Boiler, in steam engineering, a closed vessel for the generation of steam under pressure. In days when steam pressures did not exceed a few pounds to the square inch, many forms of boiler were used, that are now out of the question, on account of the intrinsic weakness of their forms. At the present time, when steam pressures are often carried as high as 150 or 250 pounds to the square inch, the strictest attention must be paid to every trifling detail of design and construction, in order to ensure the safety of the structure. The fanciful shapes that prevailed in the days of Watt and other early steam engineers have perforce disappeared, and given place to a limited number of standard types that have been found to be capable of withstanding the severe conditions of modern practice. The types at present in use may be divided into two general classes, according as they are "internally fired" or "externally fired"; that is, according as the fire which furnishes the energy for the formation of steam is contained within the general contour of the boiler, or is situated externally to it. Internally fired boilers are the rule in England, but a large majority of the boilers in use in the United States are fired externally.

Internally Fired Boilers – The Cornish and Lancashire boilers are the commonest internally fired types. Each consists of a cylindrical shell with flat ends or "heads." In the Cornish type the boiler is traversed

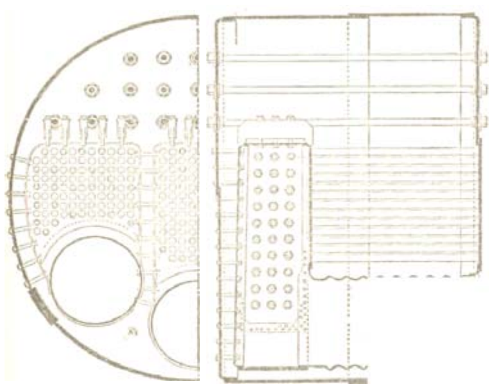


FIG. 1. The "Scotch" or Cylindrical, Marine Boiler.

from end to end by a large flue, which is often corrugated, to increase its strength. The fire is built within this flue, upon a suitable grate at one end of the boiler; and the gaseous products of combustion, after passing through the flue, are returned along the outside of the shell so as to give up still more of their heat to the water in the boiler. The large flue in the Cornish type is an element of weakness, since the tendency of a flue to collapse through the action of an external pressure increases very rapidly with the diameter of the flue. To guard against collapse, the long flue is often provided with strengthening rings, which are riveted to it externally at short intervals. The Lancashire boiler differs from the Cornish type chiefly in having two comparatively small flues in the place of a single large one. Such a construction is intrinsically stronger, and since there is a fire in each of the flues, the fuel can be replenished, and the fires cleaned, alternately. This implies a greater steadiness of pressure, and less strain upon the boiler from the chilling action of the comparatively cold air that enters and strikes against the heated flue-walls when the fire doors are opened. The Cornish boiler is cheaper to build, and the Lancashire boiler is harder to fire, owing to the smaller size of its flues. The Galloway boiler does not differ in any essential particular from the Cornish or Lancashire types, except that its flues are crossed by conical-shaped water tubes, which serve the double purpose of increasing the heating surface, and of stiffening the flues that they traverse. The conical shape is adopted for the cross-tubes chiefly on account of the ease with which tubes of this form can be put in position, by passing the flange of the smaller end through the opening to which the larger end is to be riveted.

The Scotch, or cylindrical marine boiler, shown in Fig. I, is a very common type in marine practice. It contains several furnaces (three in the illustration), which are usually corrugated. These furnace-flues do not pass through the entire length of the boiler, as in the Cornish and Lancashire types, but each is connected, within the boiler, to a separate "combustion chamber." The products of combustion pass from the furnace back into the combustion chamber, and then return to the front end of the boiler through banks of small tubes which occupy the water space of the boiler, above the furnace. A "breeching" (or hood) of sheet steel, secured to the front of the boiler, then receives them, and conducts them to the stack.

Among the kinds of internally fired boilers that are more familiar to the engineers of the United States, the vertical tubular boiler and the locomotive boiler deserve special mention. The vertical tubular boiler consists of a cylindrical shell, with flat heads at the top and bottom, and traversed by a large number of small vertical tubes. The Manning boiler, shown in Fig. 2, is a good example of this type. At the lower end, the shell of this boiler is enlarged to provide a greater space for the fire-box than could be had if the shell were of the same diameter all the way. Another object that the designer had in view, in increasing the diameter of the shell in this way, was to give the boiler a certain degree of elasticity. The tubes are often hotter, in service, than the outer shell; and hence they tend to expand more, and thus throw stresses upon the heads and the tube ends. The reversed flange by which the main shell is secured to the fire-box is supposed to yield sufficiently, under the bending stress thus thrown upon it, to relieve the more vulnerable parts of the boiler from the expansion strains to which they would otherwise be subjected. The fire-box of the Manning boiler is surrounded by an annular space containing water, the inner plates of this space (or "water leg") being secured to the outer ones by screw stay bolts that are spaced evenly, at short distances, so that they form the corners of a system of small squares. These bolts are supposed to be screwed into each of the shells of the water leg, and afterward riveted over at both ends. They are also commonly made hollow, or drilled through lengthwise with a small hole, so that if one of them should break or corrode away seriously, the escaping steam or water would attract the attention of the fireman. Vertical tubular boilers are particularly useful when the available floor space in the boiler

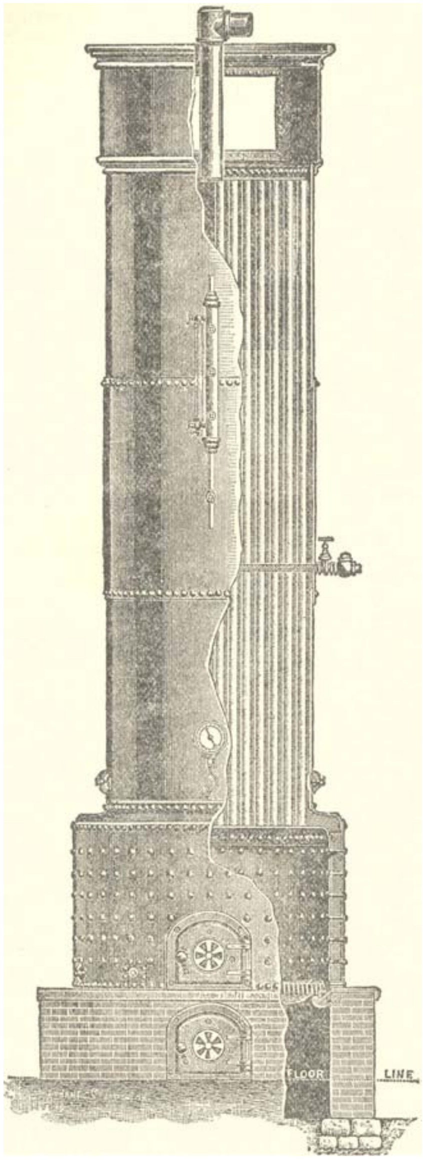


FIG. 2. The Manning Boiler.

room is small; but they are often hard to clean out, and hence are not to be recommended when the water supply is known to form considerable deposits of scale matter. Such scale matter, in whatever part of the boiler it is formed, will eventually fall upon the lower tube sheet, or else into the water leg. That which falls into the water leg will do no great harm unless it is allowed to accumulate to an unreasonable extent. Handholes are provided along the bottom of the water leg, on the outer shell, and these should be opened as often as experience with the particular feed water that is used indicates to be necessary, and the water leg thoroughly freed from scale and mud. Handholes should also be provided on the same level as the lower tube sheet, for a like purpose; but it is not so easy to remove the scale from this sheet as it is to remove it from the water leg. That which lodges around the edges of the tube sheet can be removed without any great trouble, but the deposit that lies toward the middle of the tubes can hardly be got at from the handholes. Yet it is of the highest importance that the tube sheet should be kept free from such deposits, because otherwise the ends of the tubes will become overheated and loosened, and serious mischief, or even disastrous explosion, may follow.

The locomotive boiler is built in a great variety of forms and proportions, but the fundamental principles of design are substantially the same in most of them. Like the vertical tubular boiler, it has a fire-box that is surrounded by a water leg on all sides, though it is open at the bottom for the discharge of ashes, and for the admission of air for combustion. The inner and outer walls of the fire box are connected by stay-bolts, and the upper sheet of the furnace (technically known as the "crownsheet" is supported in some efficient manner, so that the pressure of the steam shall not force it down out of position. The support thus necessary for the crown-sheet is sometimes afforded by running "sling stays" from it to the neighboring parts of the outer shell, and sometimes by providing parallel, horizontal girders over the sheet, these being secured to the crownsheet, at short intervals, by means of hangers, or long, thimbled rivets. Not infrequently these two methods of support are combined in the same boiler, as suggested in the illustration (Fig. 3). The products of combustion pass forward from the furnace, through a bank of small tubes that conduct them to a "smoke box" or "extension" at the front end, to which the stack is attached. When the locomotive type of boiler is used in stationary practice, the draft required for combustion is provided by a chimney or tall stack, as in other types of stationary boiler; but when used in railway service it is impossible to obtain the draft in this manner, and a "blast-pipe" is therefore provided, through which the exhaust steam from the engine cylinders is discharged up the stack. The gaseous products of combustion are expelled from the "front extension" by the blast of steam, and an equivalent quantity of air is drawn up through the fire. The draft produced in this way is quite powerful. "Baffle plates" are therefore provided in the furnace, in many cases, to deflect the hot gases that come from the fire, and bring them into contact with a considerable portion of the surface of the fire-box, before they pass out into the tubes. The weakest points about the locomotive type of boiler are the crown-sheet and the staybolting. If sediment lodges upon the crown-sheet, and thereby keeps the water from direct contact with the metal there, overheating is sure to occur, and the sheet may become so softened and burned as to lose its strength, tear away from its fastenings, and permit the entire contents of the boiler to be discharged into the furnace. Many of the explosions of locomotive boilers are due to this action. The stay-bolting at the sides of the fire-box is likewise a source of frequent trouble, because it is found that the stay-bolts sometimes corrode away very rapidly, so that they are in reality badly wasted and weakened, when the engineer in charge believes them to be still sound and strong. As in the vertical boiler, the stay-bolts are made hollow so that they may automatically give notice of breakage by leaking. This artifice is helpful, but unfortunately it does not invariably work as it is intended to, and broken or badly corroded stay-bolts exist, not infrequently, without giving the alarm that they are supposed to give.

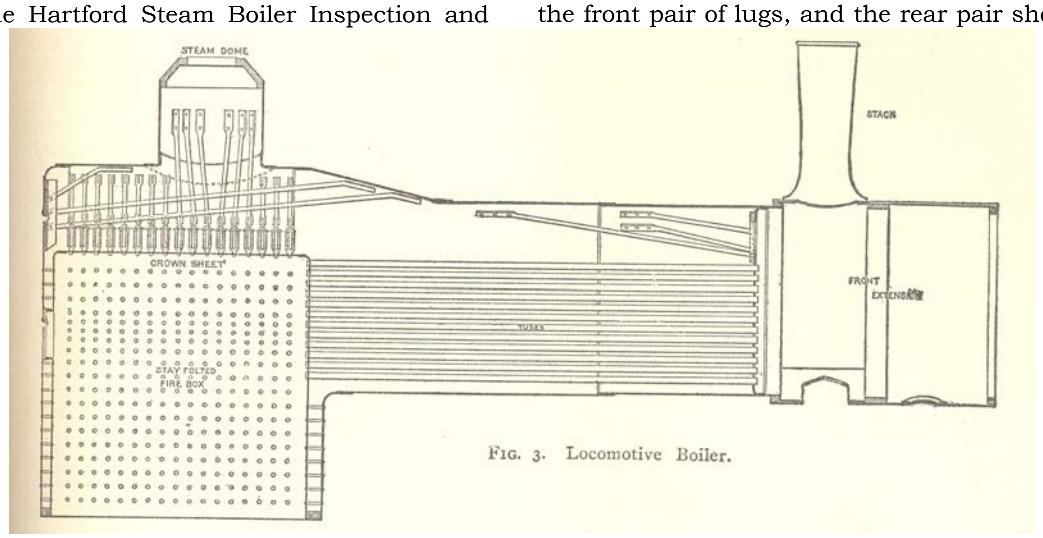


FIG. 3. Locomotive Boiler.

FIG. 3. Locomotive Boiler

Externally Fired Boilers. – The commonest type of externally fired boiler, in the United States, is the horizontal tubular. The standard design of this boiler, according to the Hartford Steam Boiler Inspection and Insurance Company, is shown, with its brickwork (or "setting") partially torn away, in Fig. 4. It consists of a cylindrical shell, usually composed of three courses or "rings" of plates, riveted together. The circular joints in these boilers are almost invariably single-riveted; but the longitudinal joints are double-riveted, triple-riveted, or riveted in some even more substantial manner, according to the pressure that the boiler is to carry.

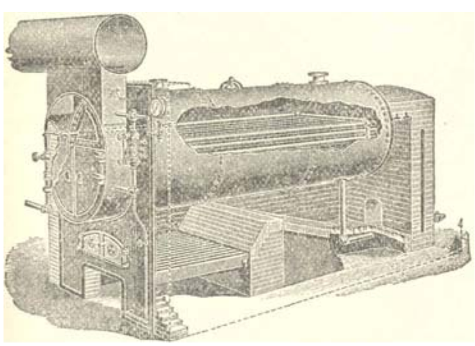


FIG. 4 Horizontal Tubular Boiler

The longitudinal joints, which are not shown in the engraving, should be high enough to be well out of the way of the hot gases from the furnace. A multitude of tubes extend through the boiler from end to end, and the furnace gases pass from the furnace back underneath the boiler shell to the "combustion chamber" at the rear, after which they rise and return to the front end through the tubes. They then enter the "smoke box" at the front end, and finally pass upward into the flue that leads to the chimney. The weight of the boiler is sustained by means of cast-iron (or steel) projections, or "lugs," that are not shown in the illustration, but which are riveted to the shell, and rest upon the side walls of the brick setting. Three pairs of lugs are often provided, but two pairs are sufficient except when the boiler is very long; and two pairs can be brought to a good bearing upon the side walls more readily than three. The boiler should be "anchored" by the front pair of lugs, and the rear pair should be provided with rollers so that the boiler may expand and contract freely, without producing strains in the setting or in itself. The course of the feed-pipe, through which water is introduced into the boiler, is indicated quite plainly in the engraving. If there are several boilers set together in one battery, the main feed-pipe runs along the fronts, just under the projecting ends of the boilers. From this main feed-pipe a branch pipe is taken off for each boiler. The branch pipe is taken off on the left-hand side of the boiler, and near the main pipe it is provided with a ground union, or with a flanged connection. Immediately above the union there is a check valve and above this is the globe valve which controls the feed. The feed pipe enters the boiler just above the tubes, and passes down the boiler on the inside, nearly to the back head. It then crosses over to the right-hand side and discharges downward between the tubes and the shell. It is found by experience that when feed water is introduced in this way it becomes heated almost to the temperature of the water in the boiler before it is discharged so that the annoying and often dangerous effects that are produced when the shell is chilled by cooler feed-water are entirely avoided. On large boilers the feed-pipe should have a diameter of at least an inch and a half. The blow-off pipe (which is used for drawing off the contents of the boiler) should be located at the rear end, and should enter the boiler at the bottom, and not through the back head. To strengthen the construction, the shell should be reinforced where the blow-off enters it, by a ring of boiler plate securely riveted in place, about the point of attachment of the blow-off. The neglect of this simple matter of reinforcement has led to many serious accidents, through the blow-off pipe pulling out and permitting the contents of the boiler to be discharged through the opening so made. As the blow-off is exposed to the action of the fire, it is also important that it should be encased in some sort of a protecting sleeve, as indicated by the dotted lines. A piece of larger pipe, slipped over the blow-off, is often used for this purpose, but it has the disadvantage of rendering the blow-off itself inaccessible for examination. A piece of asbestos rope coiled about the pipe is equally satisfactory, and permits of easy inspection of the pipe. The blow-off pipe of a boiler that is properly cared for is not likely to burn nor to become otherwise injured. Most of the accidents from the burning of such pipes have been primarily due to permitting the pipes to become choked up with mud or scale, so that water could not enter them freely from the boiler, to keep them properly cool. This may be almost certainly avoided by opening the blow-off (say) twice a day for a moment or two, until any sediment that may have fallen into it has been thoroughly swept out. The blow-off pipe is often so arranged that the elbow comes in the combustion chamber; but this is not good practice, and it is much better to carry the pipe down until it passes below the floor of this chamber. The pipe itself should be about two inches in diameter. It should be provided with a plug cock or with a gate valve, but a globe valve should never be used upon it, since valves of this type do not have a straight passage through them, and are therefore likely to catch and retain pieces of scale, which often prove to be very troublesome impediments. It should be mentioned that those parts of the heads of a horizontal tubular boiler that lie above the tubes are intrinsically weak, and must therefore be sustained in some manner. The necessary support is usually secured by running braces from the heads to the side of the boiler shell, though sometimes the braces are run through the entire length of the boiler, from one end to the other.

The horizontal tubular boiler has many excellent points, not the least of which is that it is accessible for examination and cleaning in practically every part. No boiler can be expected to work ideally when the feed water is bad, but the horizontal tubular type gives as good service, even under this trying condition, as can be had from any known type. Its weak points are (1) that it is not so well adapted to extremely high pressures as some of the water-tube types, of which one will be presently noticed; and (2) when it ruptures (as must happen occasionally with every type of boiler) the explosion is likely to be considerably more destructive than the explosion of a sectional boiler, because the large quantity of energy that it contains is liberated more suddenly.

Another class of externally fired boilers that is becoming more and more widely used, both in the United States and Europe, is the "watertube" type, which is characterized by the fact that its tubular elements contain water, instead of serving for the transmission of the furnace gases, as in all the other forms that have been considered above. One of the best-known

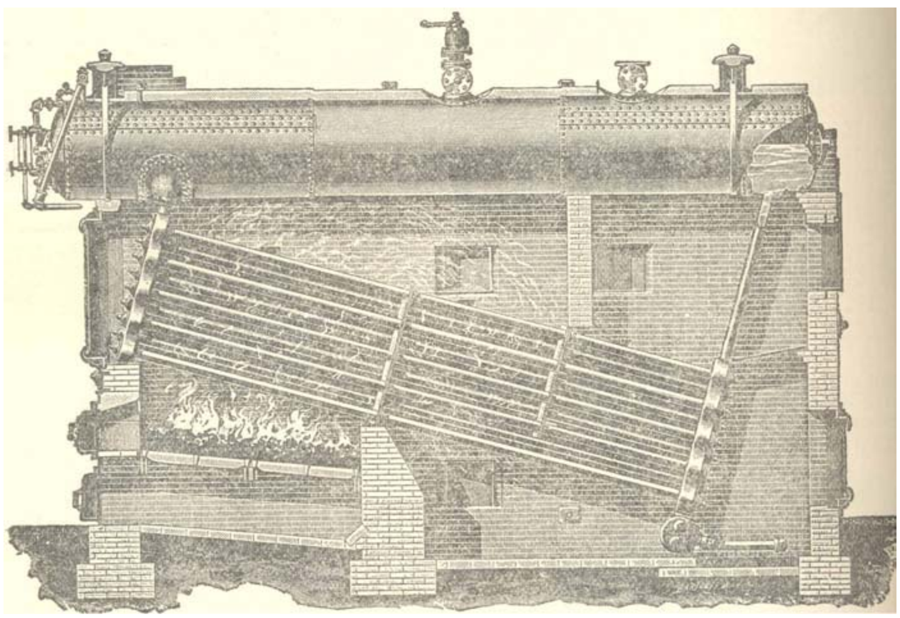
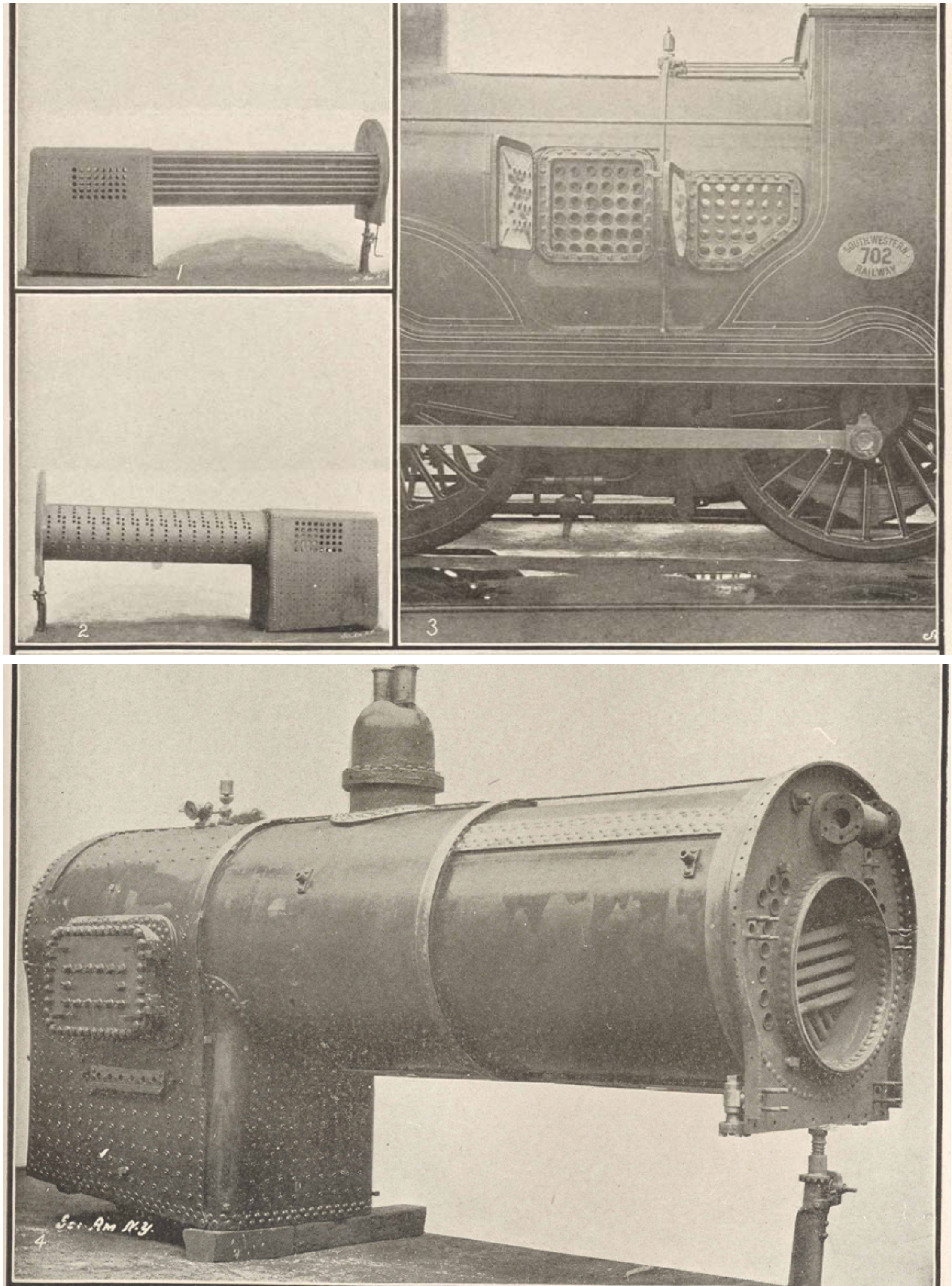


FIG. 5. The Babcox and Wilcox Water Tube Boiler.



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AN ENGLISH WATER-TUBE LOCOMOTIVE BOILER.
1 View Showing Auxiliary Fire-Tubes for stiffening Front End of Fire-box. 2 The Fire-box and Water-Tube Flue
3 Side Doors Open, Showing Cross Water Tubes in Fire-box 4 Complete Boiler, showing Side Door To Fire-box and Front End of Flue with Cross Water-Tubes

boilers of this class is the Babcock and Wilcox, which is shown in Fig. 5. This boiler is built up of lap-welded wrought-iron tubes, placed in an inclined position, and attached, both at the front and at the rear, to an upper drum that is made of extra thick steel or from plates, and double-riveted, or riveted with a buttstrapped joint. The tubes are not vertically over one another, but are "staggered," so that each tube comes directly over a space in the row below it. The boiler is suspended from wrought-iron girders, which rest upon iron columns that are entirely independent of the brickwork; and hence the brickwork may be repaired, or may even be removed altogether, without disturbing the boiler itself. The fire is situated under the front or higher end of the inclined tubes, and the products of combustion are guided by division plates and bridges so that after rising from the fire grate they pass between the tubes to the combustion chamber under the drum, then downward among the tubes again, and finally upward and to the chimney. This devious course, as well as the staggering of the tubes, is intended to bring the hot gases into intimate contact with the tubes at every point. As the water in the boiler becomes heated, it rises toward the higher end of the tubes, becoming meanwhile partially converted into steam. The column of mixed water and steam ascends into the drum, where its constituents separate, the steam remaining in the drum, while the water flows to the rear, where it passes down through the long, upright tubes, and so completes the circulation.

Water-tube boilers are now used to some extent in marine work, and especially in the naval service. Attention has been particularly directed to this branch of the subject by the recent elaborate investigations of the Commission appointed by the British Admiralty, for the purpose of recommending a standard type of boiler for use in the British navy. (See 'Engineering News,' 4 Sept. 1902, page 176.) The Belleville boiler, which has heretofore been somewhat extensively used in that service, is represented, diagrammatically, on plate. It consists essentially of a series of water-tubes, slightly inclined to the horizontal, and opening at the bottom into malleable iron collector boxes, and at the top into a drum to which the main steam pipe is attached. The feed water is introduced at the middle of the upper drum, and is injected under a pressure in excess of that which is carried upon the boiler itself. To prevent the comparatively cool feed water from entering any of the tubes in which steam is generated, these tubes are caused to project at least eight inches into the drum. The feed passes down through return pipes at the sides of the boiler, and enters the tubes below, after its temperature has been raised by the heat of the furnace sufficiently to prevent injury from contraction strains. The proper regulation of the feed-water supply is one of the difficult practical points about the Belleville boiler; and to overcome it as far as possible an ingenious automatic feed device is provided. As will be understood from an inspection of the engraving, there is little or no true circulation in boilers of this type. The tube-groups discharge a mixture of steam and water into the drum, where the steam is supposed to be freed from the water by the aid of a system of baffle plates that are not shown. An economizer is placed in the stack above the boiler in the most approved modern installations, the construction of the economizer being similar to that of the boiler itself, except that the tubes composing the elements are smaller. The Commission already referred to reported somewhat unfavorably upon the Belleville boiler, but did not suggest any other special type of water-tube boiler for general use aboard ship. It inclined rather toward cylindrical boilers for ordinary purposes, with auxiliary water-tube boilers for emergencies.

All boilers are supposed to be provided with certain appliances intended to secure safety, and uniformity of working. Noteworthy among these are the safety valve, and the gauges that indicate the pressure of the steam and the position of the water level. These are described under separate headings.

The "horse-power" of a boiler is often spoken of; but the term is a loose one, without any definite significance, because the horse-power that can be realized from a boiler depends to a very great extent upon the engine that is used to develop the power, and upon bow hard the boiler is forced. The Centennial Commission adopted, as the definition of a horse-power (when that expression is used in connection with a boiler), the "evaporation of 30 pounds of water per hour, when the temperature of the feed water is 100° F., and the pressure of the steam is 70 pounds per square inch, as read from the gauge."

Steam boilers may explode from anyone of a great variety of causes. Of these three are specially worthy of mention: (1) The boiler may be poorly made or poorly designed, so that even when it is new it is not capable of safely withstanding the load that is put upon it. All boilers, however well made, should have a "factor of safety" of five; that is, they should be able to sustain a pressure five times as great as the regular working pressure, before bursting. (2) A boiler, originally good, may be wasted away, either locally or generally, by corrosion or other form of deterioration, or it may develop defects in service, which detract from its original strength sufficiently to lead to explosive failure. Competent periodical inspection will materially lessen the liability to explosion from causes of this sort. (3) The water in the boiler may become low, through neglect or through the failure of the feed-apparatus, so that the metal becomes overheated or burned, and loses its strength. This is the cause almost invariably assigned, by the general public and even by minor "experts," when the boiler explosion occurs, and the attendant is frequently censured for his carelessness when the explosion was really due to some totally different cause. When an explosion is attended by great manifestations of force and energy, it is safe to conclude that a plentiful supply of water was present; for a boiler full of heated water contains vastly more energy than one that is merely filled with steam at the same temperature. (See Thurston, 'Steam Boiler Explosions.')

Pound for pound, steam contains more energy than water, when the two are at the same temperature; but cubic foot for cubic foot (and this is the way that the comparison should be made in reasoning about a boiler explosion), the water has an enormous advantage, owing to its greater density. For further details concerning boilers, consult F. R. Hutton, 'The Mechanical Engineering of Power Plants' ; J. G. A. Meyer, 'Modem Locomotive Construction'; Peabody and Miller, 'Notes on Steam Boilers'; R H. Thurston, 'A Manual of Steam Boilers.' and 'Steam Boiler Explosions'; William Kent, 'Steam Boiler Economy'; W. H. Shock, 'Steam Boilers'; Leslie S. Robertson, 'Water Tube Boilers' ; and W. H. Ford, 'Boiler Making.' See also the 1899 'Code' for boiler trials, in Vol. 20 of the 'Transactions of the American Society of Mechanical Engineers.'

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