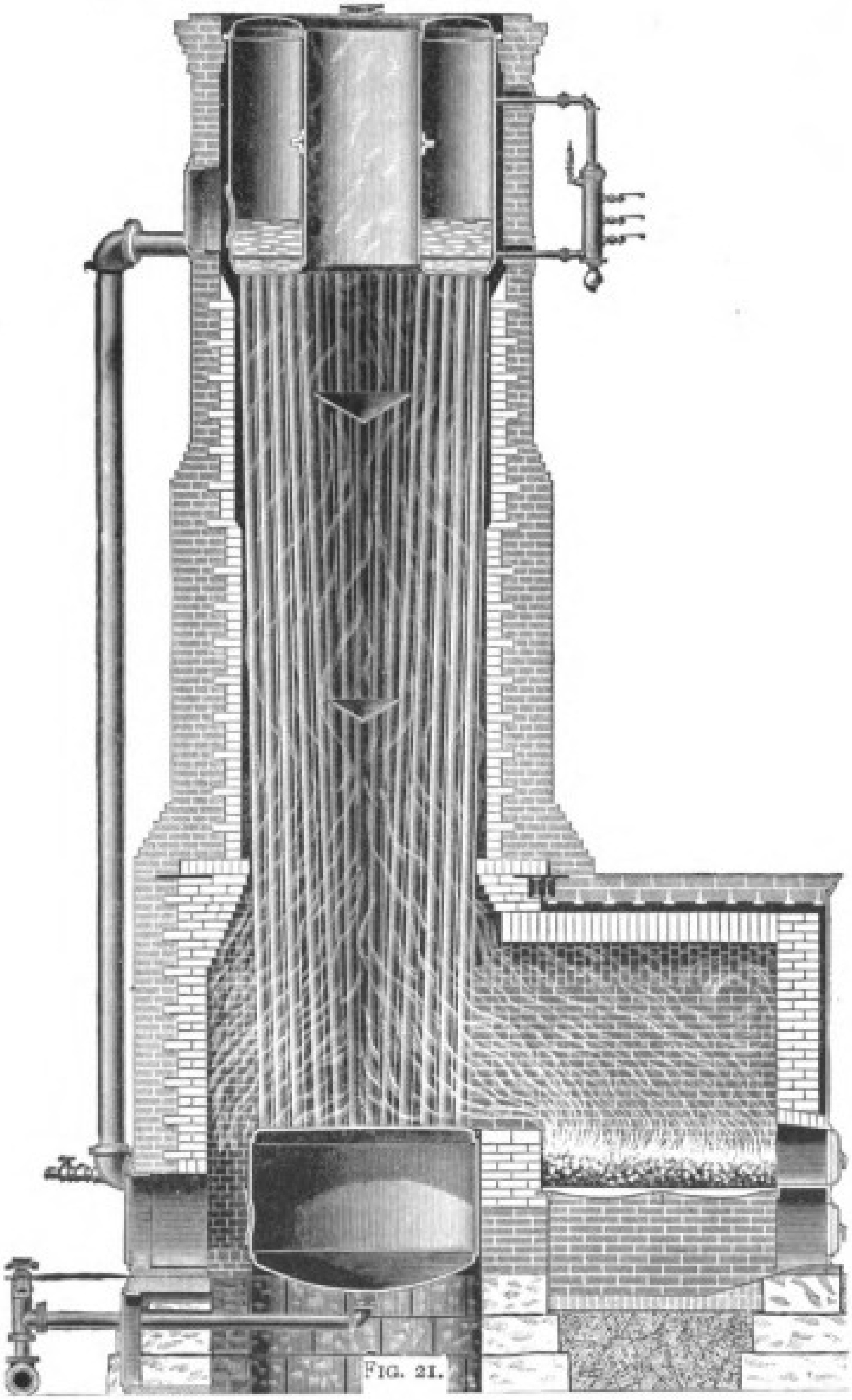


FIG. 21.

Water-tube Marine Boilers.—With the advent of very high steam-pressures on steamships there has been a tendency to replace the Scotch boiler by some form of water-tube boiler. A large number of French merchant steamers and a few French naval vessels have been fitted with Belleville boilers, a type of water-tube boilers that had already found favor for stationary purposes. This type of boiler has also been used to some extent on the Great Lakes. Recently this boiler has been largely introduced in the English Navy. Other water-tube boilers, either designed specially for marine boilers or modified from land boilers, have been used to some extent. In the United States Navy some vessels have been fitted with both shell-boilers and water-tube boilers; the former are intended for use in ordinary service, and the latter when running at high speed.

The objects that are sought in water-tube boilers for steamships are a larger power for the weight and the ability to carry high pressures. It still remains a question whether the water-tube boiler will or can replace the Scotch boiler for ordinary service on steamships. Indeed, it is a question whether there is any real profit in carrying steam at very high pressure.

The Belleville Boiler is represented by Fig. 22; it consists essentially of a series of coils of pipe made up with bends and elbows around which the products of combustion pass on the way to the chimney. At the top there is a steam-drum *A*, connected by two circulating-pipes *B* and *C*, with a drum *D* at the bottom. From the mud-drum *D* a rectangular feed-supply runs across the front of the boiler to all the coils or elements of the boiler. Each element is continuous from the feed-supply to the steam-drum, and is made up of slightly inclined pieces of pipe with horizontal bends or connections at the end. The effect is much as though a helical coil were flattened into two vertical tiers of pipes. The amount of water in the boiler is so small that it cannot be run without

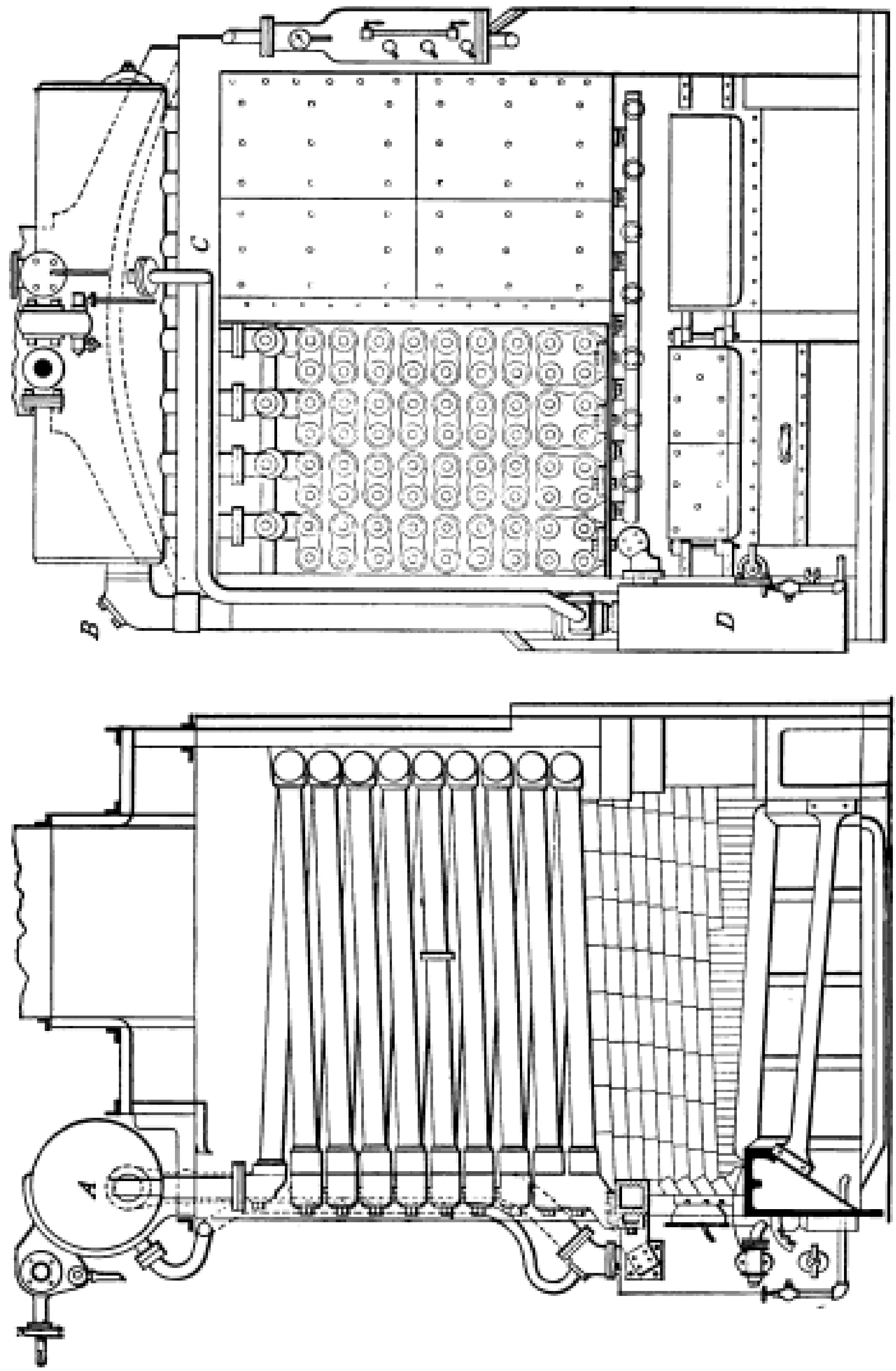


FIG. 22.

an automatic feed-water regulator, which in turn requires the attention of an expert feed-water tender. The several elements deliver a mixture of water and steam to the steam-drum, which does not appear to act efficiently as a separator. as an external separator is placed between the boiler and the engine. The feed-water is supplied to the steam-drum and passes through the external circulating-pipes to the mud-drum, where it deposits much of its impurities.

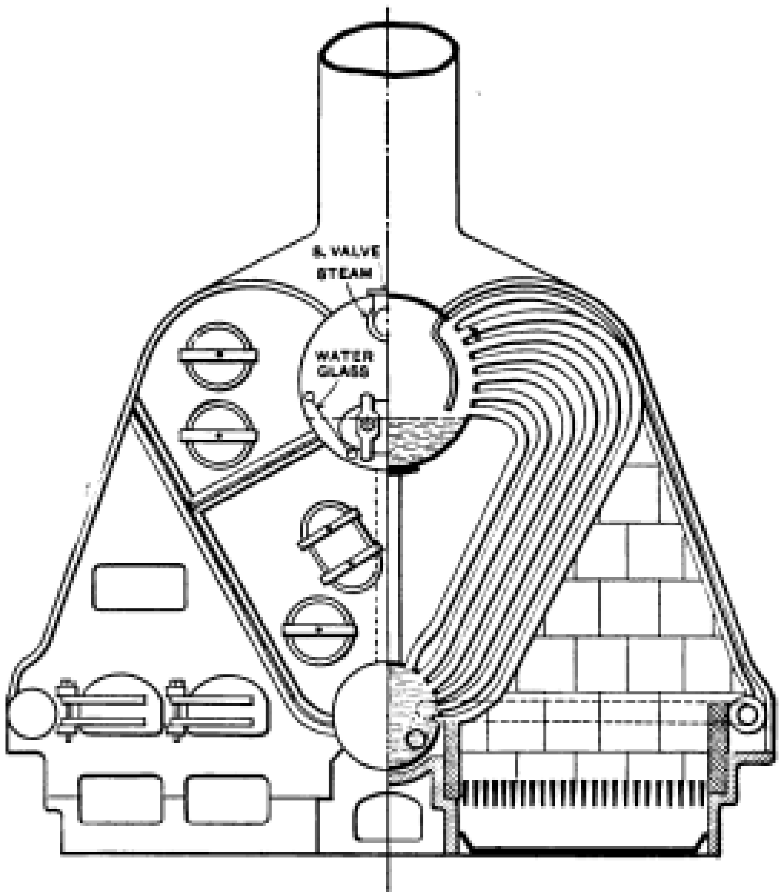


FIG. 23.

Thornycroft Boiler.—The boiler represented by Figs. 23 and 24 was built for the torpedo-boat destroyer, "Daring," by Mr. Thornycroft; boilers of slightly different forms have been fitted by him, in torpedo-boats and steam-launches.

The boiler consists essentially of a large drum or separator at the top and three drums at the bottom, connected by a large number of bent-tubes. There is, inside of the casing, a large tube connecting the top drum to the middle drum at the bottom, and this drum is connected to the side drums by smaller pipes. The circulation is down from the top drum to the middle lower drum, and from that to the side drums, then up through all the bent water-tubes to the upper drum, where mingled water and steam is delivered

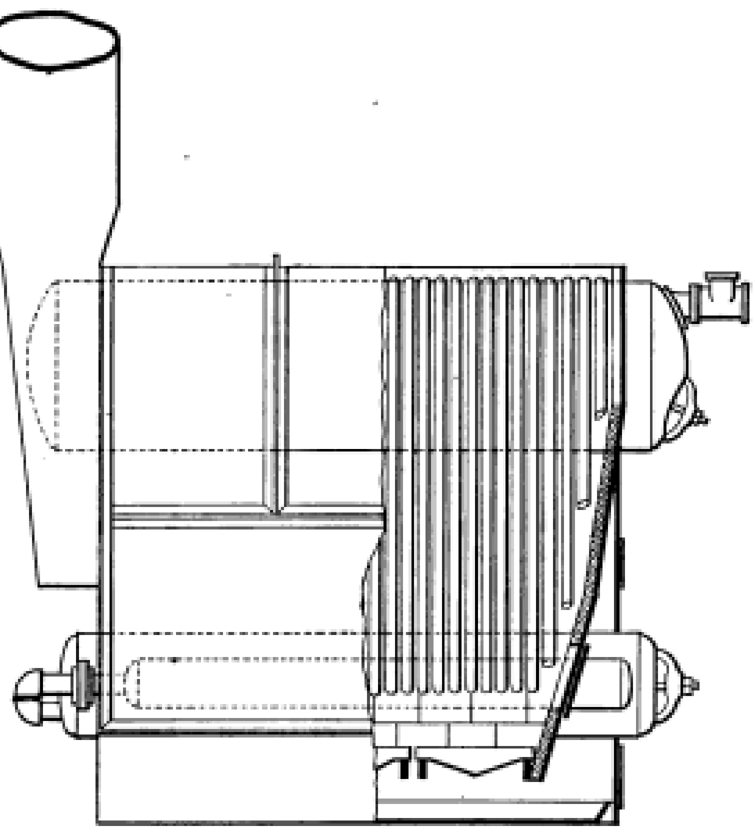


FIG. 24.

against a baffle-plate above the water-line. Steam is drawn from a nozzle at the rear end of the top drum.

The arrangement of grates and fire-doors is shown in elevation and section by Fig. 23. The middle drum divides the grate into two parts; over that drum is a space which is in communication with the uptake, as shown by Fig. 24. The products of combustion pass among the tubes leading from the middle drum; the tubes to the outer drums intercept the radiant heat which would otherwise strike on the boiler-casing.

The boiler-setting is an iron frame, and the casing is thin plate iron lined with incombustible non-conducting material. There are numerous doors through the casing for cleaning the tubes.

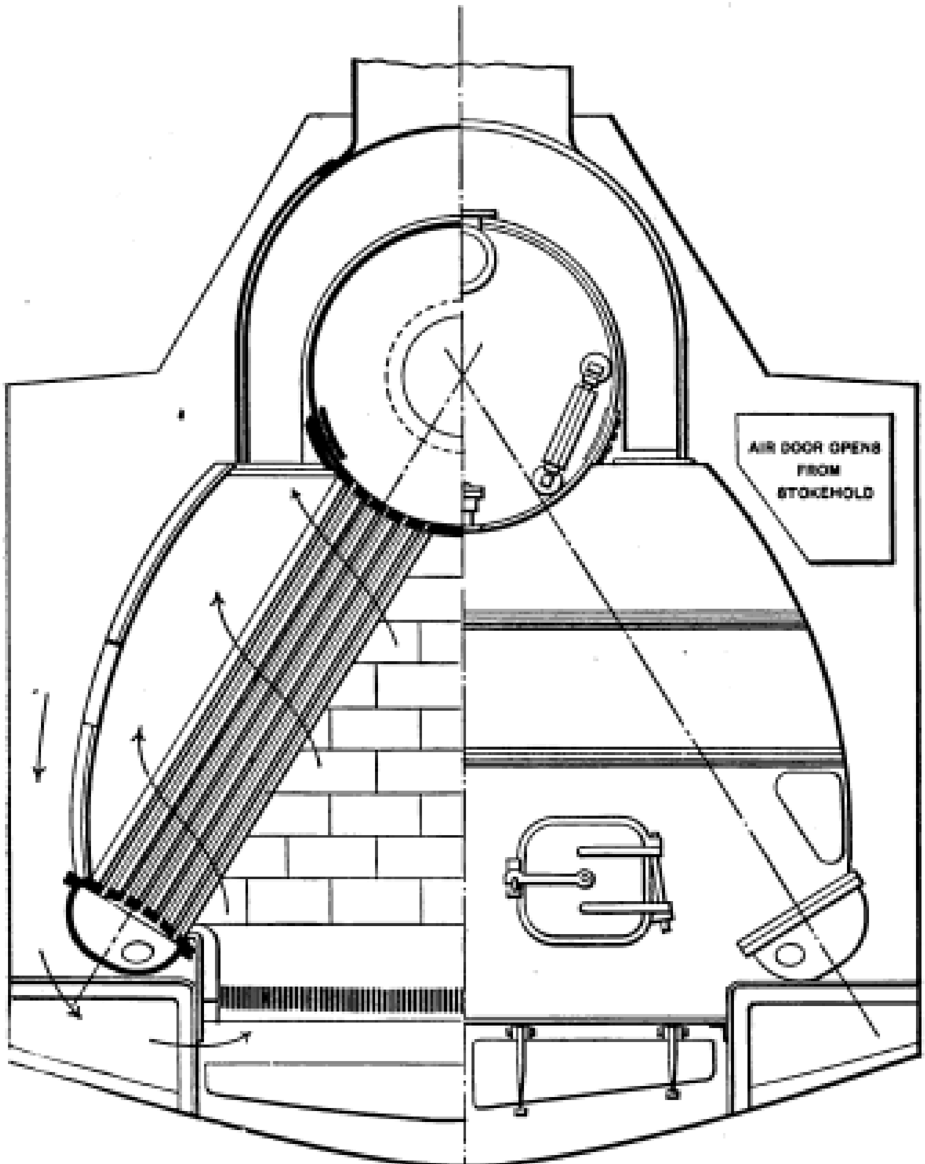
This boiler has proved very successful with a forced draught, making steam freely and giving little trouble. The boiler contains so small an amount of water that steam may be raised quickly, and any demand for steam can be quickly met. On the other hand, the feed-supply must be regulated with care and skill, and the pressure is liable to fluctuate.

The Yarrow Boiler.—The form of boiler used by Mr. Yarrow for torpedo-boats, is shown by Fig. 25. It resembles in general arrangement a form used by Mr. Thornycroft with one grate. It, however, differs radically in certain particulars, namely, in that the tubes are straight and that they enter the upper drum below the water-line, and in that there are no pipes outside the casing to carry water from the upper drum to the lower drum or reservoirs. Some of the tubes deliver water and steam to the upper drum, from which steam is drawn; other tubes carry water from the upper drum to the lower drums. A given tube may act sometimes in one way and sometimes in the other. Naturally those tubes which receive the most heat and make the most steam deliver to the upper drum, and tubes that receive less heat carry down water.

The air for the fire is drawn from an iron box or casing outside the boiler-casing, so that the heat escaping from the boiler-casing is largely carried back to the fire, and the fire-room, and also the rest of the vessel, is heated up less.

The Almy Boiler.—This boiler, which is represented by

Fig. 26, is made of short lengths of pipe screwed into return-bends and into twin unions. At the bottom is a large tube or pipe forming three sides of a square at the sides and back



YARROW BOILER

FIG. 25.

of the grate. From this water-space the tubes lead into a similar structure at the top. The steam and water are discharged into a separator in front of the boiler, from which