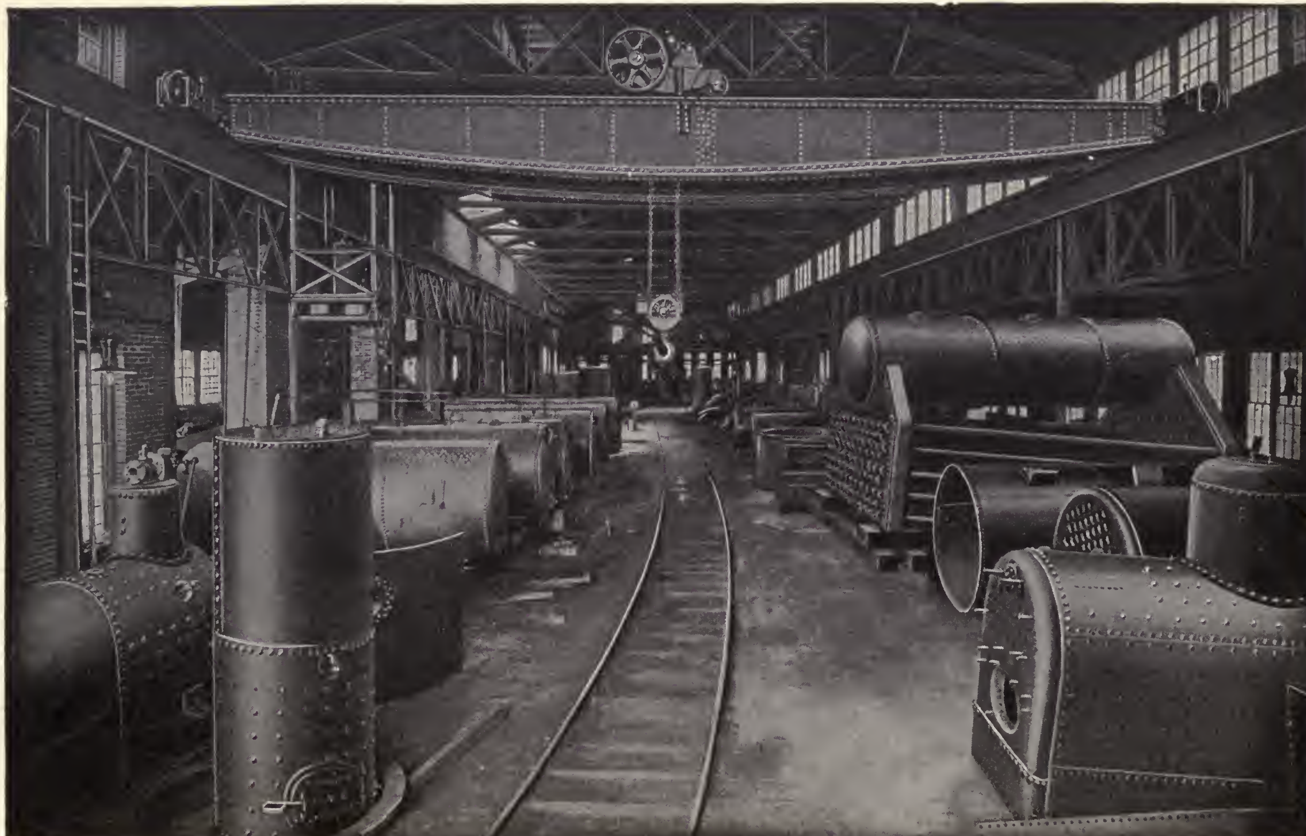

ERECTING SHOP.
E. Keeler Company.

Steam Boilers

A Practical Treatise

ON THE MATERIALS AND APPROVED METHODS OF CONSTRUCTION OF STEAM BOILERS, WITH COMPLETE INSTRUCTION IN THE MECHANICAL DETAILS OF THE PRINCIPAL COMMERCIAL TYPES OF STATIONARY, MARINE, AND LOCOMOTIVE BOILERS

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with B. F. Sturtevant Co., Boston, Mass.

PART I—CONSTRUCTION OF BOILERS
PART II—TYPES OF BOILERS

ILLUSTRATED

CHICAGO
AMERICAN SCHOOL OF CORRESPONDENCE
1909

Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

¶ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

¶ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the common understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

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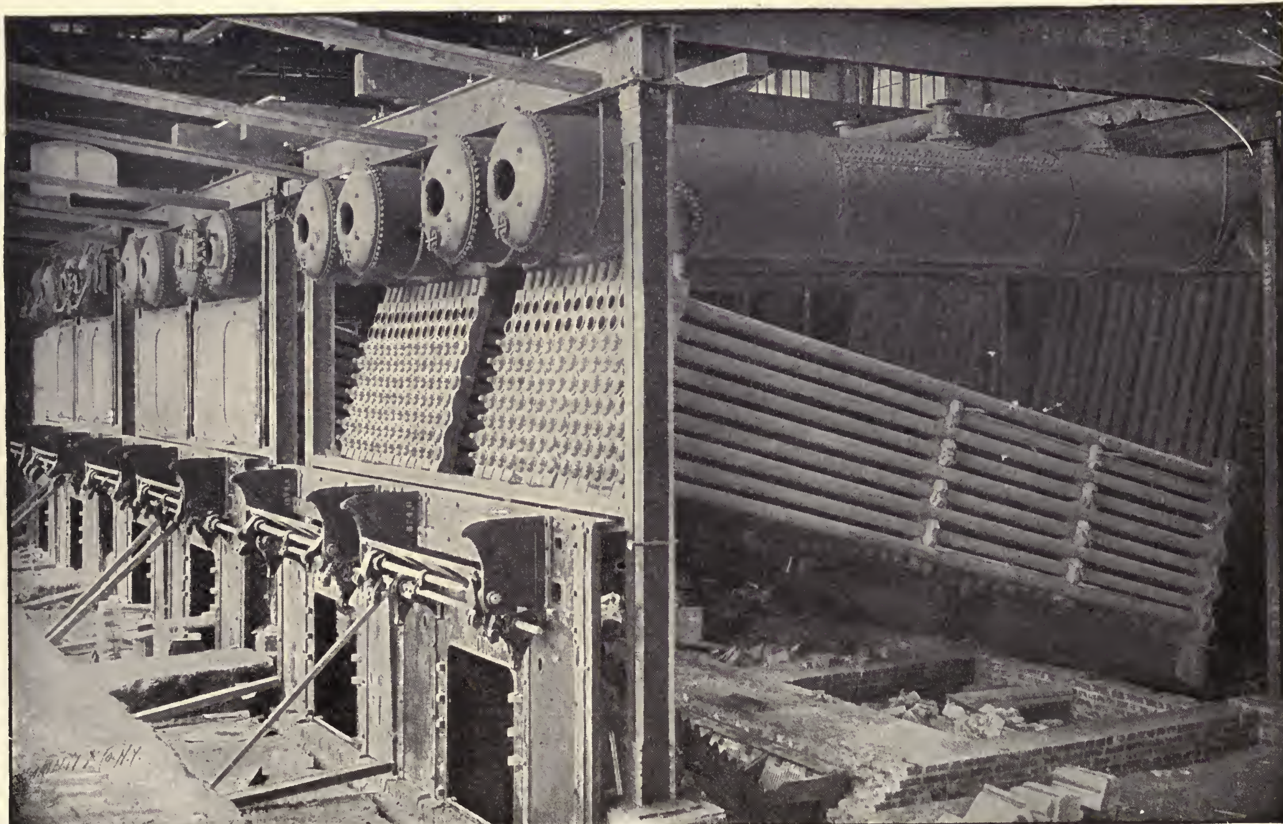


1600 Horse Power Babcock and Wilcox Boilers in Process of Erection.

CONSTRUCTION OF BOILERS.

A steam boiler, or steam generator, consists of a vessel to contain the water and the steam after it is formed; a fire-box to contain the fire; tubes, flues and uptake to transmit heat and conduct the hot gases from the fire to the chimney, and various fittings to facilitate the safe and economical operation. Boilers are often classified according to their uses and conditions; thus we have stationary, marine and locomotive boilers. Boilers having a shell partially filled with tubes, through which the hot gases pass, are called tubular, fire-tube or shell boilers; and those having a large flue in which is placed the fire, are called flue boilers. If the tubes are filled with water and the hot gases are outside, the boiler is called a water-tube boiler.

Steam boilers are made in a variety of shapes, according to the type, uses and conditions. Let us first consider boiler construction in general, leaving out the peculiarities of marine, locomotive and water-tube boilers.

MATERIALS.

The materials of which boilers are constructed are exposed to conditions which weaken them and shorten the life of the boiler. Among these conditions are corrosion, both external and internal, high pressure, and expansion and contraction, due to varying temperature and pressure.

Cast iron was the material of which the earliest forms of boilers were made, but on account of its low tensile strength and its unreliable nature, it is now but little used, except for parts of water-tube boilers, and sometimes for the ends of low-pressure cylindrical boilers and for fittings. It is cheap and resists corrosion but on account of its unreliability and brittleness, the parts must be made thick and therefore heavy.

Wrought iron, up to about 1870, was the principal material used for boiler plates. It is a pure iron prepared from pig iron by a process called puddling, described in "Metallurgy." Wrought iron is well adapted for use in boiler construction, as it is strong, tough and fibrous, and combines high tensile strength with ductility and freedom from brittleness. When the properties mentioned are well combined, wrought iron will resist strains due to unequal expansion. Boiler fastenings, stays and other parts made by welding are sometimes made of wrought iron. It is customary to consider that a bar loses about one-quarter of its strength by welding, although it is often stronger in the weld, owing to the working of the metal during the welding process.

Steel has entirely displaced iron for boiler-shell work. Boiler steel is made by the open-hearth process, and contains for ordinary thickness of 1 or $1\frac{1}{4}$ inches 0.25 per cent carbon, while thinner plates of $\frac{1}{4}$ inch should not contain over 0.15 per cent carbon. Larger percentages of carbon, while accompanied by an increase in tensile strength, lessen the ductility. The following properties show steel to be the best boiler material at present: great tensile strength, ductility, homogeneity, toughness, freedom from blisters and internal unsoundness. Blisters and unsoundness are faults sometimes met with in wrought-iron plates.

Copper in many respects is superior to wrought iron for boiler construction. It is homogeneous, resists oxidation (the corrosive action of most feed waters) and incrustation. It is more ductile and malleable and a better conductor of heat, which not only gives it a higher evaporative power, but also enables it to last longer under the intense heat of the furnace. Its disadvantages are its low tensile strength, about 30,000 pounds per square inch, and its decrease of strength with an increase of temperature. In heating from the freezing point to the boiling point it loses 5 per cent of its strength, and at 550° F. it loses about one-quarter of its strength. For these reasons and on account of its high price, it is now seldom used in boiler work.

Brass is an alloy of copper and zinc in which the proportions of each vary considerably. The red color comes from a larger per cent of copper. Red brass is better and more expensive than yellow brass. Brass is used for valves, gauges and other fittings.

Bronze is an alloy of copper and tin, and is advantageously used for valves and seats of safety valves where the wear is great.

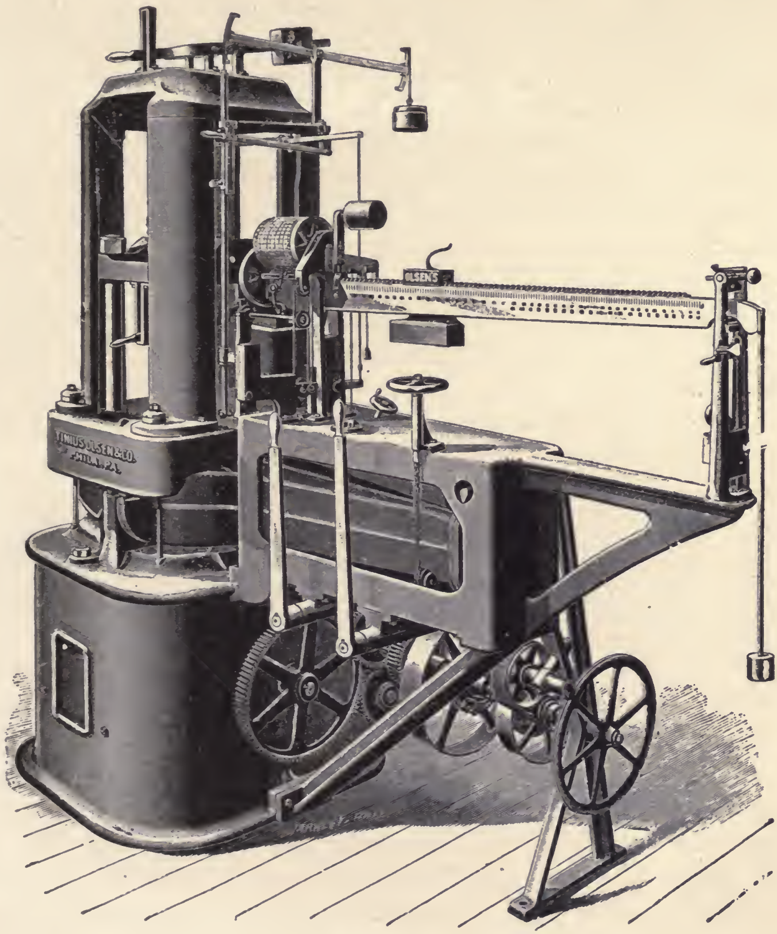


Fig. 1.

TESTING MATERIALS.

In order to determine the strength and the other qualities of the materials, specimens are tested. The results of these tests show the ultimate tensile strength, elastic limit, contraction of area and elongation.

The simplest way to test a piece of iron bar or plate would be to fix it firmly at the upper end and hang weights on the other end, adding other weights until the bar is broken. This is but a crude method, and in order that the elastic limit and elongation may be determined at the same time, testing machines are used. There is a large variety of testing machines, adapted for various materials, but the general principles are the same.

Testing Machines. The testing machine consists of a frame and two heads, to which the ends of the test piece are fastened by wedges or other devices. By means of steam or hydraulic power one head is drawn away from the other for tensile tests. The pull is transmitted to some weighing device, usually levers and knife edges like the beam of ordinary platform scales. In small machines the pull may be applied by a lever.

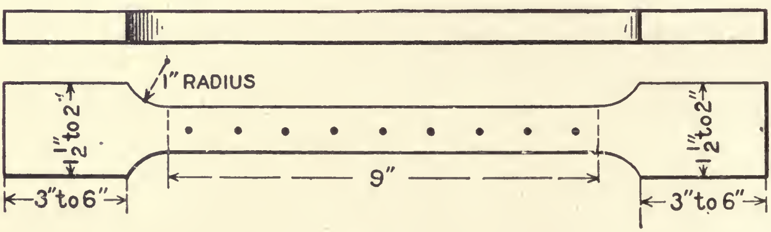


Fig. 2.

Testing machines are made for all varieties of testing: tensile, compressive and shearing stresses. Also for deflection of beams and for strength of wood, cement, brick and stone. Fig. 1 shows an Olsen testing machine designed for tensile and compressive tests of iron and steel.

In order to test materials, test pieces or specimens are prepared. For testing iron plate the test piece should be at least 1 inch wide, about 2 feet long and planed on both edges. Many engineers recommend these dimensions. According to the Board of Supervising Inspectors of Steam Vessels, the test piece should be 10 inches long, 2 inches wide and cut out at the center.

To ascertain the tensile strength and other qualities of steel, a test piece should be taken from each plate. These test pieces are made in the form as shown in Fig. 2. The straight part in the center is 9 inches long and 1 inch wide; and to determine elongation it is marked with light prickpunch marks at distances 1 inch apart, the marked space being 8 inches in length. The ends are $1\frac{1}{2}$ inches to 2 inches broad and 3 inches to 6 inches long.

As has been explained in "Mechanics," the force necessary to break the piece is the proportionate part of the tensile strength per square inch. Thus if the test piece having a reduced section of .4 square inch is broken at 19,200 pounds, the tensile strength of the plate is $\frac{19,200}{.4} = 48,000$ pounds per square inch.

EXAMPLES FOR PRACTICE.

1. If a piece of boiler plate breaks at 33,500 pounds and the reduced section is $1\frac{1}{8}$ inches by $\frac{1}{2}$ inch, what is the ultimate tensile strength?

Ans. 59,555 pounds.

2. A boiler plate is claimed to be of 64,000 pounds tensile strength. If the section is 1 inch wide and .63 inch thick, what should be the reading of the testing machine when the specimen breaks?

Ans. 40,320 pounds.

3. A test piece of the form shown in Fig. 2 measured 8 inches between the prickpunch marks before testing and 9.56 inches after testing. What was the per cent of elongation?

Ans. $19\frac{1}{2}$ per cent.

4. If the area of section before breaking is .4825 square inch and after breaking is .236 square inch, what is the per cent of reduced area?

Ans. 51 per cent.

STRENGTH OF BOILER MATERIALS.

The crushing strength of cast iron is high, varying from 50,000 to 75,000 pounds per square inch; its tensile strength is low, varying with the chemical and physical properties of the iron from about 15,000 to 22,000 pounds per square inch.

Wrought-iron plates having a tensile strength of from 50,000 to 60,000 pounds, with an elongation or ductility of from 20 per cent to 30 per cent, are suitable for boiler work. Boiler iron may be tested in the following ways if testing machines are not available: Cut from the plate a strip about 2 inches wide and bend it cold, down upon itself; if it shows no fracture on the outside curve, it is satisfactory. This is, however, a severe test, and only the best flange iron will stand it; on the other hand, any iron which, when heated to a cherry red and bent, shows cracks or fracture on the outer curve, is unfit for use in boiler construction. When wrought iron was used for boiler plates it was customary to give the plate what is called the hammer test. The plate was suspended clear of the ground and struck with a hammer at intervals of three or four inches over its surface; a clear, ringing tone indicating a sound plate, while a dull sound indicated with fair certainty a defect such as internal unsoundness.

Mild steel has a tensile strength of from 55,000 to 65,000 pounds per square inch, with an elongation of 25 per cent. A test piece cut from a plate $\frac{3}{4}$ inch thick or less should stand bending double, when hot or cold, and not show any cracks; thicker plates should be capable of being bent at a small radius to a large angle without showing any cracks. Steel should never be worked at a blue heat, as in this state it is very brittle. It is also mechanically tested by being heated to a cherry red, quenched in water at 82° F. then bent in a curve of small radius; if it cracks, it has become tempered, and it is therefore unsuitable for this work. If the tensile strength of the steel is under 70,000 pounds per square inch, it is sufficiently tough and ductile and can be easily worked.

In general, boiler materials are carefully tested for the following qualities:

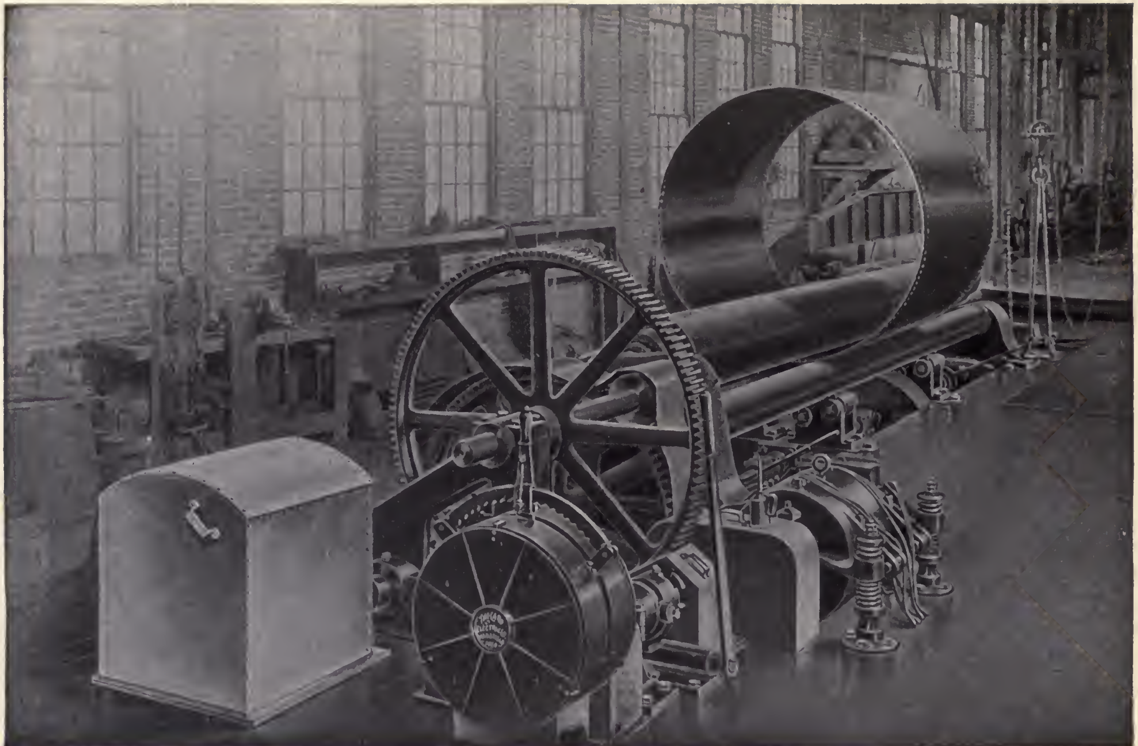
Tensile strength, to resist rupturing strains. Also in order that the plates may be thin.

Toughness and elasticity, to resist corrosion and the wear and tear of manufacture.

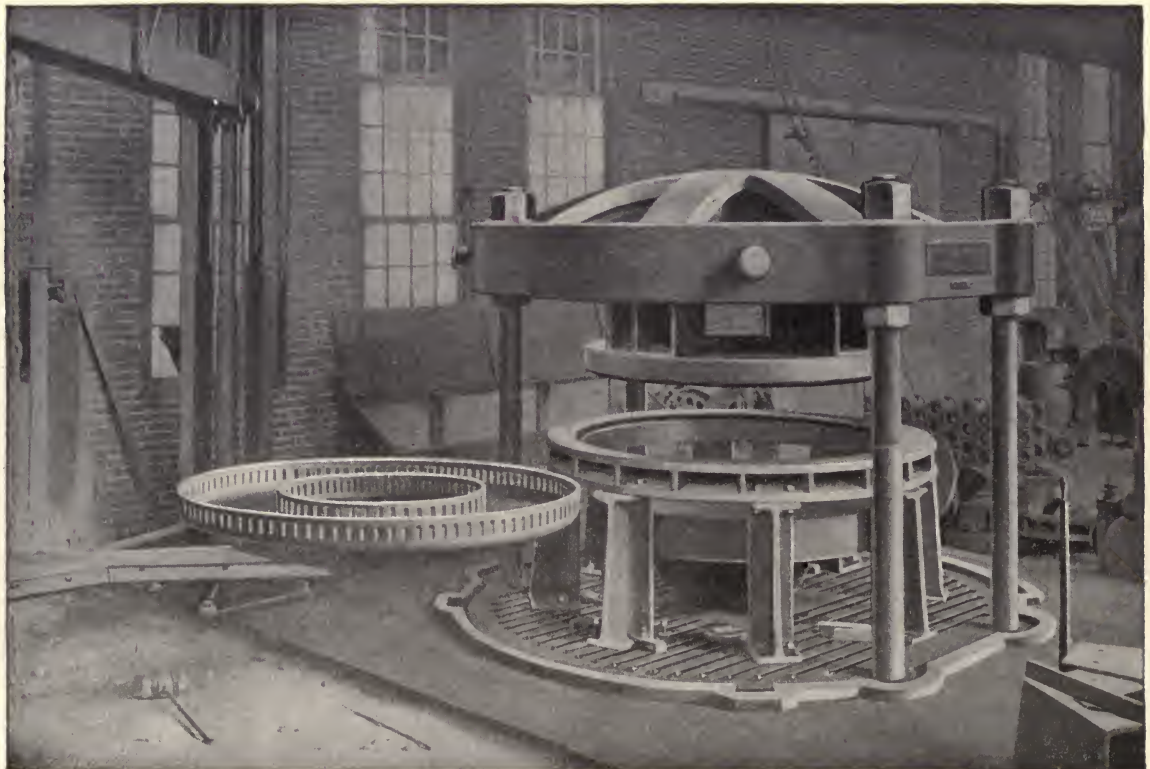
Ductility, so that the boiler may change its shape slightly without rupture. This is a more important quality.

BOILER CONSTRUCTION IN DETAIL.

The drawing or design of the boiler is worked out in the draughting room, as explained later under the head of Boiler Design.



TWENTY-FOOT BENDING ROLLS.-CAHALL FACTORY.



HYDRAULIC FLANGING PRESS. "CAHALL" FACTORY.

The draught shows the general arrangement of the boiler, together with complete detail drawings, from which the materials are ordered. These materials are plates, rods for stays, rivets, stay bolts, tubes, steel bars, angles and channel bars for stiffening, etc.

In some boiler shops it is customary to lay the boiler out on a large blackboard full size, thereby checking the drawing. In ordering plates the blank forms are filled out in the following manner:

Messrs. John Blank & Co:

Please furnish us with the following Steel Plates, Ultimate Tensile Strength, *60,000;* Elongation, *25 per cent:*

Number wanted.	Thickness	Dimensions.	Marks.	Remarks.
6	1″	90″×70″	S 14	Shell

The dimension which runs in the direction the plate is to be bent is given first. The plates are marked as per order blank, and this serves to identify the plate when the occasion arises. When ordering any odd shape, a sketch with dimensions must be placed in the column headed "Remarks."

In ordering plates, allow for trimming, particularly in the case of irregular shapes. Rivets are sold by the pound, regardless of their shape or size. Round and flat iron may be ordered by the running foot. Manufacturers publish tables showing weight of rivets, round iron, etc., with which they furnish boiler makers.

Boiler shops are equipped with the following tools: plate rolls, plate planers, shears, drill presses, punches, countersinking machines, flanging machines, hydraulic and steam riveters, and a compressed-air system for operating pneumatic machines, such as calkers and chippers. They also have machine shops for doing such machine work as is required for fittings, furnace fronts, etc., and a system of cranes for handling and transporting material. In connection with the above is a storeroom of sufficient size, a forge shop, and an engine and boiler for supplying the shop with the power necessary to operate it.

In boiler-shell work drilling has entirely displaced punching, and to-day all holes are drilled. Punching is cheaper than drilling, but it is more injurious to the plates and not as accurate. It is easy to see that drilling rivet holes, even if twenty are being drilled at once, is done with less strain on the plates than when done by a multiple punch forcing several holes at once. The force required to punch a plate gives the best idea of the harm done to the plate. Experiment shows that the resistance of a plate to punching is about the same as its resistance to tensile tearing. Suppose this to be 50,000 pounds per square inch; then the force required to punch the plate is the area cut out times the shearing strength, or $d \times \pi \times t \times 50,000$.

In which formula

$d =$ diameter in inches and

$t =$ thickness in inches.

For a hole $\frac{3}{4}$ inch in diameter in a $\frac{1}{2}$-inch plate, the force will be

$$\tfrac{3}{4} \times 3.1416 \times \tfrac{1}{2} \times 50,000 = 58,900 \text{ pounds.}$$

If the force required to punch one hole is 58,900 pounds, the force required in punching several holes by means of a multiple punch is enormous.

A good, ductile plate is but little injured by punching; but if of a hard, steely nature, it is likely to be seriously injured. For this reason wrought-iron plates are usually punched and steel plates are drilled. On the whole, a drilled plate is somewhat stronger than a punched plate for any kind of joint.

Some boiler makers punch the rivet holes slightly smaller than the desired size and then ream them out. By this process the injured metal around the holes is cut away. Another method to overcome the injurious effects is to anneal the plate after punching.

The ordinary process of annealing consists of heating the plate to red heat, and then allowing it to cool slowly. By this means, hard and brittle iron or steel is made soft and tough. While the metal is hot, the surface becomes oxidized. For most purposes this scale of oxide in not harmful, but in some cases it must be removed. As this is expensive, a process of annealing in illuminating gas has been devised. The action of the gas is to reduce the oxide without altering the properties of the piece. The results obtained from annealing depend upon the kind of iron or steel, the temperature to which it is raised, and the rate of cooling. It is a great advantage to all steel of over 64,000 pounds per square inch in tensile strength, but softer steels are little better for the process.

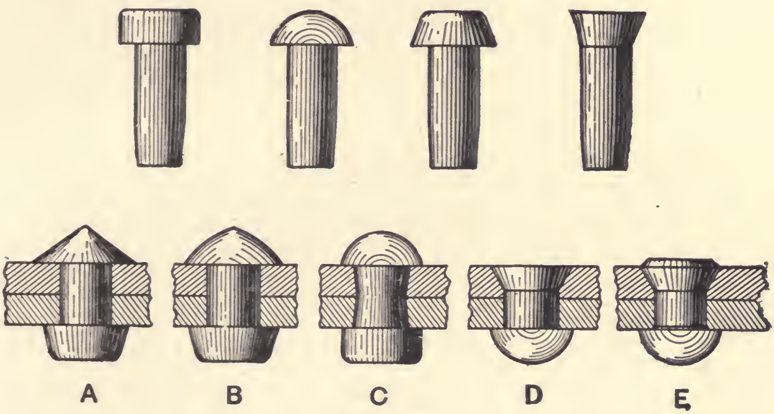


Fig. 3.

After the shell plates are planed to correct shape and the holes drilled or punched, they are put through the bending rolls and bent into a cylindrical shape, the amount of curvature being determined by a template made for the purpose. Plates are usually sheared to size, and then the edges planed with a slight bevel to facilitate calking. In the meantime the heads are being flanged by a hydraulic flanging machine; when the flange is completed, the head is put on the platen of a boring mill and turned so as to exactly fit into the shell. In some shops it is customary to punch or drill only a few holes in the shell and flange of the head, these holes serving to take bolts for holding the parts together. The back head plate is bolted into the rear course of plating, and the parts thus assembled are hoisted up to drill if the plates, etc., have not been previously drilled or punched, otherwise to the hydraulic riveter.

RIVETS AND RIVETING.

Rivets are formed by forging, from round iron bar or mild steel, with a cup or pan shaped head. The cylindrical part, called the shank, is a little smaller than the hole and has a slight taper. Fig. 3 shows common forms of rivets. As rivets are not as reliable in tension as in shear, they are used mainly at right angles to the straining force. If the stress is parallel to the axis, bolts are used, since they are strong in tension. The shearing strength of steel rivets is about 45,000 pounds per square inch, and of iron rivets about 40,000 pounds per square inch. Steel rivets are often used with steel plates, but many boiler makers prefer to use iron rivets in all cases.

Three types of rivets in use are shown in Fig. 4, the following table giving the dimensions:

Diameter of Rivet.	Cone Head. A			Countersunk. B		Button Head. C	
D	E	F	G	E	G	E	G
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{19}{32}$	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{9}{32}$	$1\frac{1}{16}$	$\frac{7}{16}$
$\frac{11}{16}$	$1\frac{1}{8}$	$\frac{21}{32}$	$\frac{39}{64}$	$1\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$1\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{7}{16}$	$1\frac{7}{16}$	$\frac{3}{4}$
1	$1\frac{5}{8}$	$\frac{15}{16}$	$\frac{27}{32}$	$1\frac{5}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{3}{4}$

Formerly all joints of boilers were riveted by hand, but now all riveting is done by machines, except those joints to which a machine cannot be applied. If done by hand, the red-hot rivet is inserted in the hole, and the second head formed by two riveters working with hammers. This head is either made conical by the hammers alone or finished with a cup-shaped die called a "snap." This latter is the more usual method. The disadvantages of hand riveting are slowness and a tendency to form a shoulder before the rivet fills the hole.

Machine riveting is preferable, as the work is done better, faster and more accurately ; the pressure coming gradually on the entire rivet, compresses it completely into the hole before the head is formed. Before riveting, care should be taken that the plates are close together, so that a shoulder will not be formed between the plates and prevent a good joint. Rivets should always be put in while red hot, for in this condition they are more easily worked, and when they cool they contract, nipping the plates together in a tight joint.

Hydraulic riveting is more gradual and is generally preferred to steam riveting. The pressure from the steam riveter often comes as a sudden blow and does not allow time for the rivet to completely fill the hole.

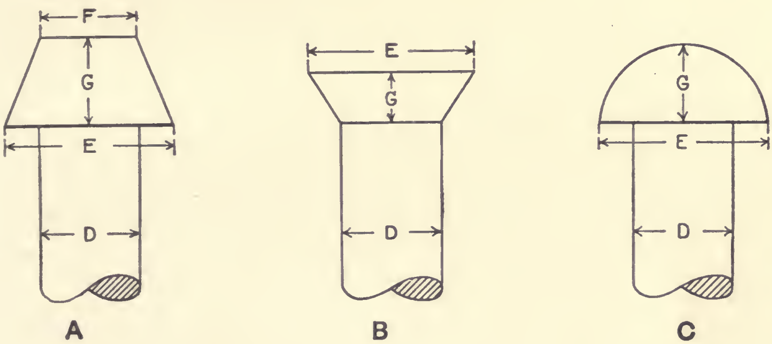


Fig. 4.

It is sometimes desirable to rivet with a countersunk head; that is, the rivet does not project above the plate. The countersunk head is formed by hammering down the end of the rivet into the countersink in the plate. This form is shown at D, Fig. 3. This joint is often used in shipbuilding and in boiler making when it is necessary to attach mountings. It should always be avoided, if possible, on account of its weakness, and especially when the straining force acts in the direction of the length of the rivet, as the head has a very insecure hold and is likely to be pulled through the hole.

Rivets may be tested in a boiler shop as follows : the rivet to be bent cold in the form of a hook around another rivet of the same diameter, and show no flaws or cracks; to be bent hot down upon itself and show no cracks, head to be flattened while hot until its diameter is $2\frac{1}{2}$ times the diameter of the shank, and show no flaws.

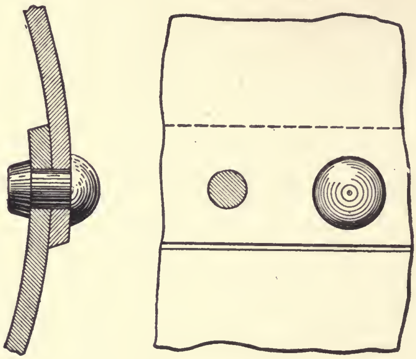


Fig. 5.

The uniform heating of steel rivets is of more importance than in the case of iron rivets, where it is sufficient to heat the points only. Steel rivets also should not be heated to a white heat, as iron rivets are, but to a bright cherry red, for if heated beyond this point they will burn. The fire in which steel rivets are heated should be kept thick, and the draught moderate. This should also be observed in heating steel plates for flanging.

There are various forms and strengths of riveted joints. It

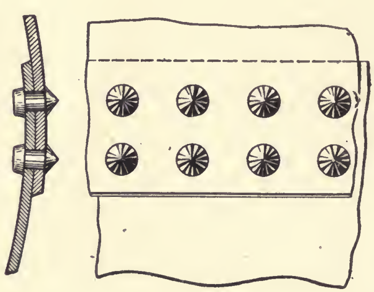


Fig. 6.

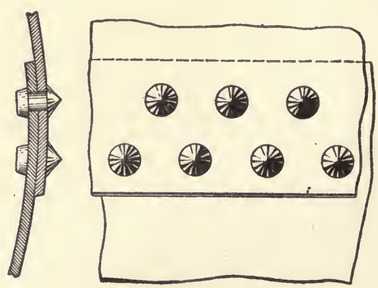


Fig. 7.

is obvious that in punching or drilling, a plate is weakened to the extent of the sectional area cut out, and that if the holes are punched, the metal between the holes is weakened. In treating the strength of a joint it is customary to speak of it as a percentage of the strength of an unpunched plate.

If one plate overlaps another and is riveted to it by a single row of rivets, as shown in Fig. 5, it is called a single-riveted lap joint. This joint has about 56 per cent of the strength of a solid plate. If another row of rivets is added, it is called a double-riveted lap joint; Fig. 6 shows the double-riveted lap joint chain riveted, and Fig. 7 the double-riveted lap joint zigzag riveted.

Double riveting is done in two ways: zigzag, or staggered, and chain. When rivets are put in so that the rivets of one row are opposite the spaces of another row, it is called zigzag riveting or staggered riveting. If the rivets are placed immediately opposite each other, it is called chain riveting.

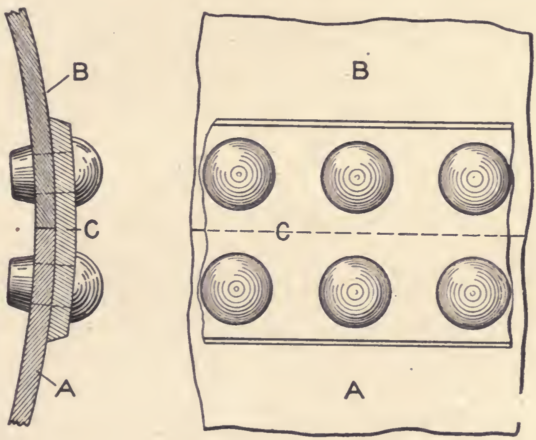


Fig. 8.

If the two plates are kept in the same plane and a cover or butt strap riveted on, it is called butt riveting (Fig. 8, in which A and B are the boiler plates, and C is the butt strap). If an inside butt strap is added, it is called a double butt joint (Fig. 9). Fig. 10 shows a treble-riveted butt joint. A single butt joint is about equal in strength to a lap joint having but one row of rivets, but a double butt joint is considerably stronger.

In this latter form of joint the rivets have double shearing surfaces, since they tend to shear off in two planes. This either makes a stronger joint or allows the use of smaller rivets. In the single butt joint the butt strap is usually about $1\frac{1}{8}$ the thickness of the plate, and if the inside butt strap is added, each butt strap is made about $\frac{5}{8}$ the plate thickness. Butt joints are now being used in the best class of boilers, and are used almost entirely for plates less than $\frac{1}{2}$ inch in thickness.

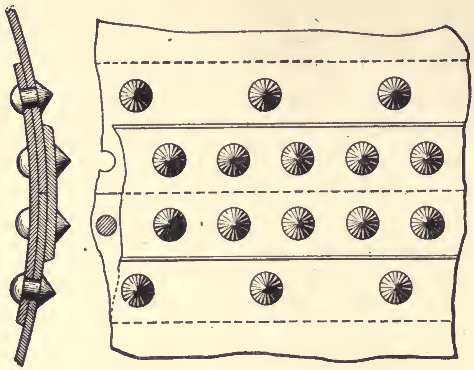


Fig. 9.

Lap joints are used for circumferential seams, and the stronger joint, the butt, for longitudinal joints. For high pressures in marine boilers, triple riveting is frequently used.

If a cover plate is riveted on the outside of a lap joint, it is called combined lap and butt joint. In this case there are three rows of rivets, the middle row having twice as many rivets as the outer rows. Fig. 11 shows the combined joint.

The distance between the centers of rivets is called the "pitch." The mathematical calculation of pitch and the distance between the rivets and the edge of the plate will be taken up later.

The following table gives an idea of the relative strengths of riveted joints:

Kind of Joint.	Riveting.	Percentage of Strength.	
		Punch.	Drilled.
Lap	Single Double	55 69	62 75
Single Butt	Single Double	55 69	62 75
Double Butt	Single Double	57 72	67 79

FLANGING IRON AND STEEL PLATES.

Iron plates are more severely tested by flanging than by any other work done upon them. This is due to their fibrous nature, and great care is necessary to prevent breaking in the bend, if the corner is sharp.

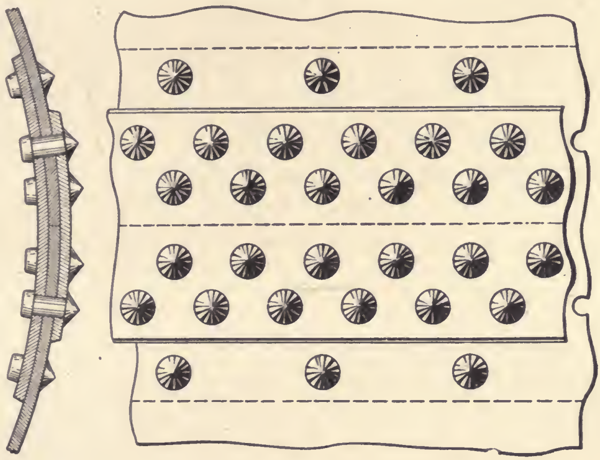


Fig. 10.

As has been stated, steel requires uniform heating and moderate curves. Flanging is almost entirely done to-day by machines. After flanging, the steel should be annealed by heating the whole plate uniformly to a dull red heat, and allowing it to cool slowly.

WELDED JOINTS.

Welded joints for boiler shells are desirable. By their use deposits which accumulate on and around rivet heads and joints, corrosion caused by leakage, and loose rivets, are done away with, and calking also. Moreover, a perfectly welded joint is stronger than the best riveted joint, and approximates nearly to the original strength of the plate. Welded steam drums are used now quite extensively for water-tube boilers of the marine type.

The soundness of such a joint is a matter of uncertainty, and depends upon the skill and care of the workmen. It is impossible, from external appearances, to judge the soundness of a welded joint. The principal use of welded joints is for furnace tubes and steam domes, but they have not been used much for boiler shells. The lack of tests on welded joints and the small amount of information on the subject, render the results of experiments of little value. The weld is best made when the edges of the plates are upset, at red heat, to nearly double the plate thickness, and beveled to an angle of about 45 degrees. The edges are then heated together, and the weld made by hammering down the joint to the original thickness of the plate.

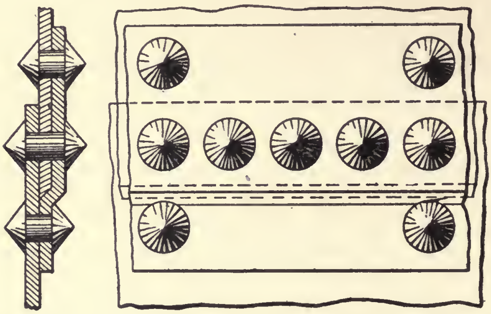


Fig. 11.

ARRANGEMENTS OF PLATES AND JOINTS.

When we take up the design of boilers we shall see that a boiler tends to rupture longitudinally. The reason for this is that the resistance of a thin cylinder to circumferential rupture is double the resistance to longitudinal. Since this is the case, lap joints are used for transverse seams, and a stronger form (the double butt joint) is used for the longitudinal.

At the junction of three or more plates, where the circumferential and longitudinal joints meet, ordinary riveted joints would be too thick. To overcome this difficulty, two or more plates are forged thin at the joint, as shown in Fig. 12.

Whenever longitudinal and girth seams meet, the plates should be arranged to "break joints"; that is, one longitudinal seam should not be a continuation of another. The proper arrangement is shown in Fig. 13.

In both vertical and horizontal boilers the inside lap is made to face downward, so that it will not form a ledge for the collection of sediment

The belts of plates that make up the length are sometimes arranged conically, with the outside lap facing backward. When the boiler is slightly inclined toward the front end, this conical arrangement facilitates draining and cleaning, as the dirt is removed at the front end. This is a great advantage to internally fired boilers, as they are difficult to clean.

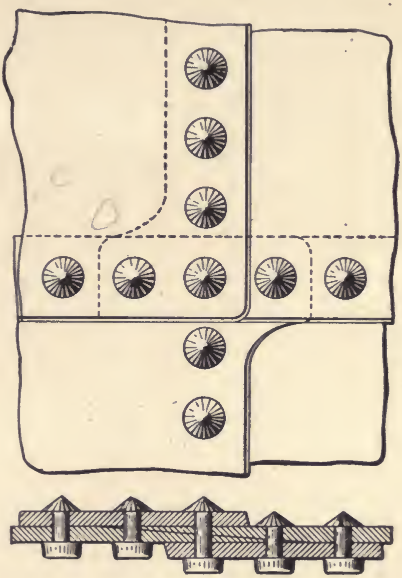


Fig. 12.

In long vertical boilers the ring seams are arranged with the inside lap facing downward, so as not to have a ledge for sediment. Sometimes the belts of locomotive boilers are arranged telescopically, with the largest diameter at the fire-box end. Of late years the best makers use larger plates than formerly. This is advantageous, especially in externally fired multitubular boilers, as the single seam is placed above the water-level, and therefore is away from the fire.

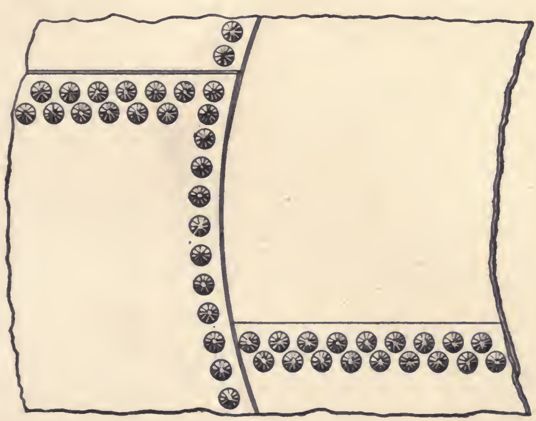


Fig. 13.

The portion of a boiler between the shell and the furnace is called the water leg. Figs. 14 to 20 inclusive illustrate the method of construction of the water leg and the joints around the furnace door. Figs. 14 and 15 show two methods of constructing

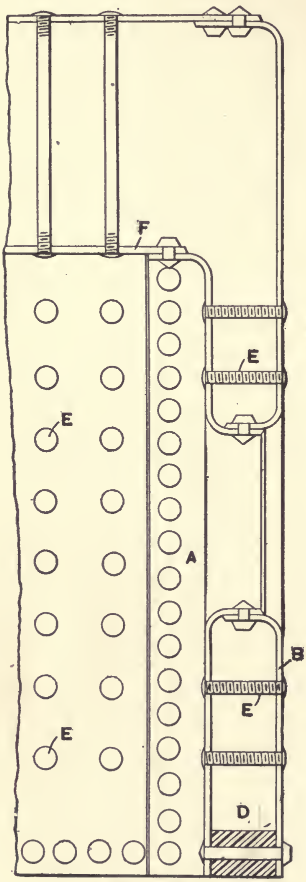


Fig. 14.

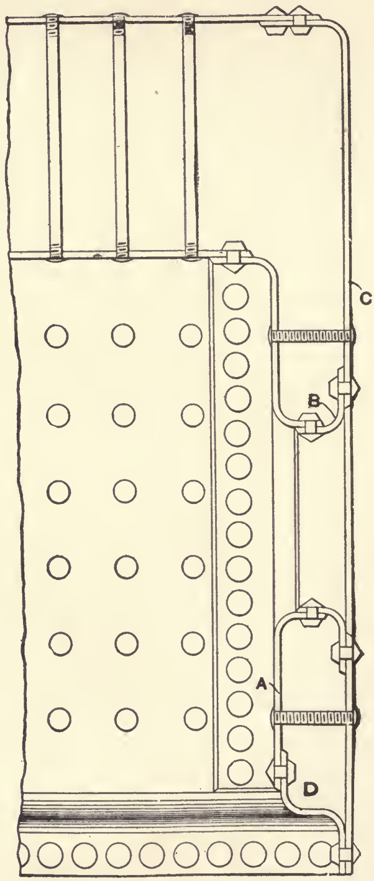


Fig. 15.

the water leg. In Fig. 14 the exterior plate and the furnace plate are riveted to the ring D by means of long rivets. This ring is usually made of wrought iron, but in many cheap boilers it is of cast iron. In Fig. 15 the two plates are riveted to the flanged ring D. This construction is better than the solid cast-iron ring, on account of flexibility, but the junction of the plates D and C forms a corner in which sediment is deposited. In Fig. 17 the plate B is flanged and riveted to C. This arrangement requires less riveting than the one shown in Fig. 15. Figs. 14, 15 and 17 also show three forms of construction of the joints around the

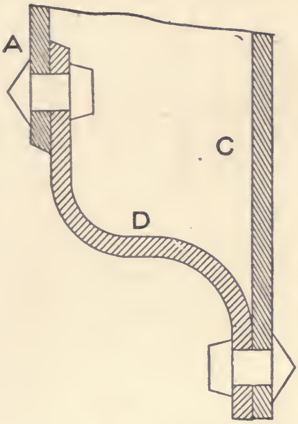


Fig. 16.

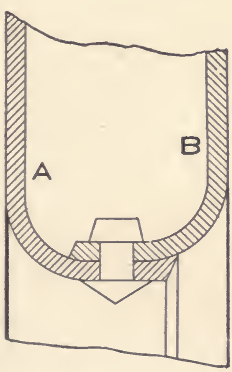


Fig. 18.

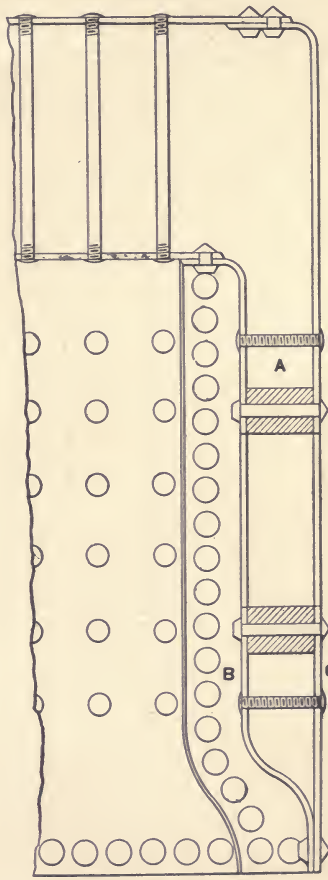


Fig. 17.

furnace door. In Fig. 14 both the exterior plate and the furnace sheet are flanged and riveted together. This is shown in an enlarged view in Fig. 18. The construction shown in Figs. 15 and 19 is not as good as that in Fig. 14, because of the extra riveting; also, it has two corners, B and C, for the deposit of sediment. Fig. 17 shows a somewhat different form of furnace construction, the two plates being riveted to the cast-iron ring. This form is better shown in Fig. 20. It makes this part of the boiler too rigid, but it has the advantage of not having rivet heads to wear off. In these methods of riveting, those which have the flanged ring are preferable to those using the cast-iron ring, because of more freedom for expansion; but the flanged ring forms an undesirable corner.

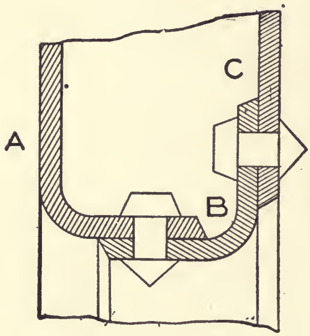


Fig. 19.

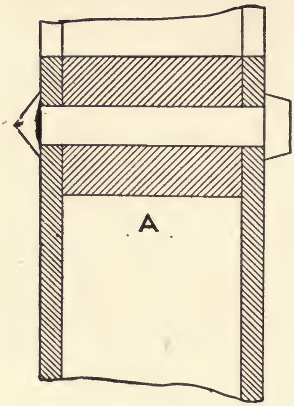


Fig. 20.

In almost every boiler, plates must be connected at right angles. An example of this is seen where the end plates are jointed to the shell plates of cylindrical boilers. There are three principal methods: riveting both plates to an angle iron, riveting to a flanged ring and flanging the end plate. In Fig. 21 the two plates are riveted to an angle iron, which is made of wrought or cast iron. This construction is too rigid; the constant variations of temperature cause repeated changes of form, which tend to crack the angle iron on the inside of the plate at the joint. Corrosion increases the evil, as it rapidly attacks iron which has once been cracked or broken. There is no definite rule for the dimensions of these angle irons, but it is safe to make the mean thickness a little greater than that of the plates.

The forms shown in Figs. 22 and 23 are better. The head is flanged and riveted to the shell plates. The flanging makes a more flexible joint. The radius of the curve of the flange should be about four times the thickness of the plate. The head and shell are sometimes connected to a flanged ring, as shown in Fig. 24. The extra row of rivets makes a complex joint.

In vertical boilers the external fire-box is joined to the cylindrical shell by riveted joints. Figs. 25 and 26 show two forms; that in Fig. 25 being the better on account of the flanged ring,

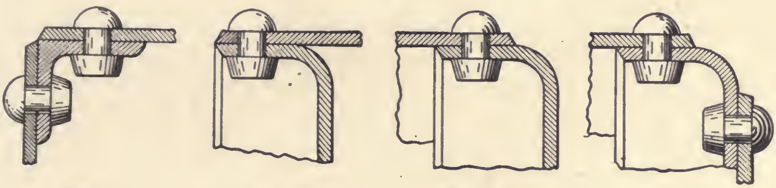


Fig. 21. Fig. 22. Fig. 23. Fig. 24.

which allows expansion and contraction of the shell and furnace plates.

Sometimes the case occurs of connecting two plates which are parallel and near together. For instance, at the bottom of the

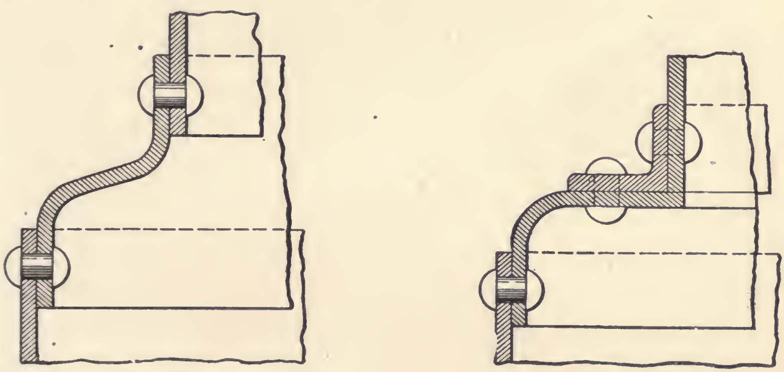


Fig. 25. Fig. 26.

locomotive fire-box a connection must be made between the inner and outer fire-box. The water-leg construction is a similar case. Several methods for this construction are shown in Fig. 27. Fig. 27A is too complicated and is undesirable, both on account of the numerous rivets and angle irons, and on account of the inside joints, which cannot be calked. Fig. 27B is better, since it has but one angle iron; it has, however, the undesirable inside joint.

Fig. 27D is a good joint, the form of connection being called a channel iron. Fig. 27E, as we have seen, is a good flexible joint, but it has the undesirable corner where sediment lodges.

We have thus briefly discussed the various methods and arrangements for putting shells together, and now let us return to our boiler, which is ready for riveting at the hydraulic riveter. A few rivets are first driven at equal intervals around the ring seam

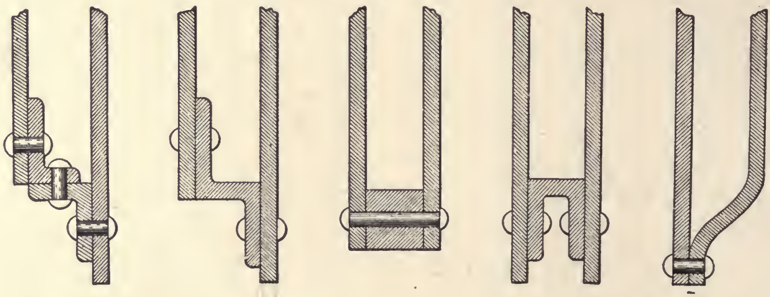


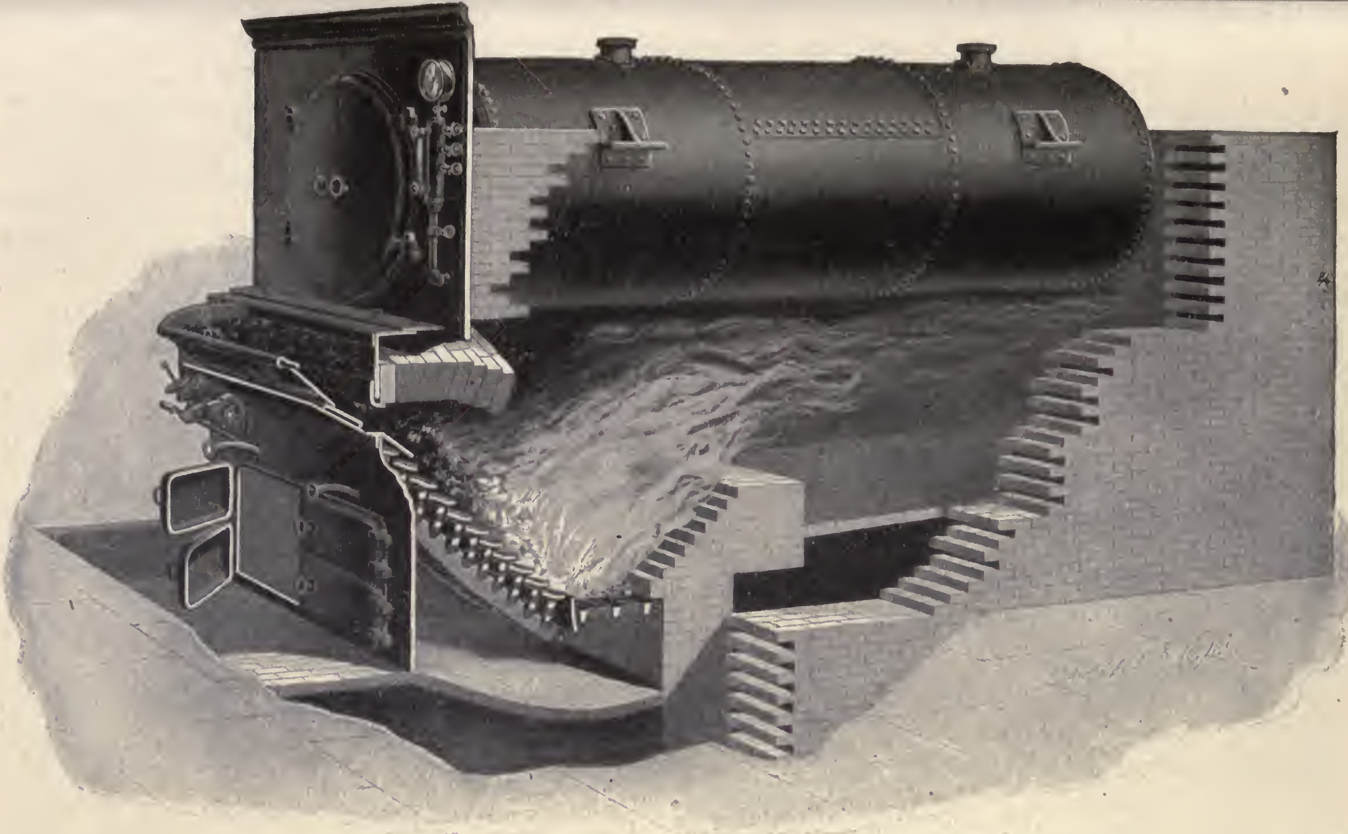
Fig. 27.

at the back head. The reason for driving only a few rivets is that any errors in the spacing of the holes are distributed and not accumulated, as would be the case if they were driven in succession. From this point on, the riveting is continued until the shell is completely riveted up.

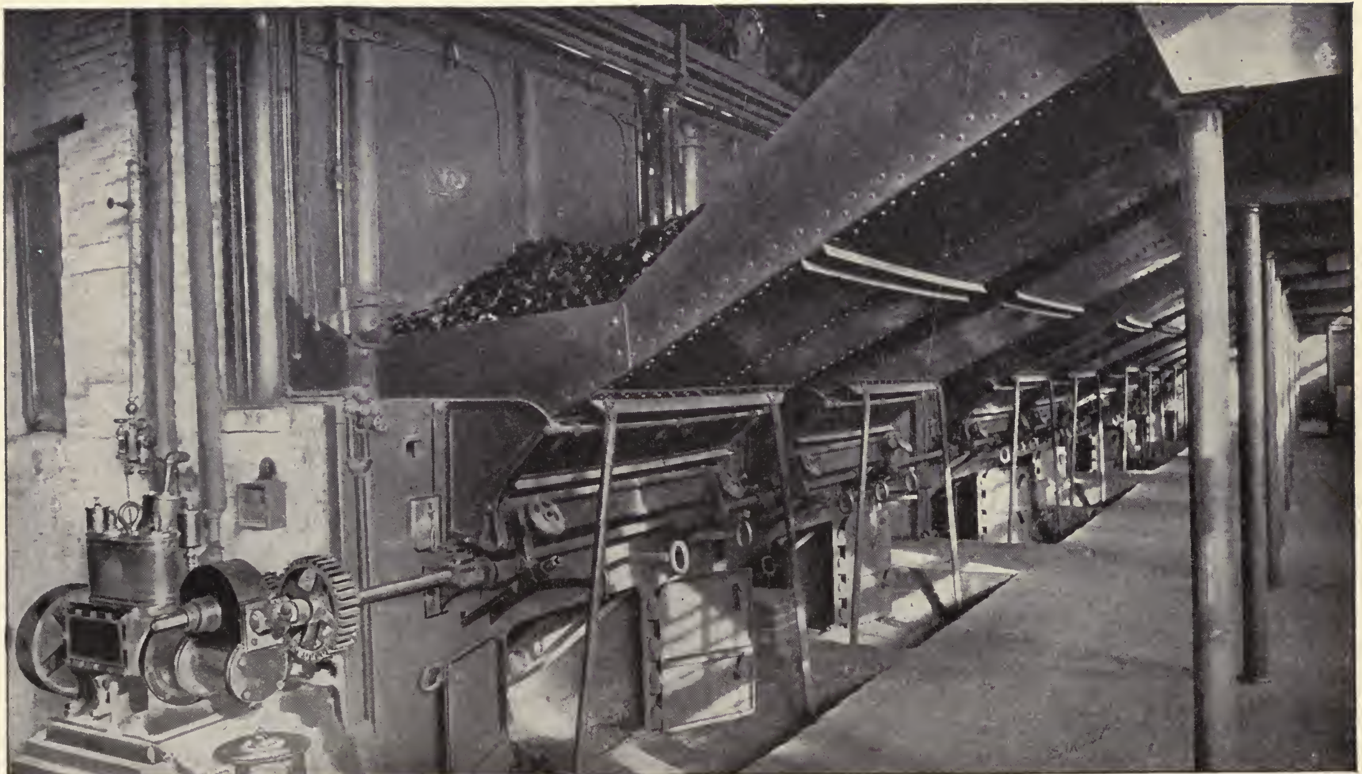
STAYING.

The shell is now ready to receive the stays. When under steam, a cylindrical shell is strained by internal pressure in two directions, namely: transversely, by a circumferential strain due to the pressure tending to burst the shell by enlarging its circumference, and longitudinally, by the pressure on the ends. If a boiler were spherical it would require no stays, because a sphere subjected to internal pressure tends to enlarge but not to change its shape. All flat surfaces in boilers must be stayed, otherwise the internal pressure would bulge them out and tend to make them spherical in shape. The ends of steam drums on high-pressure water-tube boilers are often made hemispherical.

The first and most important point in staying is to have a



GENERAL PERSPECTIVE OF THE RONEY MECHANICAL STOKER AS APPLIED TO A HORIZONTAL TUBULAR BOILER.



Roney Mechanical Stoker, Showing Coal Delivery Shutes and Operating Engine.

sufficient number of stays so that they will entirely support the plate without regard to its own stiffness. The second is to have them so placed as to present the least obstruction to a free inspection, and third, to have them so arranged as to allow a free circulation of water. Too much care cannot be taken in fitting stays and braces, as they are out of sight for long periods, and a knowledge of their exact condition is not always easily obtained. In the ordinary fire-tube boiler the principal surfaces stayed are: the flat ends, crown sheets, flat sides of locomotive boilers and combustion chambers of cylindrical marine boilers. In the case of most marine or Scotch boilers, the diameter is large compared to the length; hence the flat surface is considerable, and needs careful staying. All the plates that are not cylindrical or hemispherical must be stayed. The details should be arranged for each boiler; a few general methods and cautions can, however, be given.

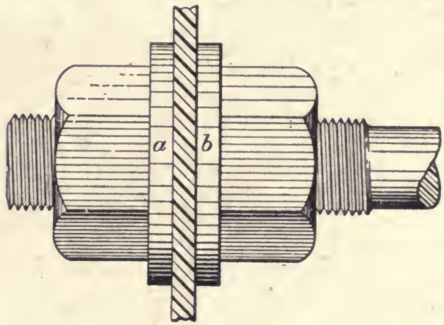


Fig. 28.

The most common and simple form of stay is a plain rod. It is used to stay the flat ends of short boilers. This stay is a plain

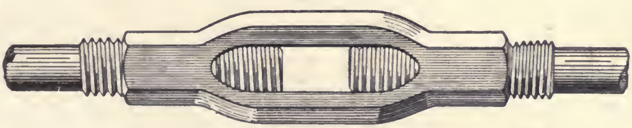


Fig. 29.

rod passing through the steam space and having the ends fastened to the heads. The ends are fastened and the length adjusted in a variety of methods; the simplest being nuts on both sides of the plate, as shown in Fig. 28. The copper washers *a* and *b* strengthen the plate and prevent abrasion by the nuts. In place of the nuts the rod is often bolted to angle irons, which are riveted to the plates. In this case, turn buckles similar to the one shown in Fig. 29 are used for adjusting the length.

The stays are usually from $\frac{3}{4}$ inch to an inch in diameter, and are made of wrought iron or steel, with an allowable stress of 5,000 to 7,000 pounds per square inch. If the ends are fastened to riveted angle irons, the combined area of the rivets is made a little greater than that of the rod.

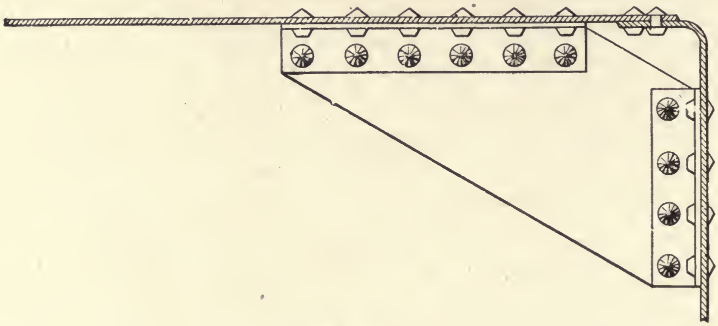


Fig. 30.

If a boiler is long, that is, more than 20 feet, long stays would sag in the middle and not take up the full stress on the end plates. For long boilers, gusset and diagonal stays are used. This form of boiler stay, shown in Fig. 30, is made of wrought-

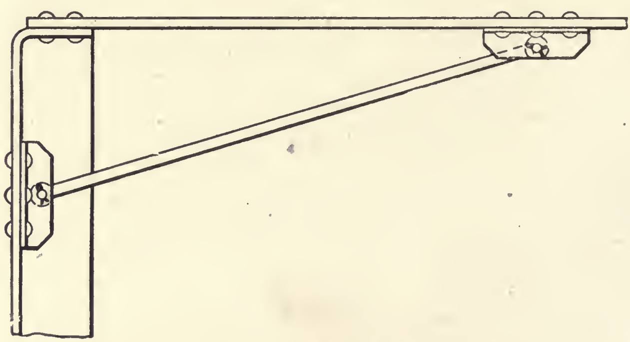


Fig. 31.

iron plate riveted to angle irons ; the angle irons being riveted to the end and shell. Boilers of the Cornish, Lancashire and Galloway types often have this kind of stay. These boilers are internally fired, and as the variation of temperature causes expansion and contraction, great care should be used in placing the gusset stay. If the stay is too near the flange or too many stays are used, the head will be too rigid and have a tendency to crack.

A form of diagonal stay is shown in Fig. 31. The plain rod is connected to angle irons by means of split pins. The angle irons are fastened to the shell and end by rivets or bolts. Another form of diagonal stay, called the crowfoot, is shown in Fig. 32. The two ends are bolted or riveted to the end and shell.

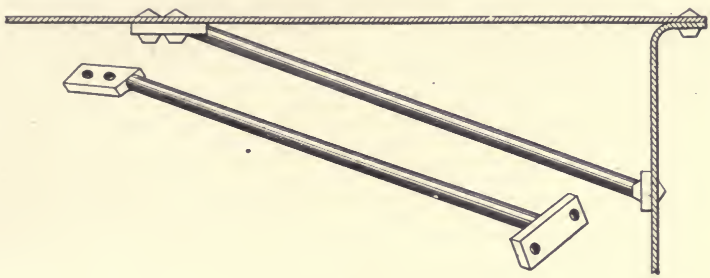


Fig. 32.

The angle between the shell plate and stay rod should be small,— not more than 30 degrees. The rod itself is designed for tensile strength, since the diagonal pull may be easily reduced to an equivalent direct pull. A large factor of safety is used to provide for future corrosion.

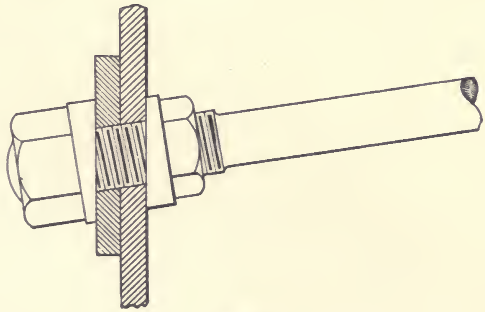


Fig. 33.

For marine boilers, a modified crowfoot stay (Fig. 33) is often used. The end passing through the head is supplied with nuts and taper washers, the washers having the proper taper to allow the nuts to be set up tightly against them.

In locomotive fire-boxes and in the combustion chamber of marine boilers, there are two flat or slightly curved surfaces that must be stayed together. These are riveted by short screw stay bolts. The bolts shown in Figs. 34 and 35 are screwed in place, and the ends riveted over. In marine boilers these stays are fastened with nuts, as shown in Fig. 36, instead of being riveted.

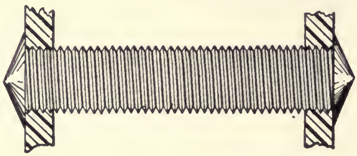


Fig. 34.

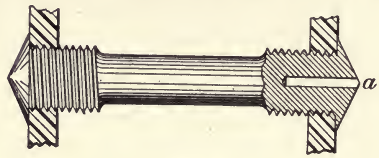


Fig. 35.

Sometimes the bolt is threaded the entire length, as in Fig. 34, or is turned off smooth in the center, as in Fig. 35. The smooth surface resists corrosion, and is less likely to fracture than the threaded bolt. Sometimes a small hole is drilled in the end, so that if the bolt breaks, the escaping steam will give warning. This is shown at *a*, Fig. 34. These bolts are $\frac{7}{8}$ inch or 1 inch in diameter.

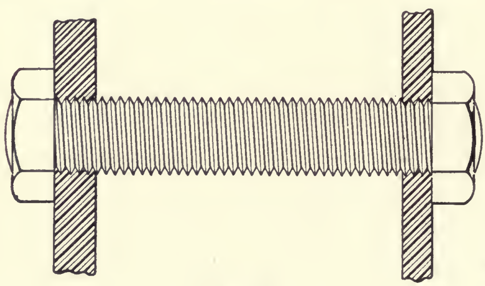


Fig. 36.

The strains which come on a stay bolt are not the same as those on rivets or on ordinary stay rods; as a matter of fact, stay bolts fail by a bending stress, and generally fracture just inside the outside sheet, due to the unequal expansion between combustion chamber or furnace and the outside boiler shell. Owing to this difference of expansion, flexible stay bolts have been designed, but have not come into general use, nor are they likely to, as they occupy considerable space and are much more complicated than the simple stay bolt. Stay bolts are made from the best quality of refined iron, which has been found to stand the strains of alternate heating and cooling better than mild steel. Iron stay bolts are more durable, because of the fibrous nature.

It should be added that boiler heads are further stiffened by channel bars or angles placed along the line of holes for the through stay rods.

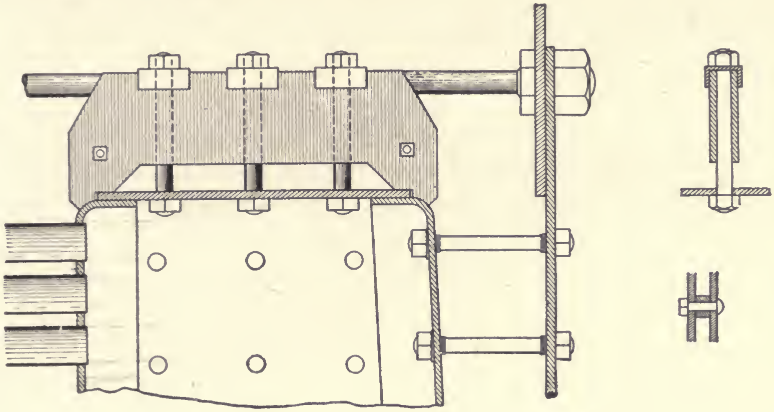


Fig. 37.

The crown sheets of fire-boxes and tops of combustion chambers are usually stayed by crown bars, which extend across the flat surfaces, as shown in Fig. 37, the ends resting on the

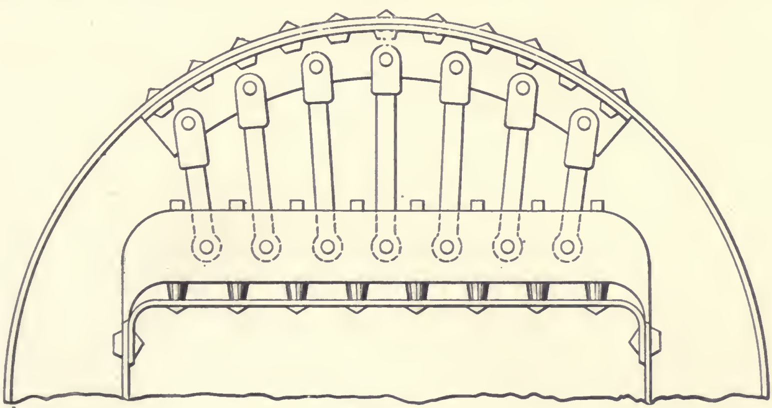


Fig. 38.

side plates. Bolts about 4 inches apart connect the crown sheet to this girder. The girder may be a solid bar, or it may be made up of two flat plates bolted or riveted together, as shown in the figure, the stay bolts being placed between the plates at intervals of about 4 inches.. Either bolts or rivets may be used to keep the plates which form the girder from spreading. Projections are sometimes forged on the bottom of the girder, so that the stay bolts may be screwed up tightly without bending the plate.

The depth of the plates which make up the girder vary from

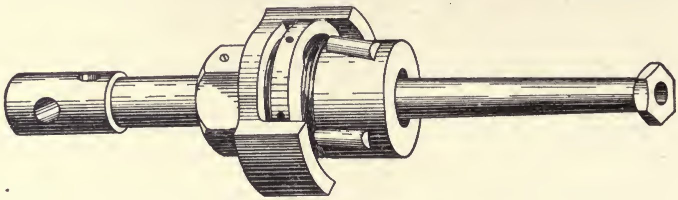


Fig. 39.

4 to 6 inches. They are from $\frac{5}{8}$ to $\frac{3}{4}$ inch in thickness. If bolts $\frac{7}{8}$ inch in diameter are used, the distance between the plates is usually 1 inch, but if larger bolts 1 inch in diameter are used, the distance should be $1\frac{1}{8}$ inches. The ends of the bars which rest upon the side plates should be carefully fitted to make a good bearing, and the area should be sufficient to prevent crushing of

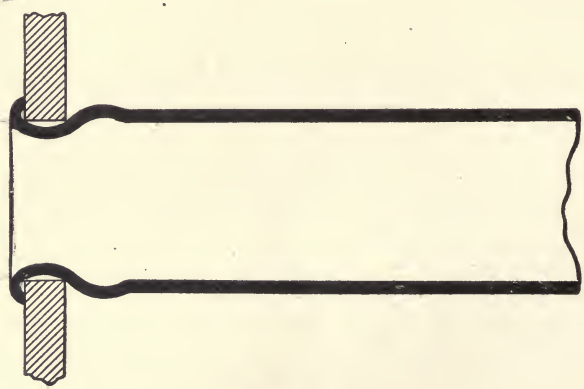


Fig. 40.

the end plates. The distance between the crown sheet and the girder should be at least $1\frac{1}{2}$ inches, so that there will be good circulation and the plates may be readily cleaned.

In some cases the girder is supported from the shell by sling stays, as shown in Fig. 38. The sling stays are connected to the girder and to an angle iron, or T-iron, which is riveted to the shell. The angle iron stiffens the shell. In designing this form of stay it is usual to make the girder strong enough to support the crown sheet without any sling stays, and these stays are used for additional support.

TUBES.

Boiler tubes are made of steel or wrought iron, but most commonly of charcoal iron and lap welded. In the formation of the lap the plate is upset, then bent around until the thickened edges lap sufficiently. It is then heated successively about 8 inches at a time, and welded over a mandrel, which is a cast-iron

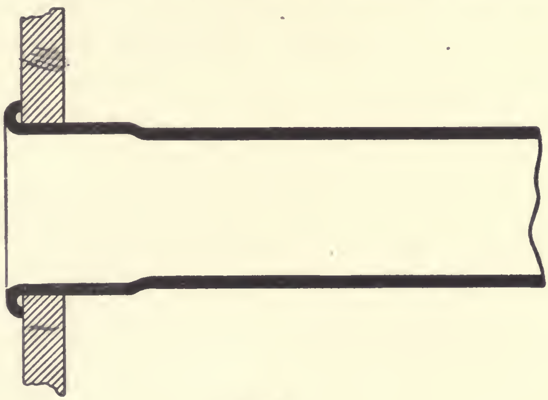


Fig. 41.

arm with a slightly convex top, over which the tube is placed Tubes are measured by their outside diameters, and are usually true to gauge, so that holes for them may be bored without taking measurements from the tubes themselves.

The holes for the tubes in the tube sheet are usually made in one of two ways. One method is to punch the tube holes the proper size by means of a helical punch. With this punch the metal is cut away by a shearing cut. The holes ought to be punched a little under size, and then reamed out, so that the surface against which the tubes are expanded may be good. The other method is to punch or drill a small hole at the point marking the center of the tube hole. A drill with a post in the center, which fits the small hole, then drills the desired size of hole.

Ordinary tubes are fastened to the end plates by expanding the metal of the tube against the tube plate. This is done by a tool called an expander, of which there are two common forms. One form consists of a steel taper pin and a number of steel segments, held in place by a spring. The outside of the segments

Fig. 42.

have the form to be given to the expanded tube, and the inside is a straight hollow cone, into which the steel taper pin fits. The segments are forced apart by hammering on the steel pin. In order that the metal of the tube may not be injured, the hammering should be done gradually and carefully, and the expander turned frequently. Another form, shown in Fig. 39, has a set of rolls that are forced against the inside of the tube by driving in the taper pin. The pin and rolls rotate as the pin is driven, and the rolls gradually expand the tube against the tube plate.

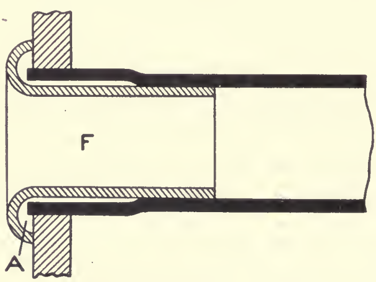


Fig. 43.

Two forms of tube expansion are shown in Figs. 40 and 41. That shown in Fig. 41 is preferable to that in Fig. 40, as the latter bears at the corners only, while the former bears against the entire thickness of the tube sheet.

After the tubes are expanded, the ends are beaded over, as shown in Figs. 40 and 41. This adds to the strength of the connection between the tube and tube sheet. The tool commonly used for this beading is shown in Fig. 42.

Ferrules are often placed in the ends of fire tubes, and serve to protect the ends from the intense heat of the fire. The arrangement is shown in Fig. 43, the ferrule F being placed within the tube for a short distance. The space A is merely an air space.

Stay tubes are not used as extensively at the present time as they were formerly. They were very common at a time when the holding power of expanded tubes had been experimented on but little. It is now apparent from such tests that the holding power of tubes expanded, as shown in Fig. 40, is more than equal to the pressure on the spaces between the tubes of an ordinary tube plate. Stay tubes are simply heavier tubes, with the ends pro-

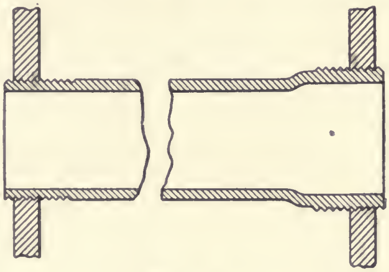


Fig. 44.

jecting beyond the tube sheet and threaded for shallow nuts. The ends of the tubes are frequently upset or thickened, and screwed into the tube sheet as well. This form is shown in Fig. 44.

FURNACE FLUES.

Flues which are subjected to external pressure should always be cylindrical. Fig. 45 shows the section of the Adamson

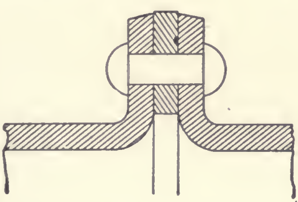


Fig. 45.

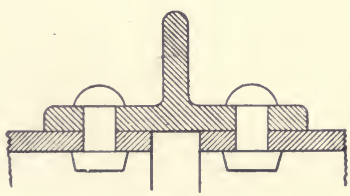


Fig. 46.

flue. This was an improvement over the plain furnace, as it is more elastic and allows expansion; the flanged rings also strengthen and stiffen it against collapse. The methods of building furnaces shown in Figs. 46 and 47 are not considered as good as the Adamson arrangement. Fig. 46 is too rigid, and does not allow a free expansion and contraction. Fig. 47, on the other hand, permits of such extremely well, but both have the fault of exposing a double thickness of plates and two rows of rivets to the fire.

The corrugated flue shown in Fig. 48 is popular and, furthermore, is excellent. There is freedom for expansion throughout its whole length, thereby reducing the strains on the boiler.

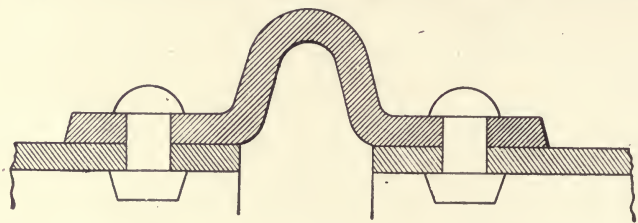


Fig. 47.

The plates should be thick enough to prevent sagging in the middle, the thickness usually varying from $\frac{5}{16}$ inch to $\frac{5}{8}$ inch. Corrugated furnaces are riveted to the rear tube sheet in the return tube boiler of the marine type, the end of the furnace being

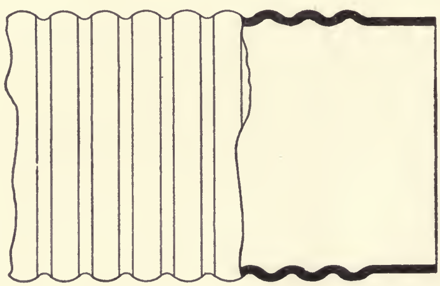


Fig. 48.

flanged at the front; and the head of the boiler is flanged around the opening cut for the furnace, which fits well into the flange.

CALKING.

In order that riveted joints of boilers may be steam and water tight, they generally require calking. This process upsets the metal of the overlapping plate, or burrs down the edge, forcing it into close contact with the lower plate, and rendering the joint steam tight.

The calking tool is similar to a chisel, the end having a variety of shapes. Fig. 49 shows a round-nosed tool which burrs down the upper plate without cutting the under plate; but it is hard to start, and in calking with such a tool the edge is first started with a sharper round-nosed tool, and then finished with one as indicated in the figure. If a square-end tool is used, as shown in Fig. 50, the under plate is likely to be cut, and the plates between the edge and the rivet be separated. The most common form of calking tool is one similar to the one shown in

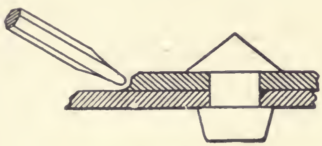


Fig. 49.

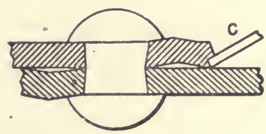


Fig. 50.

Fig. 49, except that the end is flat, with a slight bevel, and not round.

A slight bevel given the plates makes both calking and fullering more easily done. When the calking tool is thin it is sometimes driven by careless workmen into the joint, wedging the plates open. Severe and careless calking is very injurious to boilers. On the inside it often causes grooving and fracture, and the fracture of plates then follows the line of calking rather than the line of rivet holes. A pneumatic calking machine is often used in boiler shops, as it does this work about four times as rapidly as it can be done by hand. It resembles a rock drill in general principles. Air is supplied through a flexible tube, at a pressure of about 70 pounds per square inch. It makes about 1,500 strokes a minute.

BOILER DESIGN.

The rules of boiler design are controlled by practical considerations and theory, and are learned by the designer by practice only. The rules vary from place to place, and from time to time, due to progress in engineering.

The rules, methods and cautions taken up here are general, and with necessary modifications can be applied to all the more common types.

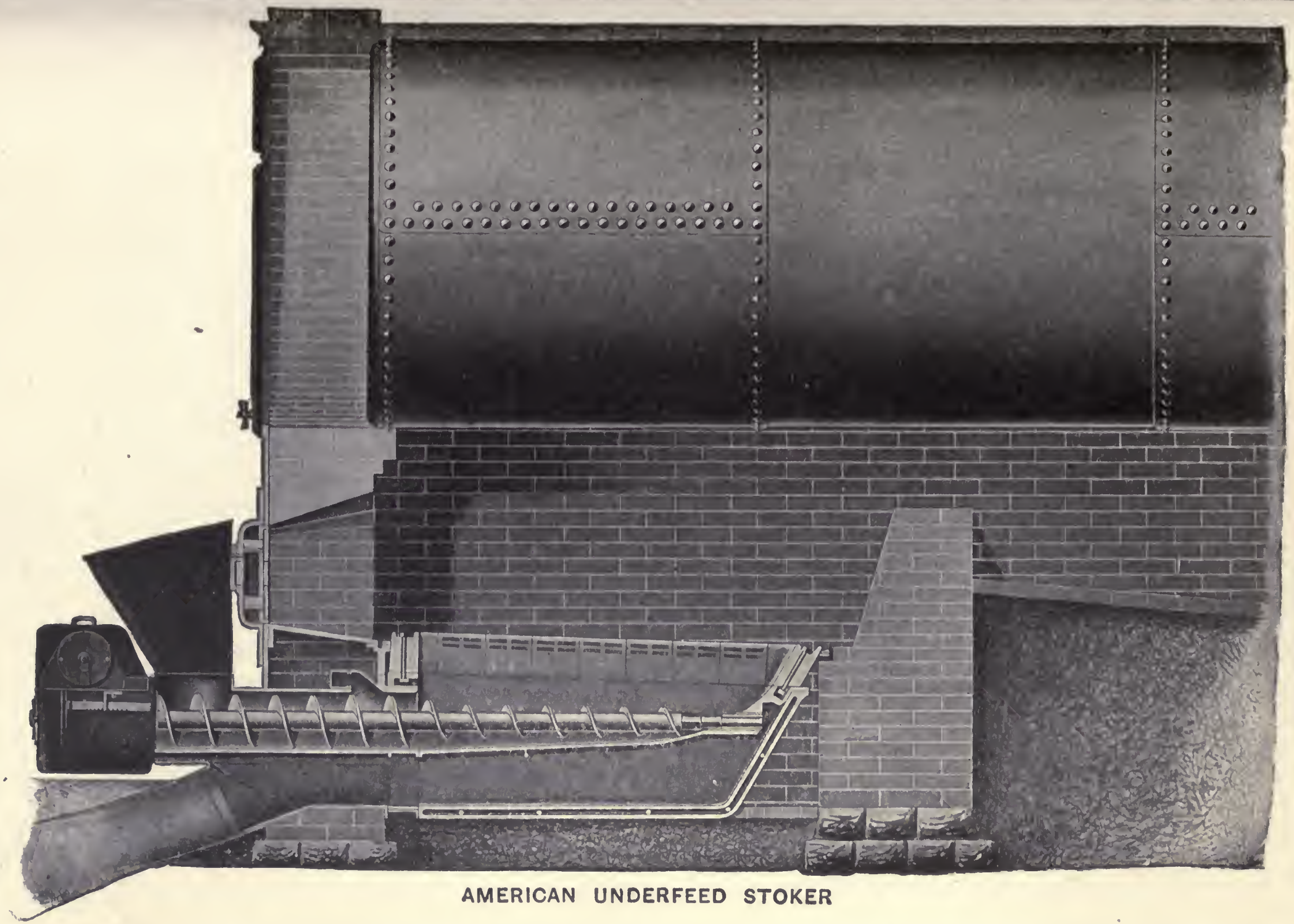
In designing a steam boiler there are several considerations that must be kept in mind. Among the most important are strength, durability, capacity to furnish the required amount of steam, convenience for cleaning, repairing and inspection, simplicity in detail, and economy both of running and first cost.

The kind, or type, to be used depends upon the work to be done, the dryness of the steam, the locality, the available space and preference of the owner. The work to be done is determined by the number and kind of engines, the constancy with which they run and the pressure. In choosing a boiler for any locality, the purity of the water, the kind of fuel and the laws which govern inspection and allowable working stress must be considered. The available space greatly influences the type and sometimes prevents choice. For instance, locomotive and marine boilers must be put in a small space. For land boilers if the floor area is limited, but there is ample height, some type of vertical boiler must be chosen.

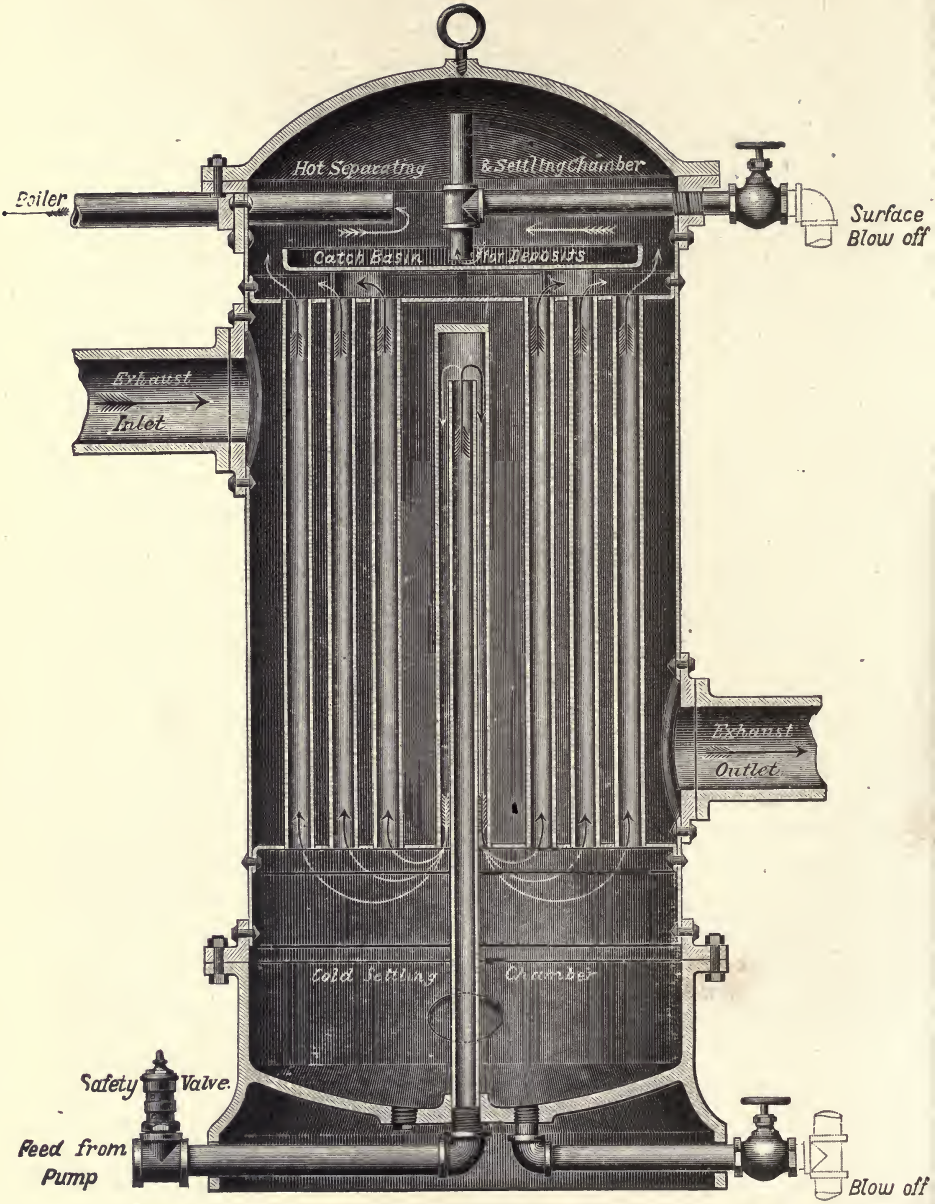
HORSE POWER.

The unit of horse-power as decided by the American Society of Mechanical Engineers is equal to 33,305 B. T. U. From the standard steam tables in treatises on Thermo-dynamics we find that 966 B. T. U. are required to evaporate one pound of water from and at 212° F. Therefore 1 H. P. is equal to the evaporation of $33{,}305 \div 966 = 34\frac{1}{2}$ pounds of water from and at 212° F. This is also equal to the evaporation of 30 pounds of water, at 100° F. into steam at 70 pounds gauge pressure.

The first thing to do is to chose the type of boiler we are to use. Then we find how many pounds of steam are to be supplied per hour; this is found by multiplying the desired horse-power by



AMERICAN UNDERFEED STOKER



REYNOLD'S FEED WATER HEATER

$34\frac{1}{2}$ or multiplying the horse-power of the engine or engines by the steam consumption per horse-power per hour. This is known approximately for every type of engine.

GENERAL REQUIREMENTS.

When we know these facts we design our boiler so as to have:

1. Sufficient area of grate to burn the required amount of fuel under the given draft.
2. Enough heating surface to absorb the heat of combustion.
3. Combustion chamber and flue area large enough to completely burn and carry off the products of combustion.
4. Water space sufficiently large so that a sudden demand will not cause too great a variation in water level.
5. Surface of water large compared to volume, in order that steam may be rapidly disengaged.
6. Steam space large enough to supply an irregular demand without causing a great change of pressure.
7. Steam outlet large enough to supply steam to the engine without wire-drawing.

If the outlet is not sufficiently large to supply plenty of steam, the demand will be greater than the supply and the steam will be throttled or wire-drawn, that is, it will lose some pressure.

For all common types of boilers, the proportions between the above requisites have been determined by experiment and mathematics. These relations, with simple calculations and good judgment on the part of the designer, are all that are needed for this work.

AREA OF GRATE.

A square foot of grate area will burn different weights of fuel in a given time, according to the nature of the draft. If the boiler can be made of any size, as is the case with many land boilers, a slow rate of combustion with natural draft is used, as it is the most economical. The length of the grate is limited by the distance to which a fireman can throw coal accurately. Usually 6 or 7 feet is the limit. In locomotive, torpedo boat and in some vertical land boilers, the size of grate is limited; in order to get the necessary work from the boiler, forced draft is used and the rate of combustion increases to over 100 pounds per square foot per hour. In Lancashire boilers, with two internal flues, the breadth is limited. The rate of combustion is stated in pounds per square foot of grate area per hour, and varies with the type of boiler and the draft. The following table gives the rates of combustion.

CHIMNEY DRAFT.

Cornish boilers, slow rate	4—6 lbs. per sq. ft. per hour.
Cornish boilers, ordinary rate	10—15 lbs. per sq. ft. per hour.
Factory boilers, ordinary rate	12—18 lbs. per sq. ft. per hour.
Anthracite coal, quick rate	15—20 lbs. per sq. ft. per hour.
Bituminous coal, quick rate	20—30 lbs. per sq. ft. per hour.
Marine boilers, ordinary rate,	15—25 lbs. per sq. ft. per hour.
Water tube boilers	10—25 lbs. per sq. ft. per hour.

FORCED DRAFT.

Marine boilers,	60—130 lbs. per sq. ft. per hour.
Locomotive boilers,	40—120 lbs. per sq. ft. per hour.

The evaporation per square foot of grate surface depends upon the type, the rate of combustion, condition of boiler and care in firing. The highest rate is obtained with slow rate of combustion, care and skill in firing, and clean plates and tubes. The table gives the equivalent evaporation per pound of coal for several types.

Plain cylindrical	5-- 8 pounds.
Vertical	7—10 pounds.
Cornish	6—11 pounds.
Lancashire	6½–12 pounds.
Galloway	9—12½ pounds.
Multitubular	8—12 pounds.
Water tube	6 –12 pounds.
Marine return tube	7—12 pounds.
Locomotive	6—12 pounds.

Experiment shows that an increase in the amount of coal burned per square foot of grate per hour gives an increase in the amount of water evaporated; but a decrease in amount evaporated per pound of fuel, or a decrease in economy.

To find the area of grate for a boiler. Let G = area of grate in square feet, R = rate of combustion in pounds per square foot per hour, E = evaporation per pound of coal.

$$\text{Then } G = \frac{\text{Pounds of water evaporated}}{E \times R}$$

Let us take an example. Suppose we have an externally fired multitubular boiler; assume the rate of combustion to be 12 pounds, and that our type of boiler will evaporate 9 pounds of water per pound of coal. How large must the grate be, if 2400 pounds of water are evaporated per hour?

$$G = \frac{2400}{E \times R} = \frac{2400}{9 \times 12} = 22.2 \text{ square feet.}$$

Then 22.2 square feet of grate surface are necessary. In this case the grate probably would be made 6 feet by 4 feet or 24 square feet.

TUBES.

On account of the small number of successful experiments concerning flues and chimneys, it is usual to proportion tubes, flues and chimneys, by comparison with those that have given good results. If the tubes are too large the hot gases in the centre pass up the chimney at high temperature. Now we will find the number of tubes. Let A = total area in square feet through which the smoke passes, that is, the combined internal area of all the tubes. The total area of the tubes, A, is usually made $\frac{1}{6}$ to $\frac{1}{8}$ the area of the grate. If we design our boiler to have the ratio 1 : 8 we probably will have enough area. Let us assume our tubes to be 3 inches in diameter and 16 feet long. From the table, on page 40, of lap welded boiler tubes we find that the internal area of a 3 inch tube is 6.08 square inches, the internal circumference is 8.74 inches, external circumference is 9.42 inches, and the external area is 7.07 square inches. As $\frac{1}{8}$ of our grate surface is $\frac{24}{8}$ or 3 square feet, or 432 square inches, the number of tubes will be $432 \div 6.08 = \mathbf{71}$.

LAP WELDED BOILER TUBES.

External Diameter. Inches.	Internal Diameter. Inches.	Thickness. Inches.	Internal Circumference. Inches.	External Circumference. Inches.	Internal Area. Square Inches.	External Area. Square Inches.	Length of tube per sq. ft. inside. Feet.	Length of tube per sq. ft. outside. Feet.	Weight per foot. Lbs.
1	.856	.072	2.689	3.142	.575	.785	4.460	3.819	.708
1¼	1.106	.072	3.474	3.927	.960	1.227	3.455	3.056	.900
1½	1.334	.083	4.191	4.712	1.396	1.767	2.863	2.547	1.25
1¾	1.560	.095	4.901	5.498	1.911	2.405	2.448	2.183	1.665
2	1.804	.098	5.667	6.283	2.556	3.142	2.118	1.909	1.981
2¼	2.054	.098	6.484	7.069	3.314	3.976	1.850	1.698	2.238
2½	2.283	.109	7.172	7.854	4.094	4 909	1.673	1.528	2.755
2¾	2.533	.109	7.957	8.639	5.039	5.940	1.508	1.390	3.045
3	2.783	.109	8.743	9.425	6.083	7.069	1.373	1.273	3.333
3¼	3.012	.119	9.462	10.210	7.125	8.296	1.268	1.175	3.958
3½	3.262	.119	10.248	10.995	8.357	9.621	1.171	1.091	4.272
3¾	3.512	.119	11.033	11.781	9.687	11.045	1.088	1.018	4.590
4	3.741	.130	11.753	12.566	10.992	12.566	1.023	.955	5.32
4½	4.241	.130	13.323	14.137	14.126	15.904	.901	.849	6.01
5	4.720	.140	14.818	15.708	17.497	19.635	.809	.764	7.226
6	5.699	.151	17.904	18.849	25.509	28.274	.670	.637	9.346
8	7.636	.182	23.989	25.132	45.795	50.265	.500	.478	15.109
10	9.573	.214	30.074	31.416	71.975	78.540	.399	.382	22.190
12	11.542	.229	36.260	37.699	103.749	113.097	.330	.318	28.516
16	15.458	.271	48.562	50.265	187.667	201.062	.247	.238	45.200
20	19.360	.320	60.821	62.832	294.373	314.159	.197	.190	66.765

STEAM SPACE.

The steam space is frequently designed as some fraction of the volume of the shell, usually about $\frac{1}{3}$. A better way is to design it from the steam consumption of the engine. Suppose the engine uses 30 pounds of steam at 75 pounds pressure per H. P. per hour. The absolute pressure then is 90 pounds (nearly) and the specific volume at that pressure is 4.85 (from steam tables). As steam is being generated at an approximately constant rate, the supply kept on hand need not be great. If the surface for the disengagement of steam is sufficient, the ratio of the steam space to the volume of the cylinder is from 50 : 1 to 150 : 1 depending upon the speed of the engine. Experiment shows that if the steam space is equal to the volume of steam consumed by the engine in 20 seconds, it is sufficient. If the space is only equal to the steam used in 12 seconds, there may be a considerable quantity of water carried over with the steam. If the engine is slow speed, that is less than 60 revolutions per minute, the steam space should be larger.

The volume of the steam space per H. P. will be the number of pounds of steam used per H. P. in 20 seconds, multiplied by its specific volume, or $\frac{30 \times 4.85 \times 20}{60 \times 60} = .81$ cubic feet (nearly) per H. P.; and if the engine is of 75 H. P. our steam space will be $.81 \times 75 = 60.75$ cubic feet.

TUBE SPACE.

The space occupied by the tubes is equal to their volumes. The volume of one tube is its external area multiplied by the length in inches. The total volume, in cubic inches, is the above result multiplied by the number of tubes. This is reduced to cubic feet by dividing by 1728. The space occupied by the tubes will be

$$\frac{71 \times 7.07 \times 16 \times 12}{1728} = 55.77 \text{ cubic feet.}$$

WATER SPACE.

Then if we assume our steam space to be $\frac{1}{3}$ the volume of the available space in the shell, the water space will be twice the steam space, or $2 \times 60.75 = 121.5$ cubic feet.

DIMENSIONS OF BOILER.

The volume of the boiler will be:

Steam space	$.81 \times 75 =$	60.75 cubic feet.
Tube space	$\frac{71 \times 7.07 \times 16 \times 12}{1728} =$	55.77 cubic feet.
Water space	$.81 \times 75 \times 2 =$	121.5 cubic feet.
Total space		238.02 cubic feet.

Since the tubes are 16 feet long the area of the end will be

$$\frac{238.02}{16} = 14.87 \text{ square feet.}$$

This area gives a diameter of about $4\frac{1}{3}$ feet or 52 inches. We will make the boiler $4\frac{1}{2}$ feet or 54 inches in diameter. Then the boiler will be 16 feet long and 54 inches in diameter; with 71 tubes 3 inches in diameter. For moderate power, a common rule is to make the length about $3\frac{1}{2}$ times the diameter; by this rule our boiler is 3.55 times the diameter.

HEATING SURFACE.

The portion of a boiler that is exposed to the flames and hot gases is called the heating surface. This is made up of the portions of the shell below the brickwork, the exposed ends, and the internal surface of the tubes. If the boiler is of the water tube type, the exterior surface of the tubes is taken in place of the interior surface.

If our boiler is an ordinary multitubular boiler we can assume the heating surface to be the total inside area of the tubes plus one-half the area of the shell. Then:

Heating surface of tubes $\frac{8.74 \times 71 \times 16}{12} = 827.38$ square feet.

Heating surface of shell $\frac{14.137 \times 16}{2} = 113.10$ square feet.

940.48 square feet.

The ratio of heating surface to grate surface will be

$$\frac{940.48}{24} = 39.2 \text{ or about } 39.$$

As this ratio is high enough we will not alter our figures. If the ratio had been too low we could have added more tubes and found a new boiler diameter. The heating surface should not be less than 1 square yard or 9 square feet per horse-power. So $940.48 \div 75 = 12.54$ or our boiler has 12.54 square feet of heating surface per horse-power. This is of course abundantly sufficient.

The capacity of heating surface to transmit heat to water depends upon conductivity, position of surface and temperature of furnace. In designing it is safe to follow proportions of heating surface to grate area in the various types, which experience has shown to give the best results. The following are the proportions for a few types.

Kind of Boiler.	Ratio of Heating Surface to Grate Surface.
Marine, Return tube,	25—38
Lancashire boiler,	26—33
Cornish,	27—32
Horizontal, internally fired,	40—50
Water tube,	34—65
Locomotive boiler (forced draft),	30—34
Marine,	28—32

RATIO OF GRATE SURFACE TO HORSE-POWER.

The ratio of grate surface to horse-power varies with the type, as is shown below.

Kind of Boiler.	Ratio.
Plain cylindrical,	.5 to .7
Multitubular,	.4 to .6
Vertical,	.6 to .7
Water tube,	.3
Lancashire,	.1 to .165
Marine return tube,	.12
Locomotives,	.02 to .06

Makers of boilers sometimes estimate the H. P. by the heating surface. That is the horse-power is a fraction of the heating surface. The ratio of heating surface to H. P. for several types is as follows:

Plain cylindrical,	6 —10
Multitubular,	14 —18
Vertical,	15 —20
Water tube,	10 —12
Marine return tube,	3.25— 4
Lancashire,	2.75— 4.25
Locomotive,	1 — 2

It is evident that some portions of the heating surface of a boiler have greater efficiencies than others. For instance, more heat will pass through the crown sheet as it is nearer the fire than through the last few feet of the tubes. Taking the efficiency of the crown sheet as 1, an estimate of the percentage of the other parts of a boiler is as follows:

Crown of furnace in flue,	.95
Plates of cylindrical boiler over furnace,	.90
Fire box tube plate of locomotive boiler,	.80
Water tube surface facing fire,	.70
Vertical side of fire box,	.50

If a cylindrical multitubular boiler is divided into equal sections, the section nearest the fire will evaporate more water than the one at the other end, as the gases have a higher temperature at the first section. Suppose we divide the boiler into six sections of equal length, and call the total evaporation 100 per cent. Then the per cent of evaporation per section will be approximately as follows:

Section	1	2	3	4	5	6
Evaporation	47	23	14	8	5	3

If the length of a boiler is increased another section, the evaporation will be increased a little but at the same time the radiating surface is increased. In case the addition of a section for evaporation causes a loss by radiation nearly equal to the gain in evaporation, it is not economical to add the section on account of the extra cost of the boiler. If forced draft or an increase of air of dilution is used, the boiler should be made longer to avoid waste. The air of dilution is the amount of air above that which is necessary to burn the coal.

WATER LEVEL.

If the steam space in a multitubular boiler is known the water level can be found, for the section of the steam space is a segment of a circle. In the above boiler the required steam space is 60.75 cubic feet; hence the segmental area is 60.75÷16 or 3.8 square feet, or 547.2 square inches. The height of this segment is 15.55 inches. This height is found either by calculation or from a table of segments. Then the mean water level is 15.55 inches from the top portion of the shell. The variation of water level in a boiler of this type and size should not exceed 6 inches.

END PLATE.

The end plate or tube sheet is usually made $\frac{1}{16}$ or $\frac{1}{8}$ inch thicker than the shell plates. This is done for additional stiffness, and increase of strength; the plate being weakened by drilling the holes for the ends of the tubes.

The tubes should be arranged in vertical and horizontal rows, if possible, in order that the rising bubbles of steam may not be hindered. To get good circulation the horizontal spaces should be a little greater than the vertical, and a central circulating space should be provided, if the necessary number of tubes can be put in without using the entire space. The tubes should be from $\frac{3}{4}$ to 1 inch apart, and to prevent burning of the tubes, the top row at least 3 inches below the water level, and the bottom tubes 6 inches from the shell. At this point, a drawing of the end plate should be made, to show the arrangement of tubes, etc. If it is impossible to put in the required number of tubes, without raising the water level, the diameter of the boiler must be increased. If we wish to increase the heating surface without increasing the diameter we can use smaller tubes or make the boiler a little longer.

STRENGTH OF BOILERS.

According to Pascal's Law, liquids and gases exert pressure equally in all directions. Steam in a boiler exerts the same pressure on all portions of the shell. As the pressure inside a boiler is considerably greater than that outside (the atmospheric pressure), there is a tendency to burst the shell. This tendency is resisted by the plates of the boiler.

A sphere is the strongest form to resist pressure, for since pressure is equal in all directions, there is a tendency towards enlarging the sphere and not to rupture. But a sphere has the smallest area for a given volume and, as a large heating surface is desirable, and on account of mechanical difficulties, a spherical boiler is never used. The boiler is made cylindrical to obtain greater heating surface and the loss in strength is made up by staying.

In the consideration of the strength of cylinders it is usual to divide the rupturing strains into two classes; those which tend to rupture the cylinder longitudinally and those which tend to rupture it circumferentially or transversely.

Let us examine them separately. The tendency to cause longitudinal rupture or to rend the cylinder in lines parallel with the axis, may be considered as the pressure exerted on a semi-circumference, and tending to rupture the cylinder in a plane through the diameter. Since pressure acts equally in all directions, the whole amount exerted on a semi-circumference is not exerted directly upwards and downwards. But all these forces may be resolved into their vertical and horizontal components. If we take the plane as horizontal, it is evident that the horizontal components have no tensional effect at the points of rupture. By taking the vertical components at an infinite number of points it can be proved that their sum is equal to the full pressure exerted on a rectangular plane equal to the projection of the cylindrical surface. In this case the projection is the plane through the diameter and has an area equal to the product of the length of the cylinder multiplied by the diameter of the cylinder. Then the force tending to rupture would be the pressure per square inch multiplied by the area. Let p = pressure in pounds per square inch, D = diameter of boiler, t = thickness of plate, L = length of boiler, S = tensile strength, E = efficiency of joint, and f = factor of safety. The force tending to rupture longitudinally will be, pLD. The strength of the cylinder to resist this rupturing force is represented by the tensile strength of the material multiplied by the areas of sections of metal. Or expressed algebraically is 2tLS. When rupture is about to take place the rupturing force and the strength are equal, or

$$pDL = 2tLS \quad \text{or} \quad pD = 2tS$$

from which $p = \frac{2\,t\,S}{D}$ and $t = \frac{pD}{2S}$ which are the formulas for pressure and thickness and for longitudinal strength.

The extra pressure due to increased length is balanced by the increase of metal as is shown by the elimination of the factor L of the equation.

The tendency to rupture circumferentially is evidently represented by the area of the end or $\frac{\pi D^2}{4}$ multiplied by the pressure per square inch. The strength to resist this force is the area of metal to be ruptured multiplied by the tensile strength or πDtS

$$\frac{\pi D^2}{4} \times p = \pi DtS$$

$$Dp = 4tS$$

By comparing these two formulas we see that with the same internal pressure, diameter and thickness of shell, a cylindrical boiler is twice as strong transversely as it is longitudinally, hence the greatest tendency to rupture is along the longitudinal seams.

Therefore, in designing the thickness of shell we use the formula for longitudinal rupture,

$$pD = 2tS \text{ or } t = \frac{pD}{2S}$$

or, inserting the factors for efficiency of joint and factor of safety,

$$pD = \frac{2tSE}{f}$$

$$\text{For allowable pressure} \quad p = \frac{2tSE}{fD}$$

$$\text{For thickness of shell} \quad t = \frac{fDp}{2SE}$$

Now let us find the thickness of the boiler that we are designing. Suppose after testing our material we find that its ultimate tensile strength is 54,000 pounds per square inch. In this case 6 will be sufficiently large for a factor of safety. This factor can be reduced if the efficiency of the joint is large. Let us assume that our joint has an efficiency of 70%. This is merely a supposition because we have not yet constructed the joint; but we assume a factor in order to find a trial thickness.

$$\text{Then } t = \frac{fDp}{2SE} = \frac{6 \times 54 \times 75}{2 \times 54000 \times .7} = .32 \text{ or about } \tfrac{5}{16} \text{ inches.}$$

RIVETED JOINTS.

The best knowledge of the strength and proportions of riveted joints can be obtained by tests of full sized pieces. Let us consider the strength and efficiency mathematically. Riveted joints may fail in several ways. 1. By shearing the rivets. 2. By tearing the plate at the reduced section between the rivets. 3. By crushing the plate or rivets where they are in contact. 4. By cracking the plate between the rivet hole and the edge of the plate. As the lap in practice can always be made sufficiently wide a joint need never fail in this last way.

As all stresses may be resolved into the three kinds, tensile, compressive and shearing, we will investigate for these stresses. Let P = the tensile stress transmitted from one plate to the other by a single rivet, t = the thickness of the plate, d = the diameter of the rivet, p = the pitch, and S_t, S_s and S_c the unit stresses in tension, shear and compression respectively produced by P on the plates and rivets. Therefore the tension on the plate, P will be equal to the area of the metal between the rivets multiplied by its unit tensile stress, or

$$P = t\,(p - d)\,S_t$$

For shear, P will equal the area of the rivet multiplied by the unit shearing stress, or

$$P = \tfrac{1}{4}\,\pi\,d^2 S_s$$

For compression, the stress is supposed to be equivalent to a stress uniformly distributed over the projection of the cylindrical surface on a plane through the axis of the rivet. Then P will be equal to the area of the projection multiplied by the unit compressive stress, or

$$P = tdS_c$$

The above formulas are for single riveted lap joints. If another row of rivets is used the plates should have a wider lap. Let p = the pitch in one row; then the stress will be distributed over two rivets.

The three formulas in this case will be.

$$P = t(p - d)S_t$$
$$P = 2 \times \tfrac{1}{4}\pi d^2 S_s$$
$$P = 2\,tdS_c$$

For single riveted butt joint, the shear comes on two rivets; this is called double shear. The above formulas become

$$P = t(p - d)S_t$$
$$P = 2 \times \tfrac{1}{4}\pi d^2 S_s$$
$$P = tdS_c$$

The efficiency of a joint is the ratio of its allowable stress to the allowable stress of the uncut plate. The allowable stress of the plate is represented by the formula ptS_t.

Then the efficiency for tension is, $E = \dfrac{t(p - d)S_t}{ptS_t} = \dfrac{p - d}{p}$

$$\text{For shear, } E = \frac{\tfrac{1}{4}\pi d^2 S_s}{ptS_t} \text{ or } \frac{\tfrac{1}{4}\pi d^2 S_s c}{ptS_t}$$

$$\text{For compression, } E = \frac{tdS_c}{ptS_t} \text{ or } \frac{dS_c}{pS_t} \text{ or } \frac{dS_c a}{pS_t}$$

In the above formulas, a = the number of rivets in the width p, and c = the number of rivet sections in the same space. The smallest value of E is to be taken as the efficiency of the joint

In designing, we try to get a joint in which all parts will have equal strength or the resistance of the plate to tension will equal the resistance of the rivets to shearing and each will equal the resistance of the rivet to compression or crushing. This will be the case if the three efficiencies are equal.

Solving for d in the second and third we get

$$\frac{\tfrac{1}{4}\pi d^2 S_s c}{ptS_t} = \frac{dS_c a}{pS_t} \text{ or } d = \frac{4aS_c t}{\pi c S_s}$$

If we know t we can find d from the above equation.

To find the pitch we make the first equation equal to the third, or the formula for tension equal that of compression, and solve for p

$$\frac{p - d}{p} = \frac{dS_c a}{pS_t},\ p = d\left(\frac{S_c a}{S_t} + 1\right)$$

substituting the value for d, obtained above,

$$p = \frac{4\ aS_c t}{\pi\ cS_s}\left(\frac{S_c a}{S_t} + 1\right)$$

To get the formula for efficiency we insert these values for d and p, in any of the formulas for efficiency already obtained. For instance:

$$E = \frac{p - d}{p} = \frac{\frac{4\ aS_c t}{\pi\ cS_s}\left(\frac{S_c a}{S_t} + 1\right) - \frac{4\ aS_c t}{\pi\ cS_s}}{\frac{4\ aS_c t}{\pi\ cS_s}\left(\frac{S_c a}{S_t} + 1\right)}$$

$$E = \frac{1}{1 + \frac{S_t}{aS_c}}$$

A good joint can be designed without these formulas (in fact they serve as a guide only), if attention is paid to the rules deduced from tests and conforming to good practice by experienced engineers and boiler makers. In designing a riveted joint, good practice favors the following:

The pitch of rivets, for single riveting, should be about $2\frac{1}{2}$ times the diameter of the rivets and for double riveting about $3\frac{3}{4}$ times the diameter.

The pitch near a calked edge must not be too great for proper calking.

Rivets must not be too near together.

The lap, or the distance from the centre of the rivet to the edge of the over-lapping plate should be at least $1\frac{1}{2}$ times the diameter of the rivet.

The diameter of the rivet is usually nearly twice the thickness of the plate and should never be less than the thickness of the plate.

The riveted seam must contain a whole number of rivets. and similar seams should have the same pitch.

The distance between rows, for double riveting, is about twice the diameter of the rivets.

In double butt riveting the rivets in double shear have $1\frac{3}{4}$ times the single section instead of 2.

The thickness of double butt straps should not be less than $\frac{5}{8}$ the thickness of the plate (each); single butt straps not less than $\frac{9}{8}$.

No one set of rules can be laid down for the best pitch of rivets for all circumstances of pressure, quality of plates, etc. The following table of proportions of riveted joints gives results for average practice in boilers of up to about 150 pounds pressure.

TABLE OF LAP JOINTS.

Thickness of Plate. Inches.	Diameter of Rivet. Inches.	Diameter of Hole. Inches.	Pitch. Inches.		Efficiency.	
			Single Riveted.	Double Riveted.	Single Riveted.	Double Riveted.
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	3	.66	.77
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{8}$	.64	.76
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{8}$	$3\frac{1}{4}$	.62	.75
$\frac{7}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{3}{8}$	.60	.74
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$3\frac{1}{2}$	.58	.73

As the stress on the transverse section is one-half that on a longitudinal section, a single or double lap joint is sufficient for any ring seam. For externally fired multitubular boilers with shell plates less than $\frac{1}{2}$ inch thick, single riveted ring seams are used. For our boiler, the plates being $\frac{5}{16}$ inch thick, we will use rivets $\frac{11}{16}$ inch in diameter, as this agrees with good practice. From the table, the pitch for a $\frac{11}{16}$ inch rivet for single riveted lap joint is $2\frac{1}{16}$. Then as our ring seam is $3.1416 \times 54 = 169.65$ inches and pitch $2\frac{1}{16}$ inches we will have 82 + rivets. But as we must have a whole number of rivets we will alter the pitch slightly and use 82 rivets with a pitch of 2.069 inches. The result depends, in each case, upon the kind of joint used in longitudinal seams. This merely shows the general method. The lap will be $\frac{11}{16} \times \frac{3}{2} = 1\frac{1}{32}$ inch.

For the longitudinal seams we will use double butt joints with single riveting. The thickness of the butt straps will be $\frac{5}{16} \times \frac{5}{8} = .20$ (nearly). To be on the safe side we will make the butt straps $\frac{1}{4}$ inch thick. The pitch for double butt joints is usually about 4 times the diameter of rivets, so in this case it will be $4 \times \frac{11}{16} = 2\frac{3}{4}$ inches. We will use the same amount of lap for this joint as for the lap joint, that is $1\frac{1}{32}$ inches.

SECTIONS.

The boiler is made up of rings or sections. The length of sections is often made equal, for convenience in ordering and cutting plates. The length is limited by the width of plate obtainable and the size of the riveting machine. This boiler being 16 feet long would probably be made in three sections, but the lengths should be so adjusted as not to bring the ring seam over the hottest part of the fire.

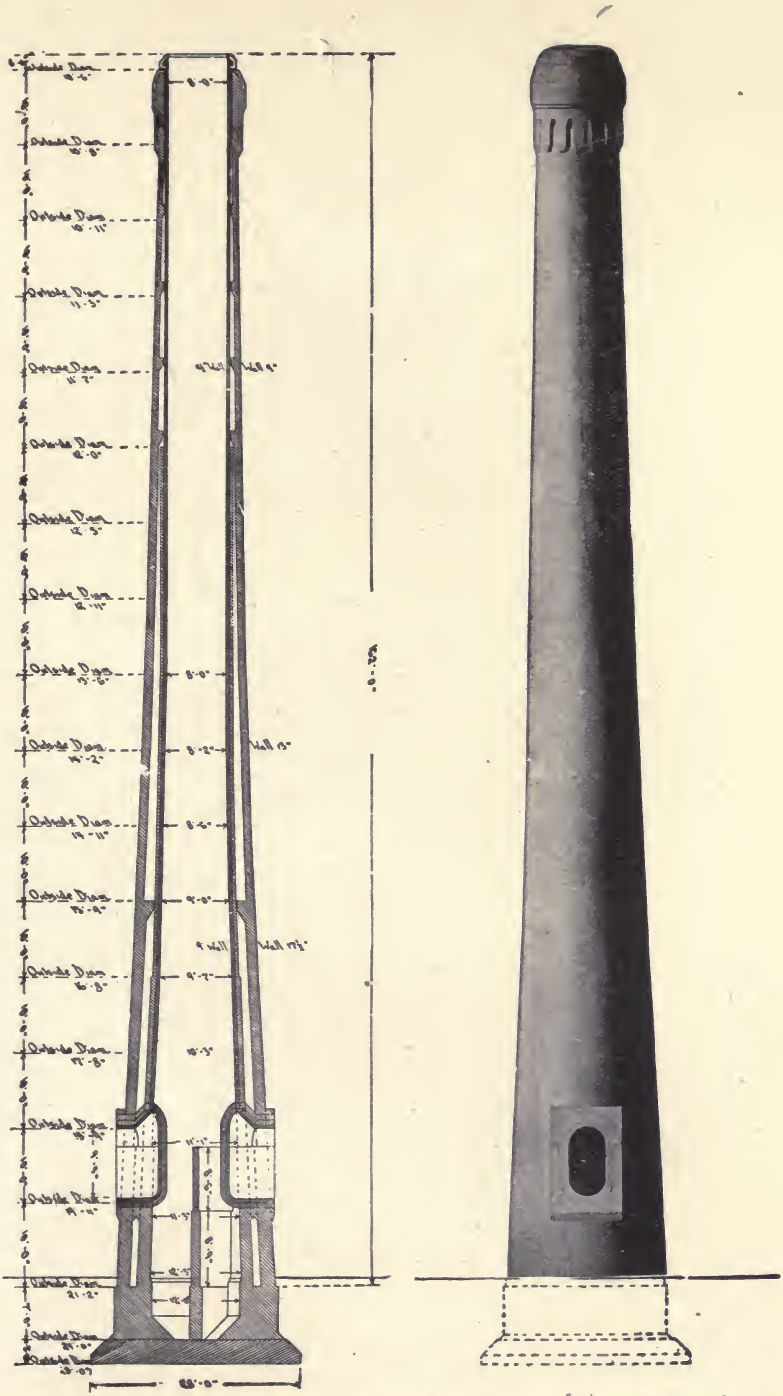
FLUES.

The internal pressure at which the boiler shell will rupture can be calculated; but the external pressure which will collapse a flue can be determined only by experiment. External pressure tends to increase any imperfection of shape. For instance, if a flue is slightly oval, the external pressure tends to make it more flat. The strongest form to resist external pressure is evidently the circle. When considering the strength of flues length is very important.

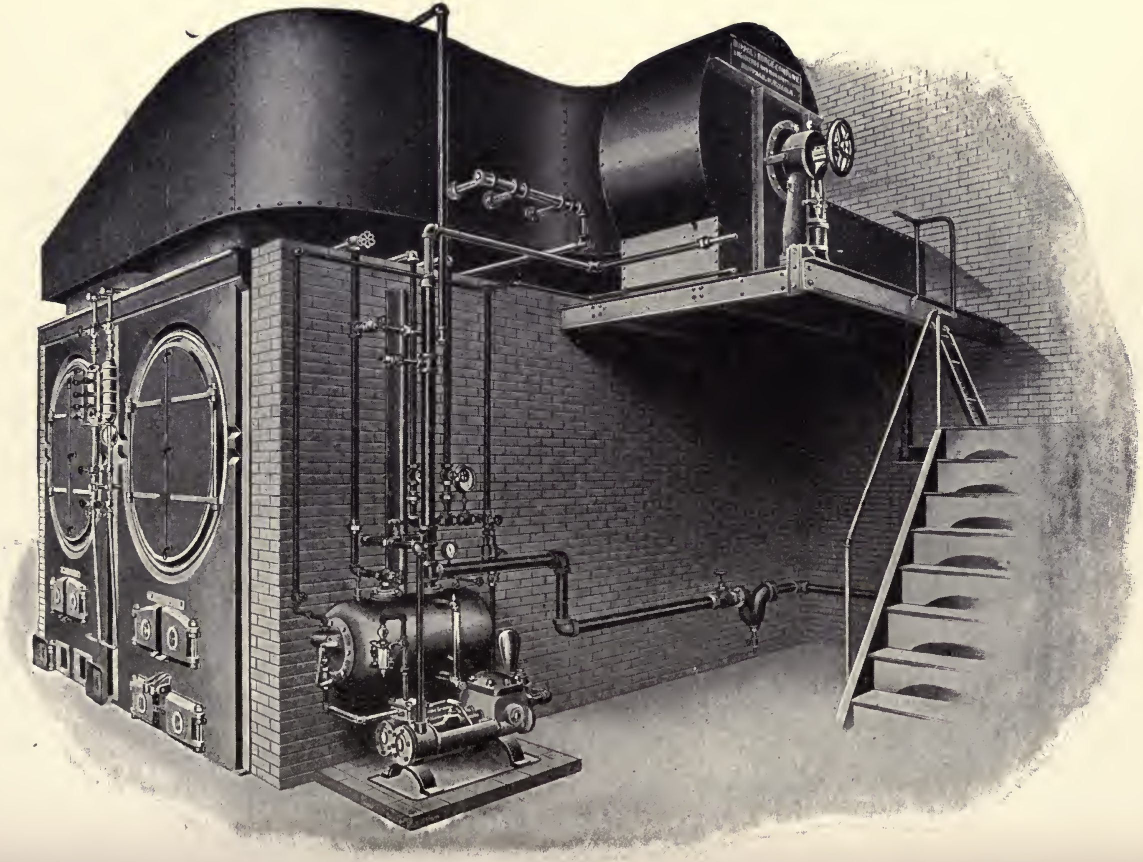
If a lap joint is used the flue will not be a true cylinder, for this reason welded or butt joints are preferable.

Fairbain gives the formula, $P = \frac{806{,}000\ t^{2.19}}{ld}$ for calculating the collapsing pressure of flues, l = length of flue in feet, d = diameter in inches, t = the thickness in inches, P = pressure per square inch. The exponent of t is often taken as 2 instead of 2.19 for convenience. This formula is empirical and was prepared from his experiments.

Hutton gives, $P = \frac{C\ t^2}{d\sqrt{L}}$. In which C is a constant, which is 600 for wrought iron and 660 for mild steel, L = length in



Brick Chimney of the Union Depot R'y Co., St. Louis, Mo.



STEAM FAN FOR INDUCED DRAFT

At the Works of the Buffalo Forge Company.

inches, d = external diameter in inches, and t = thickness in *thirty-seconds* of an inch. Results by Hutton's formula agree more nearly to those by experiment than do Fairbain's.

If the flues are oval, d in the above formula = the major axis.

Flues are strengthened by putting in hoops at stated distances. These hoops are made of T iron or angle iron.

TUBES.

The materials for tubes are iron and steel. The tubes must be tough to resist cutting by cinders. If iron is used it should have a tensile strength of at least 45,000 pounds per square inch, with an elongation of 15 to 20 per cent. If steel, the elongation should not be less than 26 per cent, when tested before being rolled. If the steel welds well there need not be any limit to its tensile strength. The ends of tubes should be annealed after manufacture. The thickness of tubes is always greater than that required to prevent collapsing, in order to weld and expand in the tube sheet. It is often desirable to use part of the tubes as stays; for this purpose the tubes are made thick enough to take a shallow nut outside the tube plate.

STAYING.

As large a portion as possible of the shell of a boiler is made cylindrical, for in this form plates can be made sufficiently strong without the aid of stays or braces. But all flat surfaces must be stayed; not only to prevent rupture, but also to provide against distortion and grooving. The theoretical investigation of the strength of flat surfaces, can be worked out only with higher mathematics. From the formula deduced, the solid end plate would have to be about 2 inches thick for a boiler only 3 feet in diameter with plates $\frac{3}{8}$ inch thick. It is evident that the flat ends if of ordinary thickness must be strengthened by stays or braces. The calculation of stresses in a flat plate, supported by stays, can be calculated only when the supported points are in rows thus dividing the surface into equal squares. Even when the stays are not to be placed in rows forming squares, it is well to make the calculation for a standard.

The equation for finding the area supported by a stay rod is,

$$a^2 = \frac{9t^2S}{2p}$$

in which a^2 = the area supported, t = the thickness of the end plate, S = the allowable stress on the area of the rod, and p = the working steam pressure. Let us find the area supported in our multitubular boiler. In order to provide for future corrosion we will use a factor of safety of 12 and assume, in the absence of exact knowledge, the ultimate breaking strength of the rod to be 60,000 pounds per square inch. It is usual to make the diameter of the rods one to two inches, so we will make ours $1\frac{1}{2}$ inches in diameter with an area of 1.767 square inches. Then the stress per rod is 5,000 × 1.767 = 8,835 pounds.

$$a^2 = \frac{9t^2S}{2p} = \frac{9 \times \frac{1}{4} \times 8{,}835}{2 \times 75} = 132.5 \text{ square inches.}$$

Then as the rod supports 132.5 square inches and the segment of the steam space is 547.2 square inches, the number of rods will be $\frac{547.2}{132.5} = 4$.

The same formula will apply in finding the number of short screw stay bolts of the fire box.

Suppose we wish to use a diagonal or crow foot stay, making an angle of 20° with the shell. If the rod is 1 inch in diameter and the stress is limited to 7,000 pounds, then it will carry a pull of .7854 × 7,000 = 5497.8 pounds, and since it makes an angle of 20°, the pull perpendicular to the head will be 5497.8 × cos. 20° = 5497.8 × .9397* = 5,166 pounds. If the end is fastened by two rivets or bolts each will carry 2,583 pounds. If each rivet or bolt supports a square with a side equal to a, then 5,166 = 75 a^2

$$a^2 = \frac{5166}{75} = 68.9 \text{ square inches (nearly).}$$

* **Note. Taken from a table of cosines.**

UPTAKE.

The area of the uptake, like the area of the tubes, is made about $\frac{1}{7}$ to $\frac{1}{8}$ of the area of the grate. We find that $\frac{1}{8}$ of the grate surface is 432 square inches. If we make the uptake 12 inches deep measured with the length of the boiler, it will be 432 ÷ 12

= 36 inches wide. The opening of the shell at the front end will be 12 inches deep and the plate cut down until it is 36 inches wide.

MANHOLES.

The manhole and handhole should be strong enough and stiff enough to sustain the stresses due to the direct steam pressure and from the stresses of the plates. The calculation of the strength of the manhole ring is difficult and the results obtained very uncertain, so they are made of forms and dimensions that have been used in good practice and given good results. These fittings are bought in steel forgings. Boiler makers design the forged rings which lie close to the shell, of a section at least equal to the section of the plate that is cut out. The bearing surfaces of the manhole cover and that of the lip against which the cover bears, should be machined to make a good smooth joint. The joints are made tight by gaskets about $\frac{3}{4}$ of an inch wide.

Hand holes are constructed similarly to manholes, and often have a taper key in place of a bolt and nut, because the nut is exposed to fire and after it has been in place some time, is often difficult to remove with a wrench.

BRACKETS.

Boilers of the multitubular types are supported by brackets usually made of cast iron. Boilers up to 16 feet long have four brackets and those more than 16 feet long have six brackets. The brackets for this boiler should be about 10 inches long, measured with the length of the boiler, and about 15 inches wide. They are riveted to the boiler with nine or ten rivets $\frac{7}{8}$ to 1 inch in diameter. The rivets can be made large, as a large rivet makes a strong joint, and in this case the pitch is not governed by calking.

The load on the brackets can be estimated by calculating the weight of the boiler full of water and adding the weight of all the parts supported by the boiler. These parts include pipes, valves, gauges, brickwork covering, etc. This load should be divided as nearly equal as possible among the four brackets, so that the tendency of the boiler toward bending shall be small.

Brackets are set above the middle line of the boiler in order that the flanges may be protected by the brickwork setting. They are usually 3 or 4 inches above the middle.

CHIMNEYS.

At the present time, the knowledge of chimneys and chimney draft is slight. The theories given are worth but little as they are based upon data which is entirely insufficient. As to the design and proportions of chimneys, there are no systematic statements and rules that can be used.

Chimneys are usually designed from empirical formulas and from tables, compiled from proportions of chimneys that have furnished sufficient draft, etc.

The draft produced in a chimney is due to the difference in temperature, and consequently difference in pressure, between the gases inside the chimney, and the air outside. The gases in the chimney being lighter rise toward the top and air rushes in at the bottom to fill the space left by the hot gases. This air as it becomes heated grows lighter and rises, thus a continuous circulation is kept up. The temperature of the gases in the chimney is considered to be about 600° F. for chimney calculation, as practice shows this to give good draft under economical conditions.

After making several assumptions, based on experiments, the following formula has been deduced:

$$H.\ P. = 3.33\ (A - .6\ \sqrt{A})\ \sqrt{h}$$

in which H. P. = horse-power, A = area of the chimney, and h = the height above the grate.

The following table on page 46 has been calculated from this formula. This table is used to a considerable extent with satisfactory results.

The part of the table which is used for ordinary proportions is filled in. If proportions are taken from the table rather than from the formula, the results will give better proportions.

To find the area of the top of the chimney for a given coal consumption, the following empirical formula has been stated.

$$A = \frac{H.\ P. \times B \times 12}{\sqrt{h}}$$

in which A = area, H. P. = horse-power of boiler, B = number of pounds consumed per H. P. per hour and h = height of chimney in feet.

This area A is the area in square inches at the top.

Diameter, in Inches.	Height of Chimneys and Commercial Horse-power.											Side of square in inches.	Effective area, square feet.	Actual area, square feet.
	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.			
18	23	25	27									16	0.97	1.77
21	35	38	41									19	1.47	2.41
24	49	54	58	62								22	2.08	3.14
27	65	72	78	83								24	2.78	3.98
30	84	92	100	107	113							27	3.58	4.91
33		115	125	133	141							30	4.48	5.94
36		141	152	161	173	182						32	5.47	7.07
39			183	196	208	219						35	6.57	8.30
42			216	231	245	258	271					38	7.76	9.62
48				311	330	348	365	389				43	10.44	12.57
54					427	449	472	503	551			48	13.51	15.90
60					536	565	593	632	692	748		54	16.98	19.64
66						694	728	776	849	918	981	59	20.83	23.76
72						835	876	934	1023	1105	1181	64	25.08	28.27
78							1038	1107	1212	1310	1400	70	29.73	33.18
84							1214	1294	1418	1531	1637	75	34.76	38.48
90								1496	1639	1770	1893	80	40.19	44.18
96									1876	2027	2167	86	46.01	50.27

Another method which is much more simple is to design the area of the chimney, as we have designed the total tube area; that is, about $\frac{1}{8}$ the grate area. This ratio for chimneys is sometimes about $\frac{1}{7}$ and decreases to $\frac{1}{9}$ and for very tall chimneys to $\frac{1}{10}$.

From the table we find the chimney to have an area at the top of about 3.98 square feet, assuming it to be 60 or 70 feet high. This area gives a diameter of 27 inches if circular, or 24 inches if square.

Let us calculate it from the formula $A = \frac{H. P. \times B \times 12}{\sqrt{h}}$

We must either assume or calculate B. As the calculation is very easy it would be better than any assumption. The total amount of coal burned per hour equals 12 × 24 or 288 pounds. The amount per H. P. per hour is 288 ÷ 75 or 3.84 pounds.

Then assuming the chimney to be 60 feet high,

$$A = \frac{.75 \times 3.84 \times 12}{\sqrt{60}} = 446$$ square inches, or about 24 inches in diameter if circular and 21 inches if square.

By the last method the area of the chimney will be 24 ÷ 8 or 3 square feet, or 432 square inches, giving practically the same result as with the formula.

As the table is reliable and gives us the larger area, we will use it and be on the safe side; also as the amount of coal burned per hour by the draft in a chimney can be found by multiplying the horse-power in the above table by 5, the chimney with an area of 3.98 square feet and 60 feet high will burn $72 \times 5 = 360$ pounds of coal per hour. The boiler in question burns only 288 pounds, so the chimney is sufficiently large.

Chimneys are usually of brick or of steel plates. If of steel they are always circular. When made of brick they are circular, square or hexagonal. With a given draft area, a circular chimney requires the least material, since a circumference has the least perimeter for a given area; it also presents less resistance to wind.

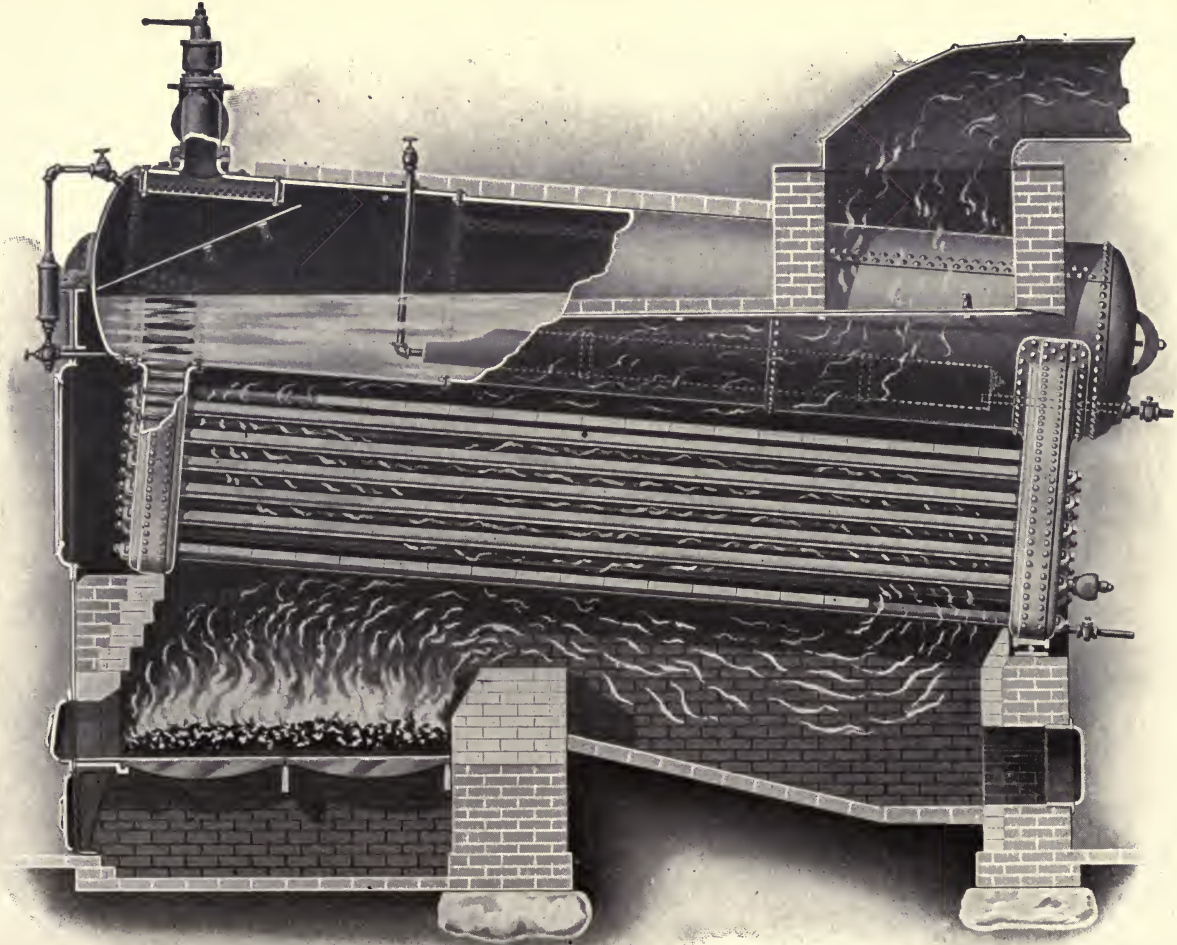
A steel chimney is made up of plates of steel riveted together. The shell is bolted through a foundation ring of cast iron to the stone foundation. It has a straight taper to the top, which is finished, for appearance with light plates. The shell is lined with fire-brick, with a thickness which varies from 12 to 18 inches at the bottom to about 2 to 4 inches at the top. This lining is used to prevent heat being lost from the shell and does not add to the strength of the chimney.

A brick chimney is built in two parts; *a* the outer shell, which resists wind pressure and *b*, the lining which is the flue. This flue is made separate from the external shell in order that it may expand, when the chimney is full of hot gases, without straining the outer shell.

The interior of both steel and brick chimneys are often cylindrical while the exterior tapers. The taper is about .3 inch to the foot. The brick at the base of the chimney is splayed out to make a large base.

As good natural earth should carry from 2000 to 4000 pounds per square foot, the base of the chimney should be large enough so that this pressure will not be exceeded.

The external shell is calculated for wind pressure and the weight of brick. This calculation for wind pressure involving higher mathematics will not be treated here. The lining is calculated for compression due to weight. The design, both of the chimney and its foundation, should be made by a competent engineer of experience, on account of disastrous results should a chimney fall.



FRANKLIN WATER TUBE BOILER.

TYPES OF BOILERS.

Generally speaking, a steam boiler is a closed metallic vessel in which steam is generated from water by the application of heat. As steam is under pressure it is evident that the vessel must be strong and tight.

To operate the boiler safely and economically there must be certain fittings and accessories—some of these are used in the care of the boiler, while others serve to increase the economy. Among the most important attachments and appurtenances may be mentioned the following:

A feed pump or injector, with valves, piping, etc., to supply water to the boiler.

Gage cocks and glass water gage to show the attendant the height of water or the water level, as it is called, in the boiler.

A pressure gage to show the pressure of steam in the boiler. The pressure is usually measured in pounds per square inch.

A safety valve to allow steam to escape from the boiler when the pressure exceeds a certain fixed amount. This attachment, being a safety device, should be automatic and reliable.

A blow-off pipe, with its valves, to blow out sediment from the boiler, reduce the amount of water in the boiler, or empty it.

A steam pipe, with its valves, to conduct the steam from the boiler to the place where it is to be used.

Manholes and handholes, with covers, for examination, repairs, and cleaning.

* **Fusible plugs** to give warning when the water level becomes too low, or melt and allow the water to escape.

* **High- and low-water alarms** to give warning when the water level is too high or too low.

* **A heater** to raise the temperature of the feed water as nearly as possible to that of the water in the boiler.

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*NOTE. Although the last three are desirable, they are not absolutely necessary, as a boiler can be successfully operated without them.

In addition to these there are other attachments such as:

Lugs or brackets for supporting the boiler.

Masonry for setting the boiler and keeping it in position, and in many cases to keep the hot gases in contact with the shell.

Furnace fittings, including grate bars, bearer bars, dampers, fire doors, ashpit doors, etc.

The chimney to carry away the waste gases and create draft.

Tools, such as shovels, slice bars, scrapers, tube brushes, etc.

DEFINITIONS.

The following definitions should be remembered in connection with the terms used in designating the various classes.

A fire-tube boiler is one having the heating surface composed largely of tubes which are surrounded with water, the hot gases passing through them.

A water-tube boiler is also composed of tubes, but in this case *water* flows through the tubes, while the hot gases pass around and among them.

In a sectional boiler the tubes and corresponding headers form comparatively small units. Each unit is complete in itself; that is, it is in communication with a steam and water drum but is independent of the other units.

A non-sectional boiler is one having all the tubes in communication with one another; in other words, all or nearly all the tubes are expanded into a common header or drum. The boiler is not made up of units.

A single-tube boiler is made up of plain tubes.

A double-tube boiler has a small tube inside of the regular tube and concentric with it.

A boiler is **externally-fired** when the furnace is separate from the shell; in such boilers the fire is usually placed in a brick furnace.

In the **internally-fired** boiler the grate is inside of a flue which is within the shell.

A fire-box boiler is one having the fire within a fire box which, although external to the shell, is rigidly connected to it. The fire box is usually made of steel plates instead of brick as in the case of the externally-fired boiler.

CLASSIFICATIONS.

The almost endless variety of boilers now in use is due largely to the many conditions under which they are used. Other reasons for the numerous forms are the great latitude in design and construction, and the competition among engineers, who have, during the last century, sought to produce, at moderate cost, steam generators that will be safe, durable, and economical.

The necessity for careful classification before discussing the details is apparent when one considers the similarities and differences. Much valuable time may be saved by selecting some make of boiler to represent a given class. Still further, the classification reduces the chances of overlooking interesting features.

CLASSIFICATION.

According to Use.

- **Stationary**
  - Early Forms.
  - Plain Cylindrical
  - Single Flue, Externally-fired
  - Flue Boilers
    - Cornish (single-flue)
    - Lancashire (two-flue)
    - Galloway
  - Multitubular
    - Externally-fired
    - Internally-fired (return-tube)
  - Fire-box Boilers
    - Horizontal
    - Vertical
  - Water-tube Boilers
    - Straight-tube
    - Curved-tube
    - Horizontal
    - Vertical
    - Sectional
    - Non-sectional
  - Mixed Types
  - Peculiar Forms
- **Marine**
  - Early Forms (box or rectangular)
  - Scotch or Drum
  - Return-tube
  - Through-tube
  - Water-tube
    - Curved-tube
    - Straight-tube
    - Sectional
    - Non-sectional
  - Launch Boilers
- **Locomotive**
  - Multitubular fire-box (common form)
  - Wooten Type
  - Corrugated Furnace
  - Peculiar Forms

Boilers may be classified in many ways. They may be divided into the following great classes: Fire-tube and water-tube, vertical and horizontal, stationary and non-stationary, or externally-fired and internally-fired. They may also be classified according to uses or according to forms of construction. For illustration, two classifications, of which the following seems better for this discussion, are given.

CLASSIFICATION.

According to Form of Construction.

Early Forms.

- **Flue**
  - Cornish (single-flue)
  - Lancashire (two-flue)
  - Galloway
  - Single Flue (externally-fired)
- **Fire-tube** (Multitubular)
  - Horizontal (common form)
  - Vertical
  - Return-tube
  - Through-tube
  - Fire-box
  - Peculiar Forms
- **Water-tube**
  - Horizontal
    - Straight-tube
    - Curved-tube
      - (Straight-tube and Curved-tube:) Sectional
      - (Straight-tube and Curved-tube:) Non-sectional
  - Vertical
    - Straight-tube
    - Curved-tube
  - Peculiar Forms

Mixed Types.

EARLY FORMS.

The earliest boilers of which we have reliable record were spherical. They were of cast iron and set in brickwork. It was customary to set this type of boiler with the fire underneath and construct flues in the brickwork to conduct the hot gases around the boiler just below the water level. The hot gases passed entirely around the boiler before escaping to the chimney.

The Haystack Boiler. The next form to be generally used was that invented by Newcomen in 1711. On account of its peculiar shape it was called the "Haystack" or "Balloon" boiler. It was of wrought iron and had a hemispherical top and arched bottom. The fire was placed underneath the arched portion; the hot gases surrounding the lower part of the boiler. An improved form of the Haystack boiler is shown in Fig. 1. Smeaton placed the fire inside the shell and arranged internal flues for conducting the hot gases to the chimney. This arrangement increases the heating surface and consequently the economy of the boiler.

The Wagon Boiler. To still further increase the heating surface, James Watt introduced his "Wagon" boiler. This form is shown in Fig. 2. The top was cylindrical and the sides curved inward. The curved plates assisted in the formation of flues on either side. The hot gases passed from the grate, underneath the boiler to the rear, through the left-hand flue to the front, then through the right-hand flue to the rear and thence to the chimney. This was called the *wheel draft* because the gases passed entirely around the boiler. In the large sizes a flue was placed in the boiler. The products of combustion returned through this flue to the front after passing under the boiler to the rear, as in the small sizes. On issuing from the flue at the front, the gases divided and passed to the chimney at the rear by means of the flues in the brickwork. This form of draft was called the *split draft*.

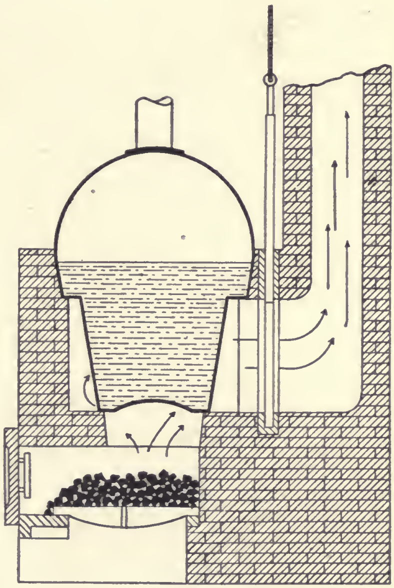


Fig. 1.

Watt used a column of water in the vertical feed pipe as a pressure gage; the rise and fall of this column also controlled the damper. The feed was regulated by a float.

MODERN BOILERS.

Although such boilers as the Haystack, Wagon, and others were fairly satisfactory in the period in which they were invented, they could not stand the higher pressures that soon became common.

About the beginning of the nineteenth century the cylindrical boiler was introduced. The earliest forms were the plain cylindrical boiler and the "Egg-end" boiler. The difference was in the form of the ends — those of the former were flat and of cast iron, while the ends of the latter were hemispherical and made of wrought iron. The egg-end boiler required no staying or bracing because its form is, with the exception of a sphere, the strongest to resist internal pressure.

The Cylindrical Boiler consisted of a shell of wrought-iron boiler plate and ends of the same material or of cast iron. It was

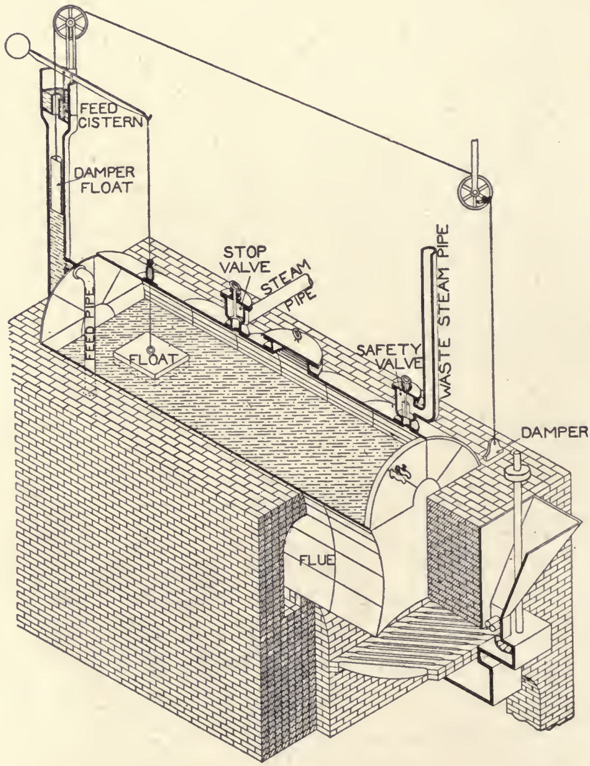
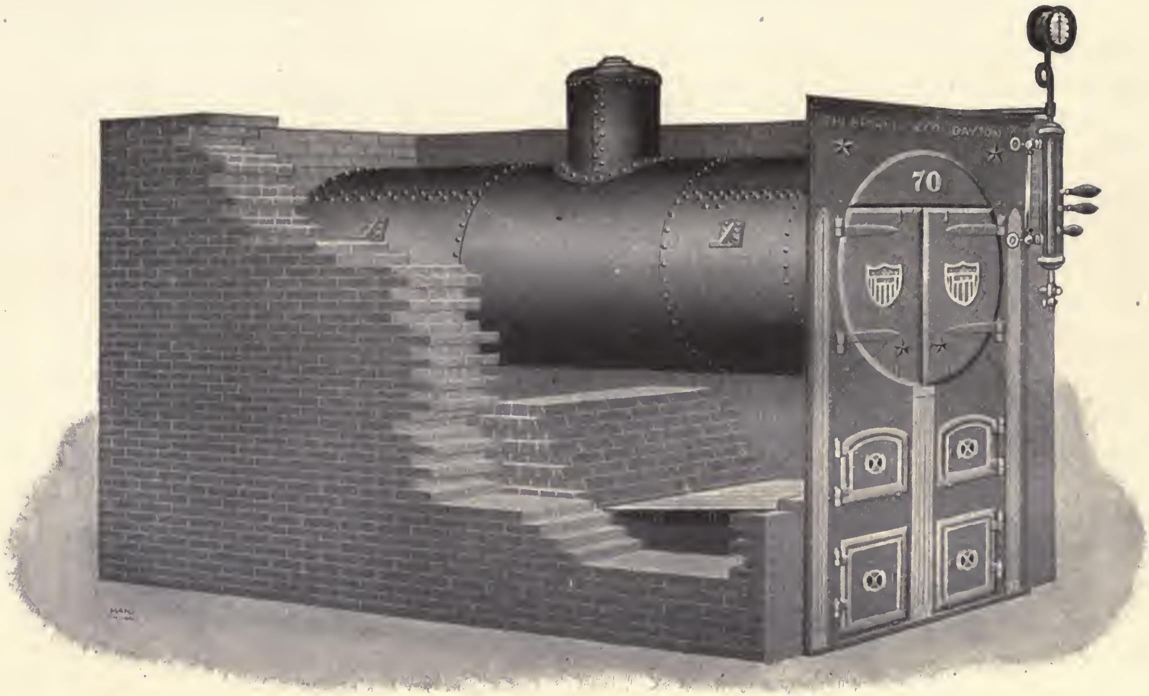
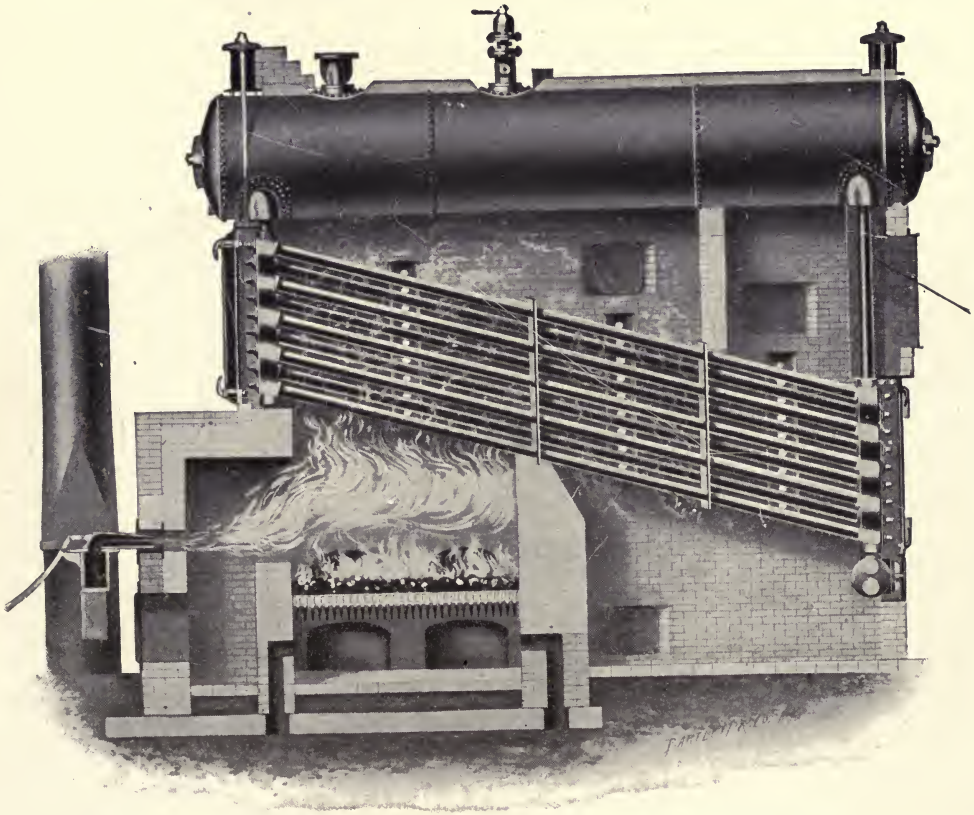


Fig. 2.

set in brickwork as shown in Fig. 3. The boiler was about two-thirds filled with water, the remaining third forming the steam space. To collect and store the steam as it rose from the water a steam dome was added. The steam pipe was attached to the dome to which the safety valve also was connected. The hot gases from the fire passed under the boiler to the rear and then to the chimney.



MULTITUBULAR BOILER.
The Brownell Company.



Section of Babcock and Wilcox Boilers Fitted with Kennedy Burners for Burning Blast Furnace Gas.

The heating surface of this type is small with a given diameter unless the boiler is made very long. As all sediment collects in the bottom, where the heat is most intense, the plates are liable to burn. Since sediment and scale are poor conductors of heat, the heat remains in the plates and overheats them instead of flowing to the water.

The disadvantages (the small heating surface and the collection of sediment) do not seem so serious when one considers the

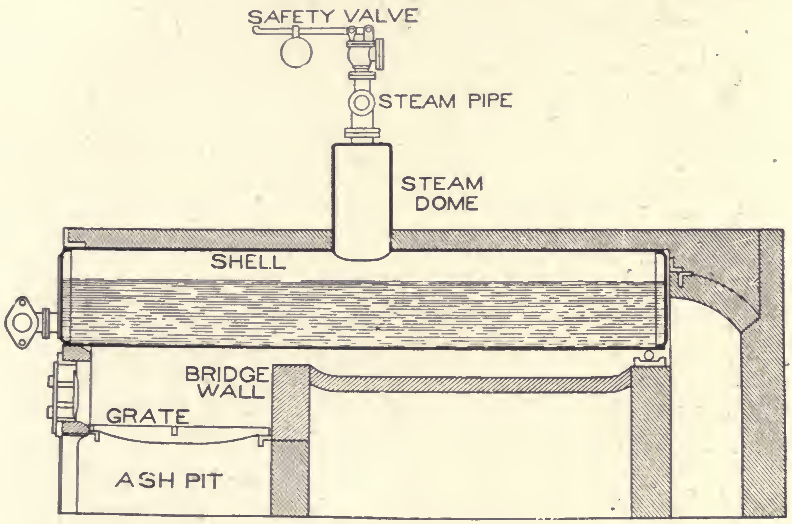


Fig. 3.

simplicity of construction, strength, durability, and ease of repairing and cleaning.

The plain cylindrical boiler was adapted for mining districts, iron works and other places where fuel is abundant and skilled boiler makers are not readily found. This boiler was made very long to get the required heating surface, the length sometimes exceeding fifty feet.

FLUE BOILERS.

In order to get the necessary heating surface in the cylindrical boiler without making it excessively long, it was made with an internal flue through which the hot gases passed to the chimney. This flue was quite large and extended from end to end. In the

United States, Oliver Evans used this type in 1800. In England, it led to the internally-fired flue boilers which were so extensively used.

THE CORNISH BOILER.

Horizontal—Single=Flue—Internally=Fired.

When it was found that about 25 per cent of the total heat of combustion was lost by radiation from the furnace, a Cornish

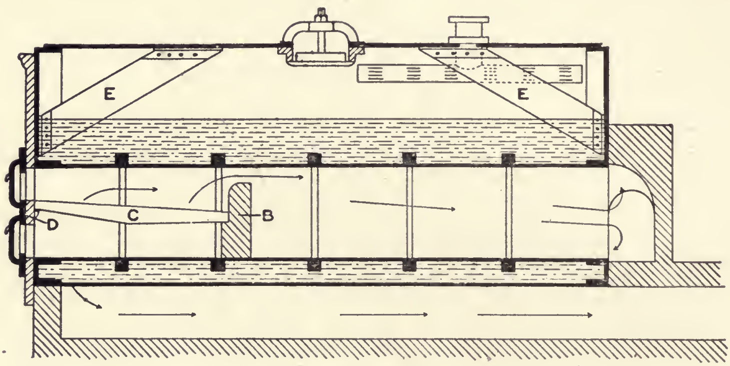


Fig. 4.

engineer named Trevithick, conceived the idea of placing the fire inside the large internal flue. He introduced this type which is known as the Cornish boiler.

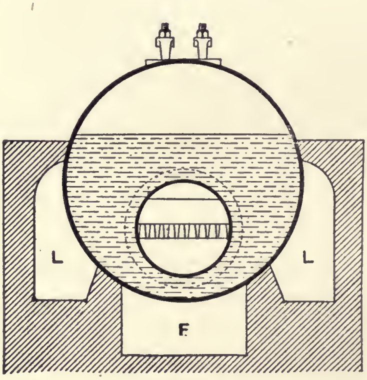


Fig. 4*a*.

The products of combustion pass from the fire on the grate bars C (Fig. 4) through the flue to the back end where they divide and return to the front end by means of the lateral flues L in the brickwork. See Fig. 4*a*. At the front the hot gases pass downward, and uniting pass through the flue F in contact with the bottom of the boiler. On leaving the boiler they go to the chimney. This arrangement of flues reduces the temperature of the gases before they come in contact with the bottom of the boiler where sediment collects. The grate bars rest on the dead plate D at one end and on the bridge B at the other; if made in two lengths (as is often the case) they are supported at the center by a cross bearer. The bridge is built of fire brick and the external flues are lined with fire brick. The heads are stayed to the shell by gusset stays E E.

The large internal flue is the hottest portion of the boiler because it contains the fire. For this reason the flue has greater linear expansion than the shell and, if the flue is a plain cylinder, the increase in length causes the ends to bulge. When the

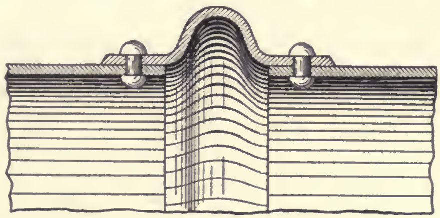


Fig 5.

boiler is cold, the flue returns to its normal length. This lengthening and shortening will soon loosen the flue at the ends. To overcome this, the flue is sometimes made up of several short rings flanged at the ends and joined by being riveted to a plain ring. This construction is shown in section in Fig. 4. Another method

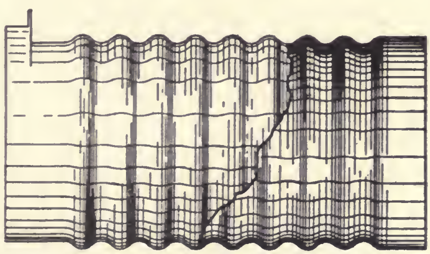


Fig. 6.

is shown in section in Fig. 5. The plain ring is riveted to the curved ring; this ring takes up the expansion, increases the heating surface, and strengthens the flue against external pressure. The same results may be obtained by the use of the corrugated flue, one form of which is shown in Fig. 6. The corrugated flue has many advantages over the devices shown in Figs. 4 and 5; it is frequently used in marine boilers.

LANCASHIRE BOILER.

Horizontal—Two-Flue—Internally-Fired.

It can be proved, both by experiment and calculation, that with a given thickness large cylinders cannot stand as much external pressure as small ones. For this reason and on account of the short distance a fireman can throw coal accurately, the Cornish boiler is suitable for small powers only. If it is made too large, the flue is liable to collapse, but if, on the other hand, the flue is of too small a diameter, the grate will be insufficient. If this form of boiler is to be used in large size it is modified by using two flues instead of one. This boiler is called the Lanca-

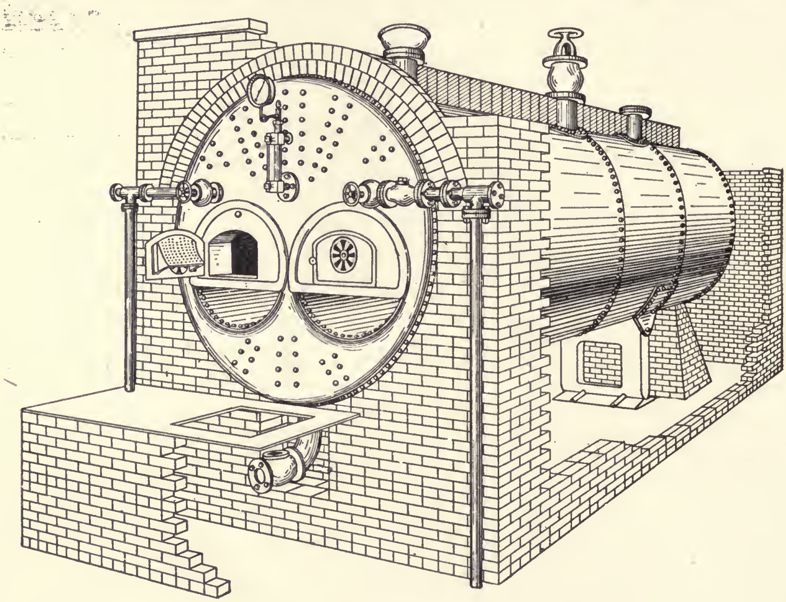


Fig. 7.

shire boiler. It is like the Cornish type except that it has two flues and, of course, two furnaces.

The flues are sometimes continued separately to the end. If they merge into one large flue, which forms the combustion chamber, it is called the "Breeches-flued" or duplex furnace boiler. These furnaces are fired alternately; the unburned gases set free from the freshly-fired coal are burned on meeting the hot gases from the incandescent coal of the other furnace. This arrangement prevents the escape of the unburned hydrocarbons.

The disadvantage of the Lancashire boiler is the difficulty in finding room for the two flues without greatly increasing the diameter of the boiler. Also, the small furnace is unfavorable to complete combustion as the space for the uniting and burning of the hydrocarbons is restricted. The combustion chamber of the breeches-flued boiler provides the necessary space, but the construction at the junction of the two flues is weak and has been the cause of many explosions.

GALLOWAY BOILER.

Horizontal—Two-Flue—Internally-Fired—Galloway Tubes.

Another boiler of the same general form is the Galloway, shown in Fig. 7. This boiler differs from the Lancashire in that short tubes are added to the flues. In the Galloway boiler having two distinct flues, the tubes were placed as shown in Fig. 8.

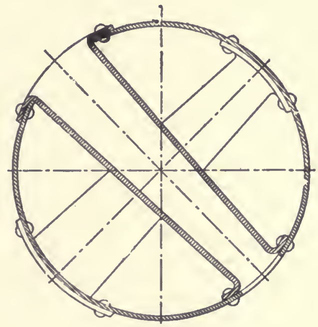


Fig. 8.

In the later form of Galloway boiler, the two flues merge into one large flue of the shape shown in Fig. 9. This flue has corrugated sides and the conical tubes are staggered, thus insuring a thorough breaking up of the currents of hot gases. The tubes are

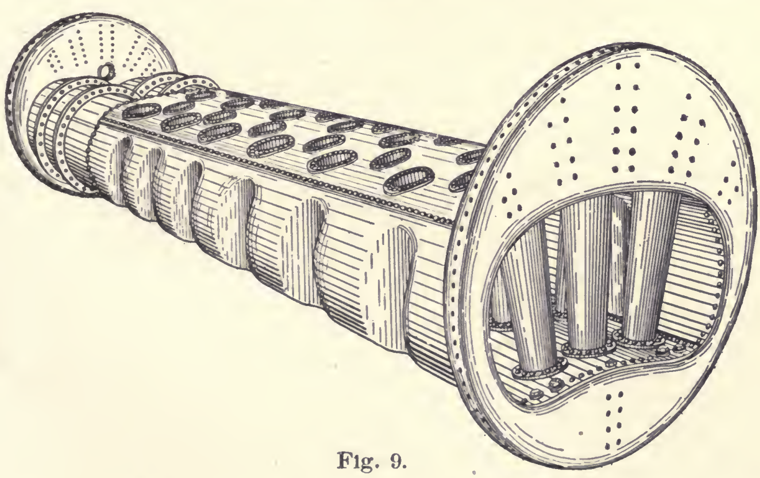


Fig. 9.

made conical to facilitate removal for repairs. The shape of the tube also permits the water to expand on being heated, and the particles rise vertically without disturbing the water on the heating surfaces above. The conical tubes are generally riveted rather than welded because the removal of a tube that is welded leaves a large hole in the flue.

FIRE-TUBE BOILERS.

SINGLE-FLUE BOILER.

Horizontal—Single Fire Tube—Externally-Fired.

In the Cornish, Lancashire, and Galloway boiler the large internal flue served as a fire box. There was, however, a flue

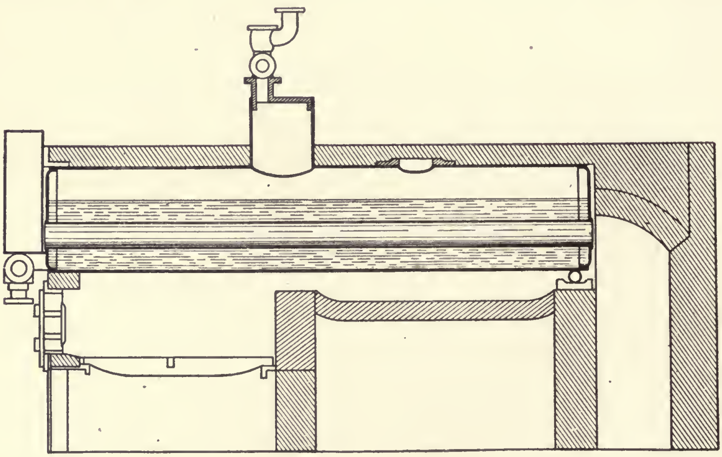


Fig. 10.

boiler having the fire external to the shell. The boiler shown in Fig. 10 resembles the plain cylindrical boiler both in appearance and setting, but it has one or more large flues extending from end to end. This flue increases the heating surface to such an extent that the boiler can be considerably shorter than the plain cylindrical.

MULTITUBULAR BOILER.

Horizontal—Many Small Fire Tubes—Externally-Fired.

When engineers found that the internal flue was such an advantage (that is, it increased the heating surface), they soon added more tubes; as the number increased, the size diminished until they became of the size used at present. This is in brief the development of the multitubular boiler. This type of boiler has for many years been commonly used for stationary work and although other types possess advantages for certain conditions, it is still considered economical, reliable, easily handled, and safe if constructed of good material and operated with care and intelligence.

Figs. 11 to 14 are selected to illustrate this boiler. The boiler without the brick setting is shown in Fig. 11. It consists of a

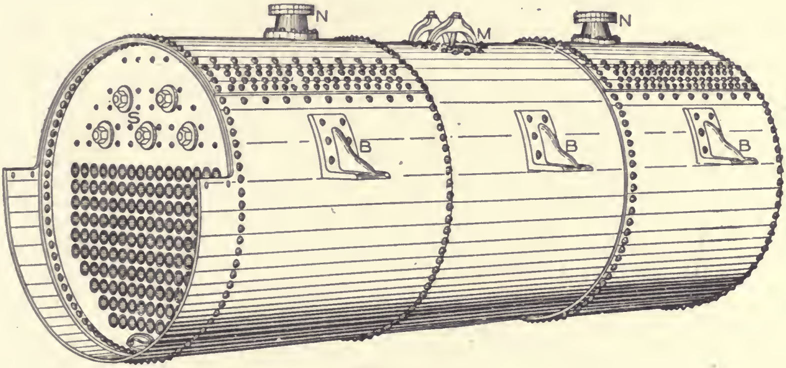


Fig. 11.

steel cylindrical shell and numerous small tubes extending from end to end. These tubes are 3 or 4 inches in diameter and are fastened to the two ends (called tube sheets) by expanding the tubes against the sheet and beading them over on the outside. The shell is made of steel plates $\frac{1}{4}$ to $\frac{3}{4}$-inch in thickness. At the front, the shell plates extend beyond the tube sheet and are cut away to allow the waste gases to enter the uptake. About one-third the volume of the boiler is occupied by the steam; the other two-thirds is filled with water and tubes. The water line is a little (from 4 to 8 inches) above the top row of tubes.

The flat ends are prevented from bulging by stays which may be of the form shown in Fig. 12 or they may be diagonal stays. The through stays are fastened to the tube plates by means of nuts and washers as shown at S in Fig. 11, and also in Fig. 12. Below the water level, the end plate is stayed by the tubes. This type of boiler may be supported by brackets B riveted to the shell or by means of beams and columns, as shown in Fig. 14. The front bracket is often fixed in the side wall, but the rear bracket should be placed on rollers so that it can move on an iron plate. This

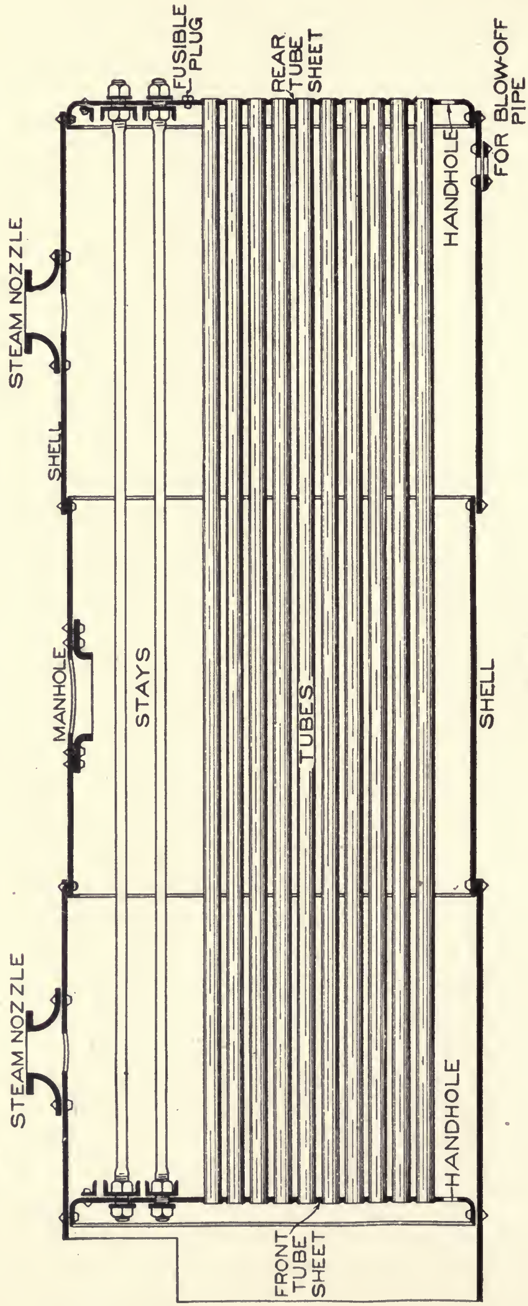

FUSIBLE PLUG
REAR TUBE SHEET
FOR BLOW-OFF PIPE
HANDHOLE
STEAM NOZZLE
SHELL
MANHOLE
STAYS
TUBES
SHELL
STEAM NOZZLE
HANDHOLE
FRONT TUBE SHEET

Fig. 12.

will prevent the straining of the plates from expansion and contraction. A small space must be left between the rear tube sheet and the brick wall to allow for expansion.

The boiler shown in Fig. 11 has two steam nozzles N. If the boiler has a dome (D Fig. 13) the steam nozzle is at or near the top of the dome. The feed pipe may enter either at the front or at the rear. It frequently terminates in a perforated pipe below the water line. The blow-off pipe is at the rear of the boiler as shown

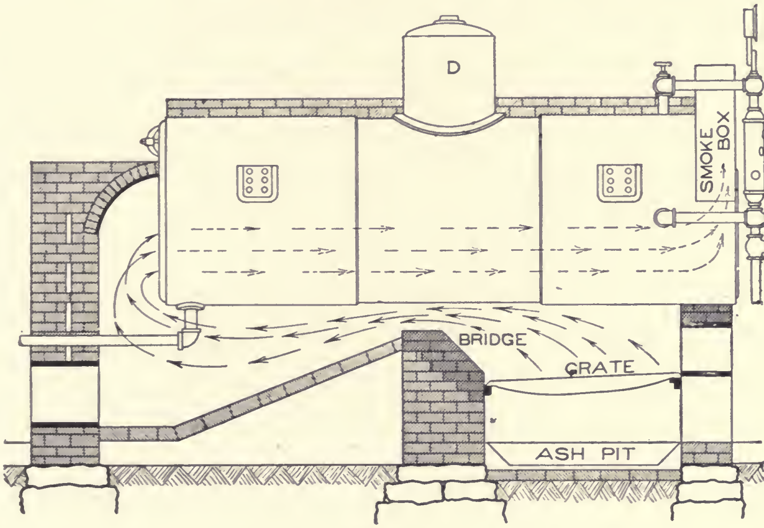


Fig. 13.

in Fig. 13. A valve, called the blow-off valve, regulates the flow and may be opened, when there is low pressure in the boiler, to blow out sediment and detached scale. The boiler is usually set with a slight inclination toward the rear so that mud and detached scale may collect near the blow-off pipe.

In order that the boiler may be entered for cleaning or repairs, it is provided with manholes and handholes. Fig. 11 shows a manhole M at the top near the middle and a handhole near the bottom of the front tube sheet. Handholes may be put in wherever desired, but manholes can be located only where the arrangement of stays and tubes will permit the entrance of a man. Manholes and handholes are elliptical; the former being about 11 inches by 15 inches in size; while the latter are about 4 inches by 6 inches.

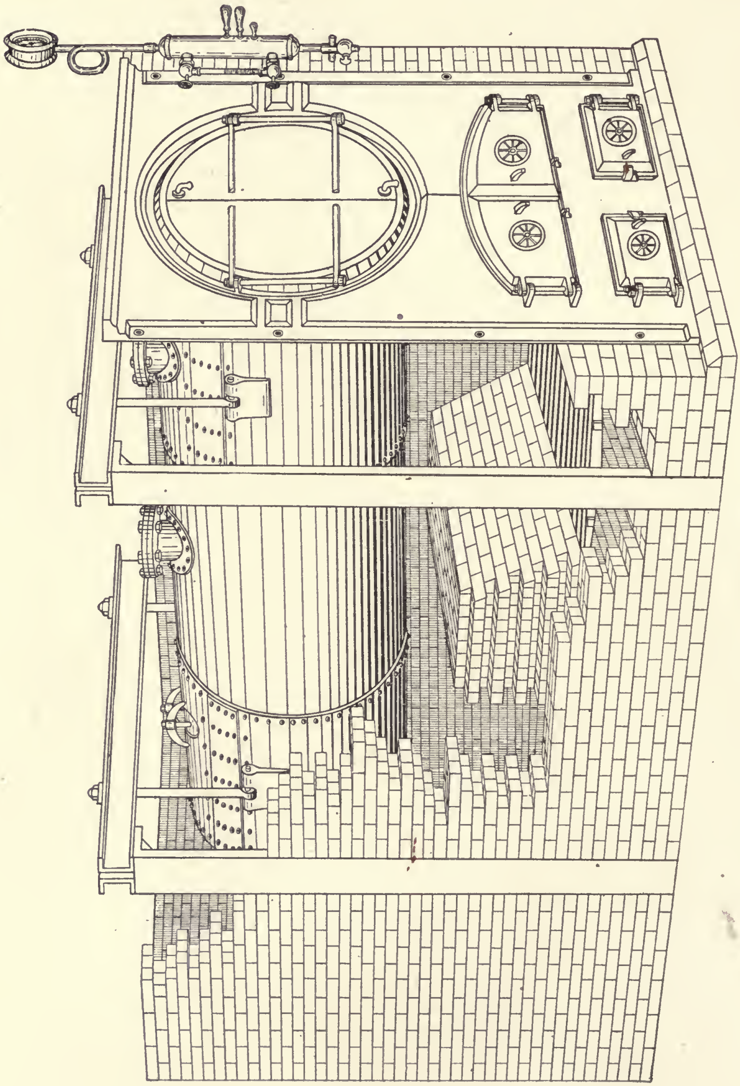


Fig. 14.

The heating surface is the surface in contact with the hot gases. In this type, the heating surface is made up of about half the shell, the tubes, and about two-thirds of the rear tube sheet. In general, all the heating surface is below the water line.

The complete multitubular boiler is shown in its brick setting in Fig. 14, and a longitudinal section of the setting in Fig. 13. The brick setting consists of brick laid in cement or mortar. The bridge and the portions of the furnace exposed to the fire are lined with fire brick. The bridge is built at the rear of the grate and forms a support for the grate bars; it also directs the flames upward. The arrows show the direction of the flow of hot gases. The furnace is formed by the bridge, the side walls, and the lower part of the boiler front. The boiler front is usually cf cast iron with the lower part lined with fire brick. The front has doors which lead to the furnace, ashpit, and smoke box. The space below the grate is called the ashpit, and through its doors ashes are removed and a large portion of the air for combustion enters. Both the fire doors and ashpit doors have draft plates, or grids, to regulate the supply of air. The doors to the smoke box give access to the tubes for cleaning and repairs.

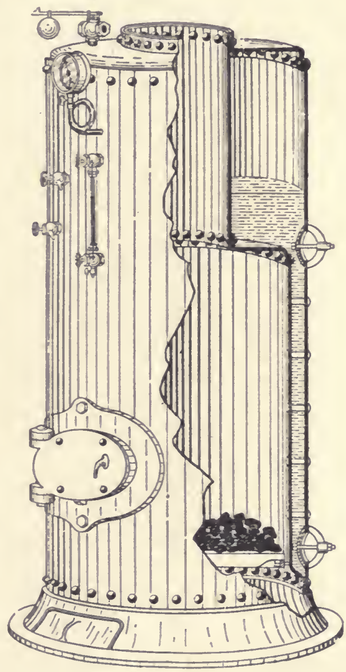


Fig. 15.

UPRIGHT BOILERS.

Vertical—Many Small Fire Tubes—Fire Box.

Upright boilers are used when floor space is valuable and there is sufficient height. In small sizes, they are used for hoisting engines, pile driving, for supplying steam for pumps, and similar work; in large sizes when it is necessary to have a powerful battery in a small space. In general they are not as economical as the horizontal multitubular boiler unless they are carefully designed and of considerable height. If the tubes are short, the hot gases escape before they give up much of their heat.

One of the simplest forms of upright boiler is shown in Fig. 15. It has a cylindrical shell with a large fire box at its lower end. This fire box is formed by the inner cylinder which is fastened to the outer shell by short screw stay bolts as shown. A

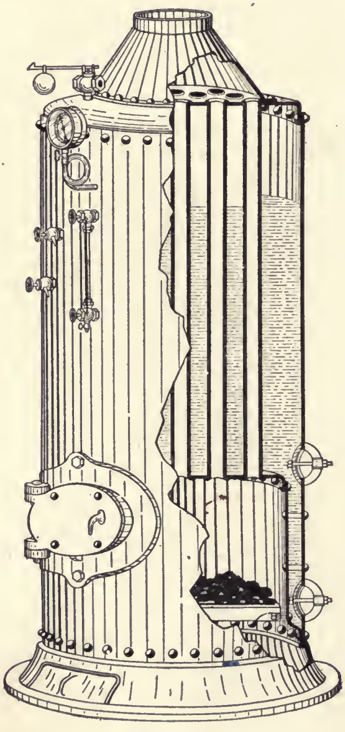


Fig. 16.

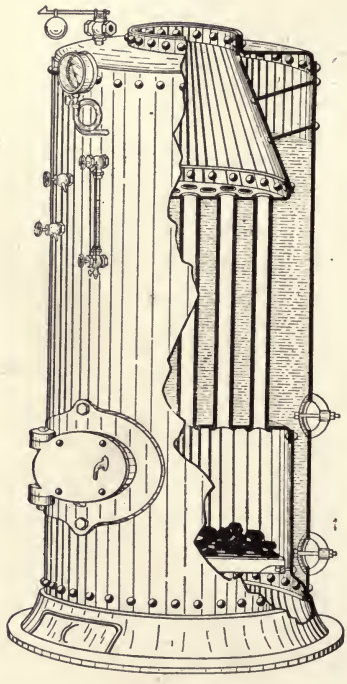
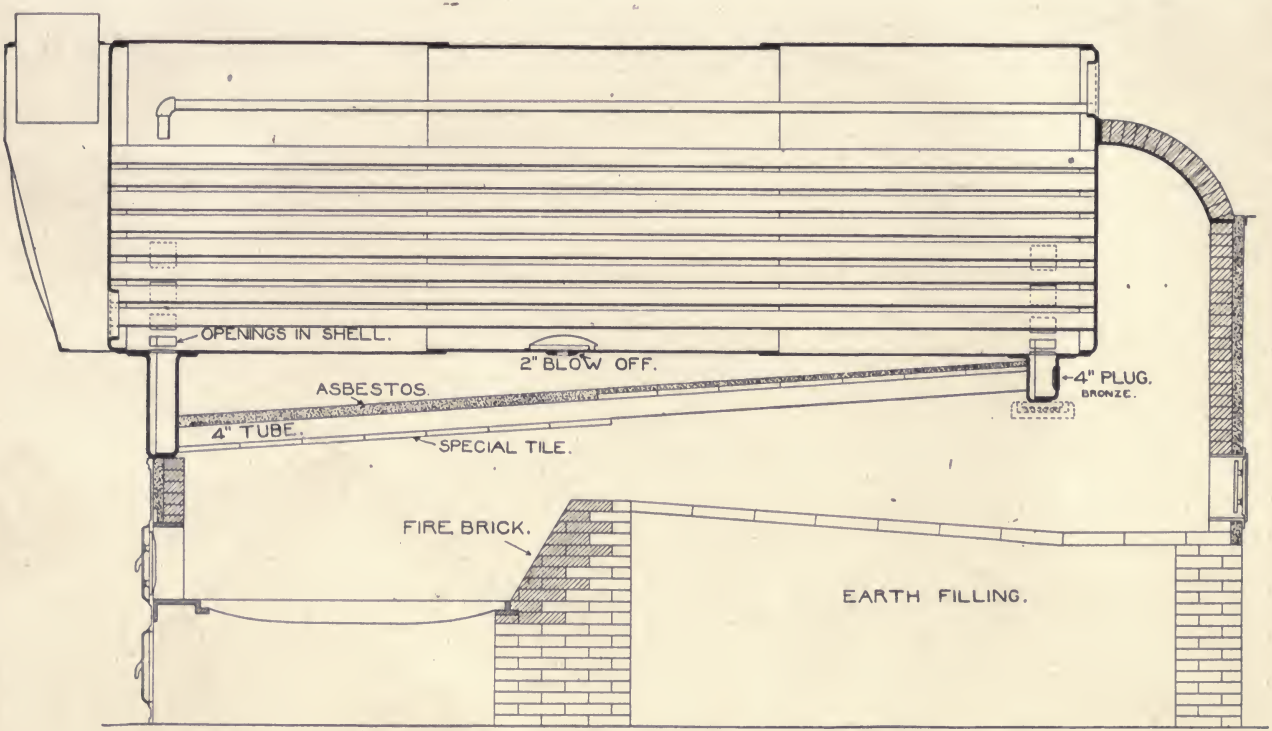


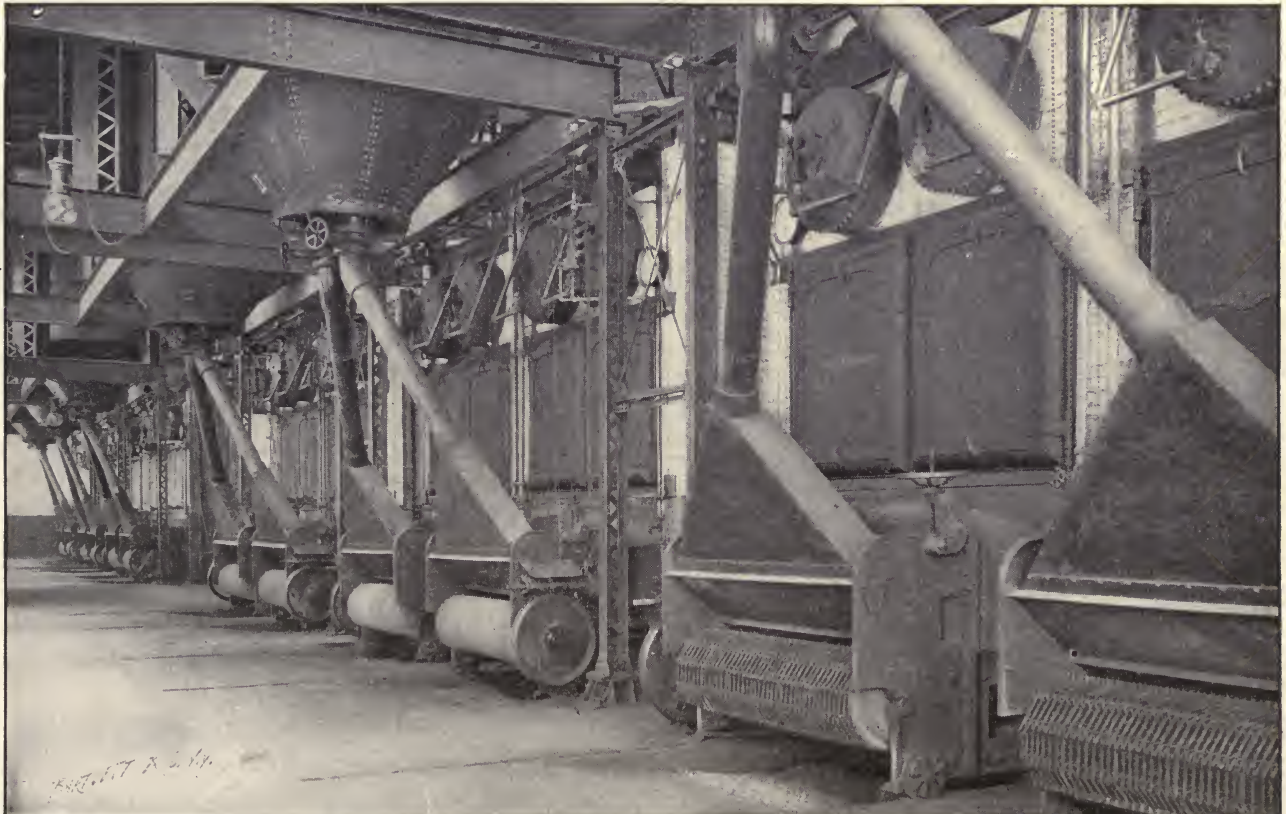
Fig. 17.

flanged ring connects the fire box with a large flue which conducts the hot gases away. The necessary handholes, gages, safety valves, etc., are provided. This form is not economical but is used on account of the little attention required.

More economical forms of the small upright boiler are illustrated in Fig. 16 and 17. The boiler shown in Fig. 16 is a common form; externally it is like the boiler represented by Fig. 15, but within, it has a somewhat different construction. It resembles



BONSON FURNACE AND HORIZONTAL RETURN TUBULAR BOILER.
Bonson Furnace & Boiler Co.



Babcock and Wilcox Boilers with Chain Grate Stokers.

a multitubular boiler placed on end. The fire box is made of an inner cylinder stayed to the outer. The top of the fire box, called the lower tube sheet, is connected to the upper head by tubes, through which the hot gases pass to the smoke pipe. It will be readily seen from Fig. 16, that the upper ends of the tubes are surrounded with steam while the lower portions are covered with water. As steam is a poor conductor of heat, the ends of these tubes are liable to injury from overheating.

In the class of boiler shown in Fig. 17 the upper ends of the tubes are below the water level, thus avoiding the weakness described in connection with Fig. 16. The upper tube sheet is submerged and is flanged and riveted to the frustum of the cone which forms the smoke box. The chief defect in this boiler is that the lower part of the cone is often placed too near the shell; this is done to admit more tubes. This construction restricts the space so much that there is not sufficient room for the steam to rise as it is formed on the tubes. The cone, which is subjected to external steam pressure, is likely to be weak and is usually carefully stayed.

These small upright boilers require no brick setting, as the fire box is within the boiler and the cast-iron foundation forms the ashpit.

MANNING BOILER.

Vertical—Many Small Fire Tubes—Fire Box.

The Manning boiler is illustrated in Fig. 18. In order to get a large heating surface, it is made 20 to 30 feet high. It is, in general, similar to the upright boiler shown in Fig. 16. At the lower portion, the shell is of greater diameter than at the top in order to provide a large grate area. The inner fire box is stayed to the shell by screw stay bolts. As the fire box is surrounded by water and there are many long tubes there is a large heating surface. The tubes are arranged in concentric circles with a space for circulation in the middle.

The external fire box is joined to the shell by a double flanged ring as shown in Fig. 19; or, by the cone-shaped section as illustrated in Fig. 20. The top edge of the internal fire box is riveted to the lower tube sheet which is flanged. The bottom of the inner fire box is connected to the outer shell by a welded ring (shown

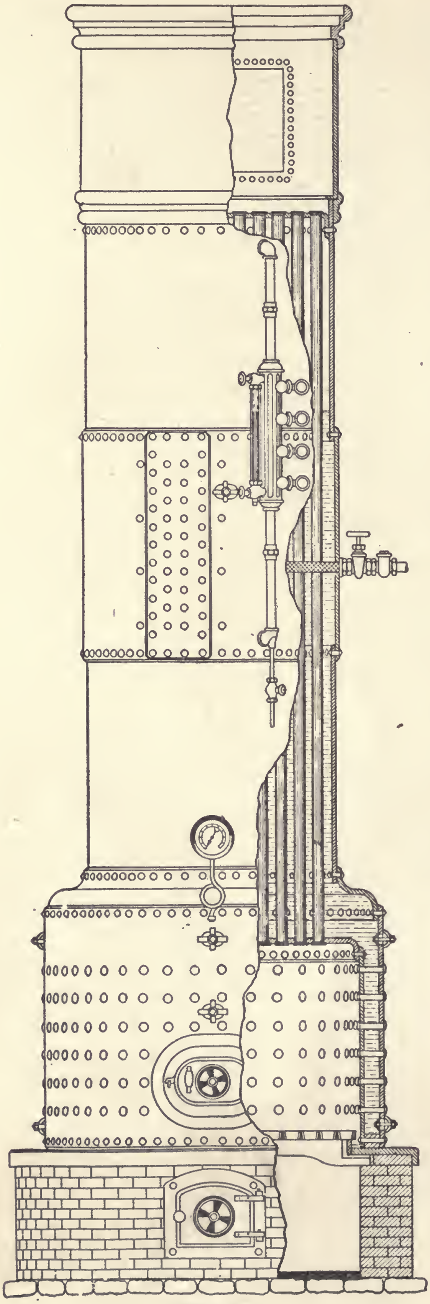


Fig. 18.

in section in Figs. 19 and 20) called the foundation ring. The water space between the inner and outer fire box plates, called the water leg, should be large.

This boiler is cleaned by means of handholes. They are placed in the shell plates near the lower tube sheet, in the external fire box just over the furnace door, and at the bottom near the foundation ring. As there are no manholes for cleaning, the boiler is suited to good feed water only.

The feed pipe enters the shell at the side near the middle of the water space, and extends across the boiler; it is perforated to distribute the water.

The heating surface consists of the inside of the fire box and the tubes up to the water level, and the tube sheet. That part of the tubes *above* the water line is the superheating surface; that is, the heat from the gases passes through the metal of the tubes to the steam, thus raising its temperature without raising its pressure. Steam heated under these conditions is called superheated steam. In small vertical boilers this superheating surface is not desirable because the work of the small boiler does not require superheated steam and the tubes are likely to be burned by the intense heat. With the long

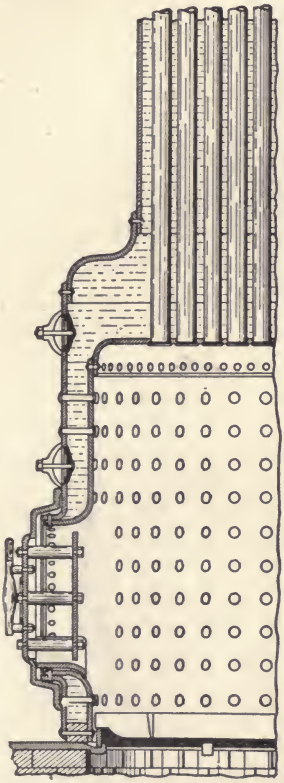


Fig. 19.

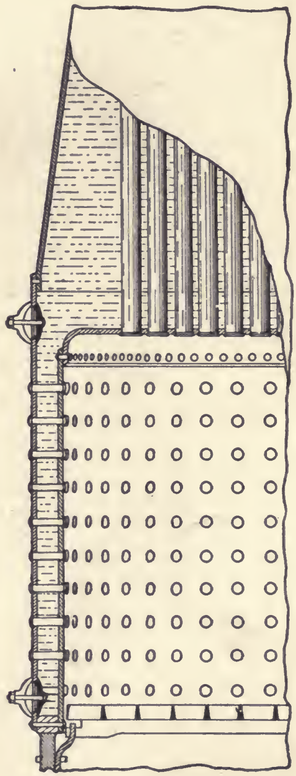


Fig. 20.

tubes of the Manning, the gases are not as hot when they reach the top, and as this boiler is built in large powers (200 horse-power being common) the engines supplied are built for economy and require dry if not superheated steam.

RETURN-TUBE BOILERS.

Horizontal—Many Small Fire Tubes—Internally-Fired.

The boilers hitherto described are used mainly for stationary work, the exceptions being so few that they need not be even mentioned. Let us now discuss another modification of the fire-tube boiler—one that has been and is now extensively used in marine work. The parts of the return-tube boiler are essentially the same as those of flue boilers (Cornish and Lancashire) and the multitubular boiler. They are, however, arranged differently in order to be used on board ship.

The earliest forms of marine boilers, working with pressures of 15 to 30 pounds per square inch, were square or box-shaped. They were economical and of convenient form for ships. When higher steam pressures became necessary, the flat surfaces required so much staying that they were abandoned and the cylindrical type introduced, as this form is the best of the practical shapes to resist internal pressure. The cylindrical form may not be as conveniently stowed aboard ship, but it will stand much higher pres-

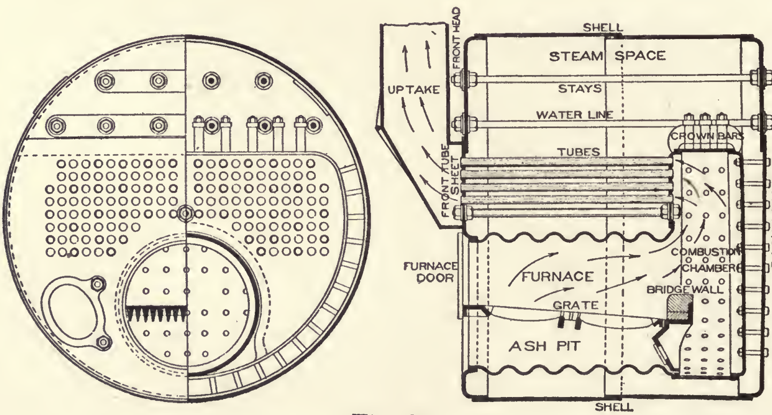


Fig. 21.

sures. The cylindrical marine boiler is frequently built for 170 pounds per square inch.

The single-ended, return-tube boiler, shown in Fig. 21, combines the internal furnace flue of the Cornish type and the numerous small fire tubes of the multitubular. The cylindrical shell is made up of plates riveted together and to the flat ends of the boiler, which are flanged to fit the shell.

The furnace is cylindrical, three to four feet in diameter and about seven feet in length. The front end of the furnace flue is riveted to the front end plate, which is flanged for the purpose. The back end is riveted to the combustion chamber plates. Formerly, the flue was a plain cylinder, but as a plain cylinder, unless of small diameter, cannot stand much external pressure, it soon became necessary to strengthen it. This was done by means of the curved ring shown in Fig. 5 and other methods; but at present the corrugated flue is used, one form being shown in Fig. 6.

The grate is placed at about the center of the height of the furnace flue; the space above this grate is occupied by the fire and hot gases, below it is the ashpit. As will be seen from the arrows

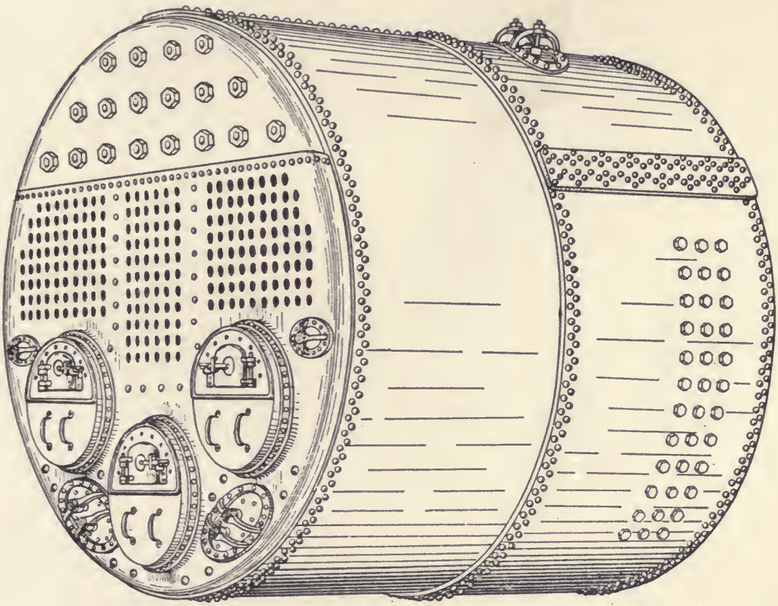


Fig. 22.

in Fig 21, the hot gases fill the space above the fire, the combustion chamber, the tubes and the uptake.

The combustion chamber in which the products of combustion are completely burned, is formed of flat and curved plates flanged at the edges and riveted together. The shape of the plates is shown in Fig. 21, which is a sectional view of a single-ended marine boiler. The back tube sheet forms the front of the combustion chamber. The space around the tubes, furnace flue, and combustion chamber is filled with water, the water level being six to eight inches above the top row of tubes. The space above the water level is called the steam space.

As the return-tube boiler has several flat surfaces, this type requires careful staying. The flat ends above the water level are prevented from bulging by long stay rods which are similar to those in the multitubular type. Below the water level, the furnace flue and the tubes aid in holding the flat plates together. In addition, a few of the tubes (shown by the heavier circles in Fig. 21) are made thicker so that a thread may be cut on the ends which are screwed into the tube sheets and held by thin nuts. The combustion chamber plates are stayed to the rear end plate and the shell by short screw stay bolts. The flat top of the combustion chamber is supported by girders or crown bars.

Number of Furnaces. The boiler shown in Fig. 21 has only one furnace, but return-tube boilers frequently have two, three, or four furnaces.

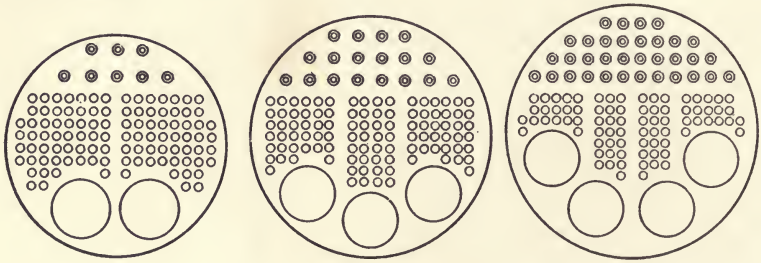


Fig. 23.

Fig. 22 shows a boiler with three furnaces. Large furnaces are more efficient than small ones because the grate area increases directly as the diameter, while the air space above the grate increases as the square of the diameter. The greater space aids combustion. The length of the grate bars is nearly constant for all sizes of flue because it is limited by the distance a fireman can throw coal. Furnace flues are usually from 36 to 54 inches in diameter. As the size of furnaces is fixed, the number depends upon the size of the boiler, for a large boiler must have a large grate area which can be obtained only by using several furnaces. The various arrangements are shown diagrammatically in Fig. 23.

A single-furnace boiler has but one combustion chamber. A two-furnace boiler may have a combustion chamber for each furnace or it may have a common combustion chamber. If there is but one boiler on board, it is better to have two combustion chambers, so that in case a tube bursts, the boiler will not be disabled. If, however, there are several boilers, it is better to have a common combustion chamber for the two furnaces, because the alternate stoking keeps up a more nearly constant pressure of steam and there is less smoke. Three-furnace boilers usually have three combustion chambers, while four-furnace boilers have two. In case four furnaces are used with three combustion chambers, the two center furnaces lead to a common combustion chamber and each outside furnace has one.

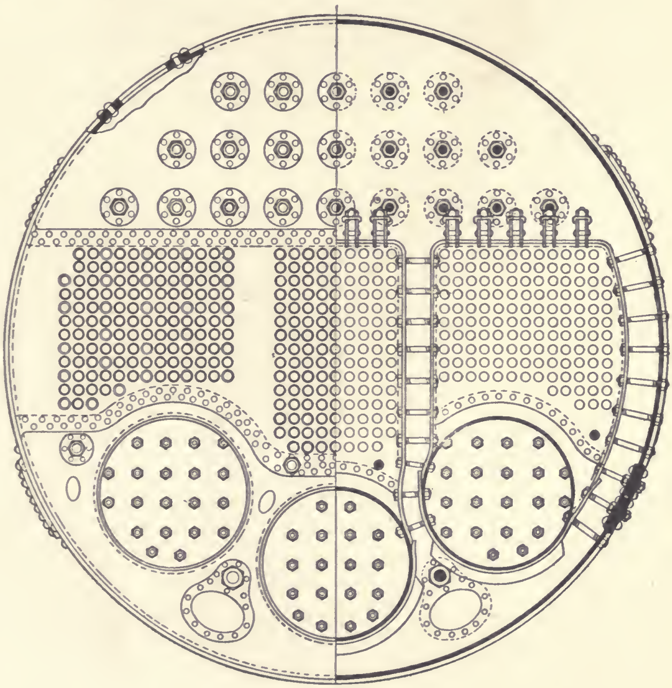


Fig. 24.

Double-ended Boilers. This form of marine return-tube boiler is practically the same as two single-ended boilers placed back to back, but with the rear plates removed. The weight of the rear plates is saved and there is less loss from radiation. This makes the double-ended boiler lighter and cheaper in proportion to the heating surface. Double-ended boilers are often made 16 feet in diameter and 18 feet long.

There are two distinct classes of double-ended return-tube boiler—those having all the furnaces open into one combustion chamber and those having several combustion chambers. The boiler having but one combustion chamber has the disadvantage that if one fire is being cleaned the whole boiler may be cooled by

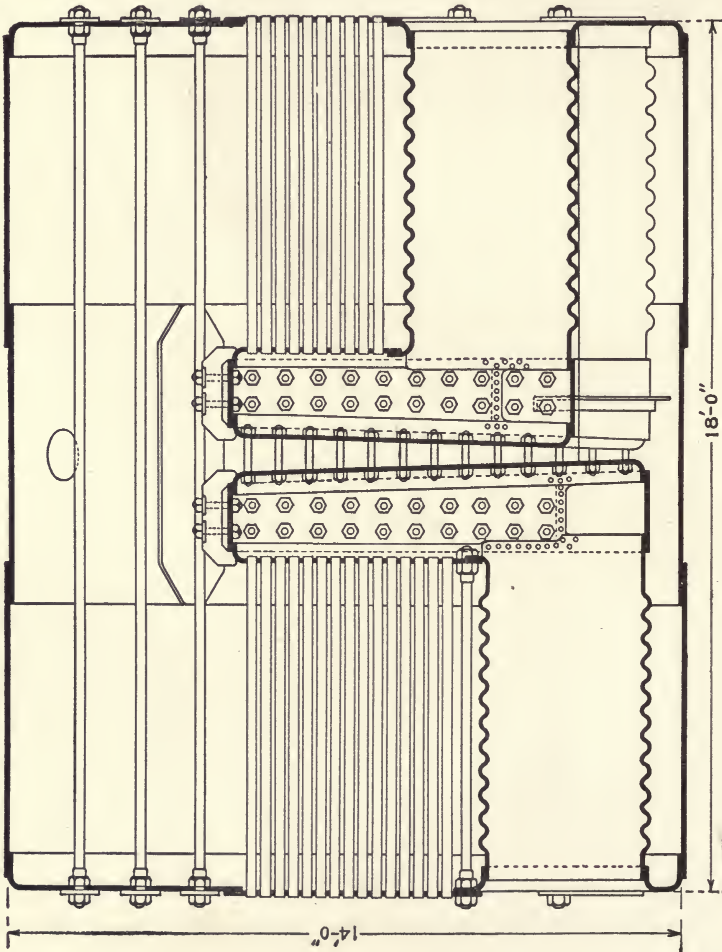


Fig. 24.

the inrush of cold air. It is better to have a combustion chamber for each furnace or at least have a combustion chamber for the furnaces of each end. The usual method of dividing up the combustion chambers is by water spaces as shown in Fig. 24, which is the section of a boiler having a combustion chamber for each furnace.

Internal Furnace Return-Tube Boiler. Although the return-tube boiler is commonly used in marine work, this type, with some changes in detail, is used in plants ashore. Fig. 25 shows

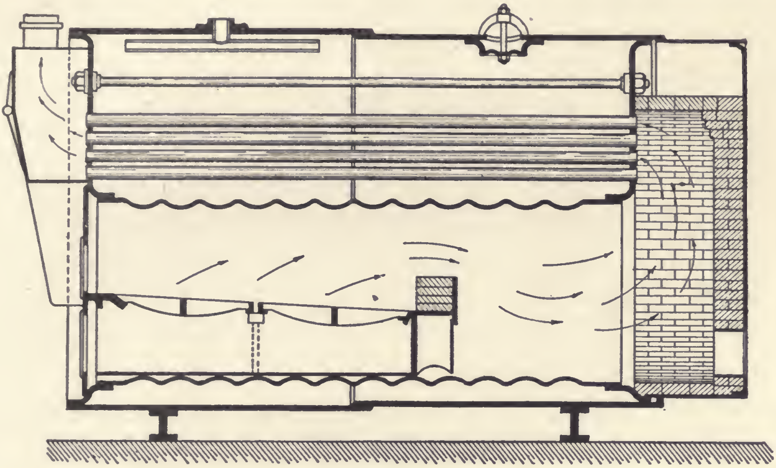


Fig. 25.

the construction and arrangement of parts. The flue is larger in proportion to the diameter than is the case with the marine form; the combustion chamber is partly external to the shell, that is, the rear tube sheet is also the rear end plate. This arrangement does away with the necessity of staying the flat plates of the combustion chamber.

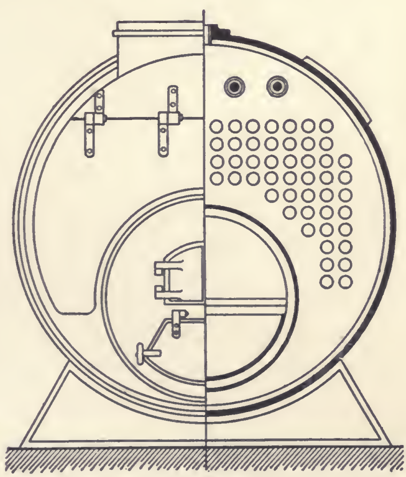


Fig. 25.

Another form of internal furnace, return-tube boiler is shown in Fig. 26. This boiler usually has two flues extending from the front to the back head. The grate is placed in the corrugated portion while conical water tubes support the flue back of a bridge wall. The large furnaces and the space around the conical tubes provide a combustion chamber of ample size.

The arrows show the direction of the hot gases. After leaving the internal flue they enter the return tubes which are below the furnace; before leaving the boiler, they pass underneath the shell. By this arrangement the hottest gases are near the water line and the cooler gases in contact with the cold water, thus there is the greatest difference in temperature at all times. At each change in the direction of the hot gases, there is an opportunity for dirt and ash to fall by gravity so that the tubes may remain clean and efficient.

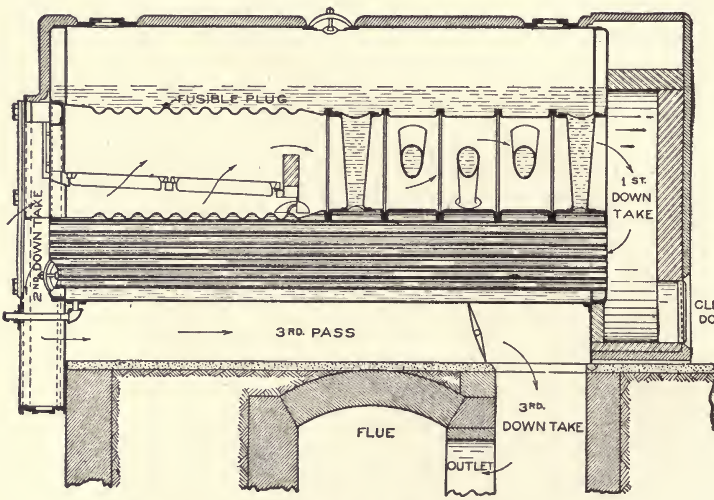


Fig. 26.

With the exception of the foundation there is no brickwork. The shell is covered with a non-conducting material. This boiler, like the Galloway, has a large steam and water space, thus insuring dry steam and great reserve power.

THROUGH-TUBE BOILERS.

Horizontal—Many Small Fire Tubes—Internally-Fired.

Vessels of slight draft require a boiler of small diameter. This is especially true of gunboats as it is desirable to have the boilers below the water line. As there is not room for the return-tube boiler, the through-tube, shown in Fig. 27, is sometimes used. This boiler is made up of the same parts as the return tube, the chief difference being that of arrangement. The rear plate of the combustion chamber forms one tube sheet and the end plate forms the other. The top of the combustion chamber is stayed to the shell by sling stays which are bars having forked ends fastened to the shell and to the combustion chamber.

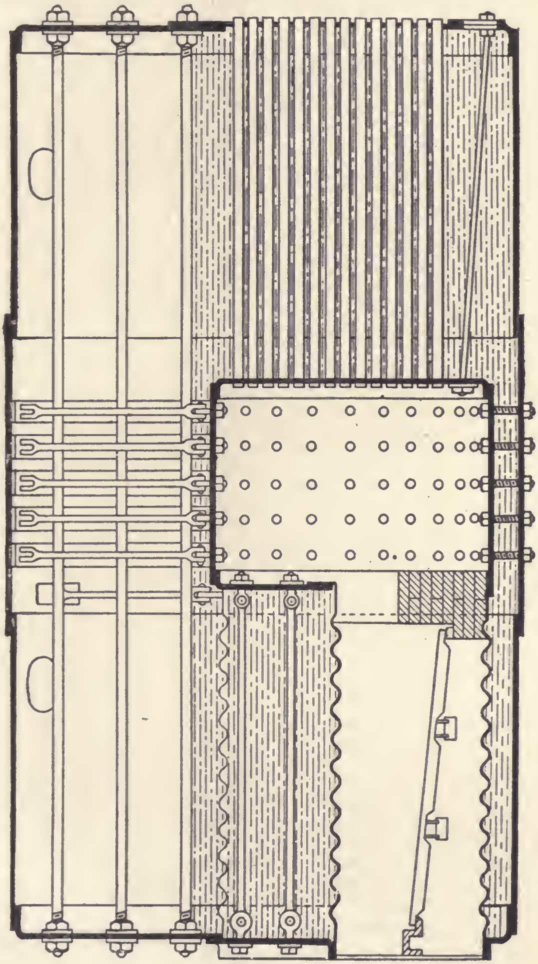


Fig. 27.

The fire is in a flue, or flues, which leads to the combustion chamber. The hot gases pass from the combustion chamber through the tubes to the uptake at the back end. The chief objection to this form is its length, for the heating surface is small unless the boiler is made very long.

FIRE-BOX BOILERS.

LOCOMOTIVE TYPE.

Horizontal—Many Small Fire Tubes—Externally-Fired.

Although vertical fire-tube boilers may be classed as fire-box boilers, yet the name fire-box boiler is usually applied to the locomotive type whether used with a locomotive or as a stationary boiler.

The usual form of horizontal fire-box boiler consists of a cylindrical shell, or barrel, partly filled with tubes, and a rectangular

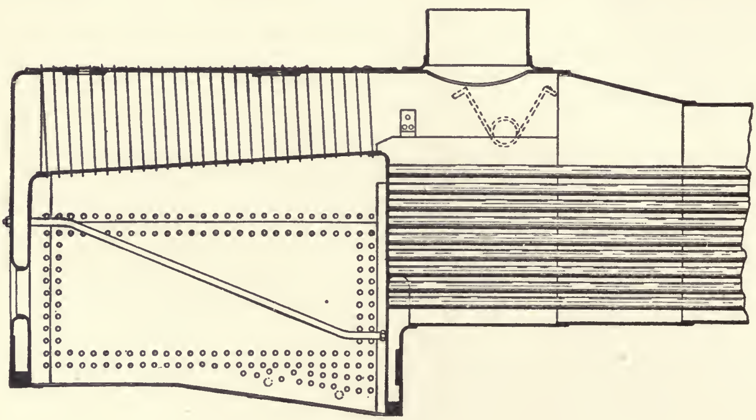


Fig. 28.

fire box. The shell is prolonged beyond the rear tube sheet to form a smoke box. The front ends of the tubes open into the fire-box, while the rear ends open into the smoke box. The hot gases from the fire pass through the tubes to the smoke box and from thence to the stack or uptake. For locomotive work, there are a large number of small tubes (usually 2-inch), but for stationary work the tubes are larger and less numerous. The reason for this difference is that in the locomotive boiler a greater heating surface is necessary, and to obtain sufficient draft to burn the large amount of coal for this heating surface, the exhaust steam is turned into the smoke box. The blast of steam carries the heated gases up the stack and a fresh supply of air passes through the grate.

The cylindrical shell is joined to the fire box by riveting to a flanged ring or to a cone-shaped portion as in the vertical boiler. The fire box has a rectangular cross-section and usually a flat top.

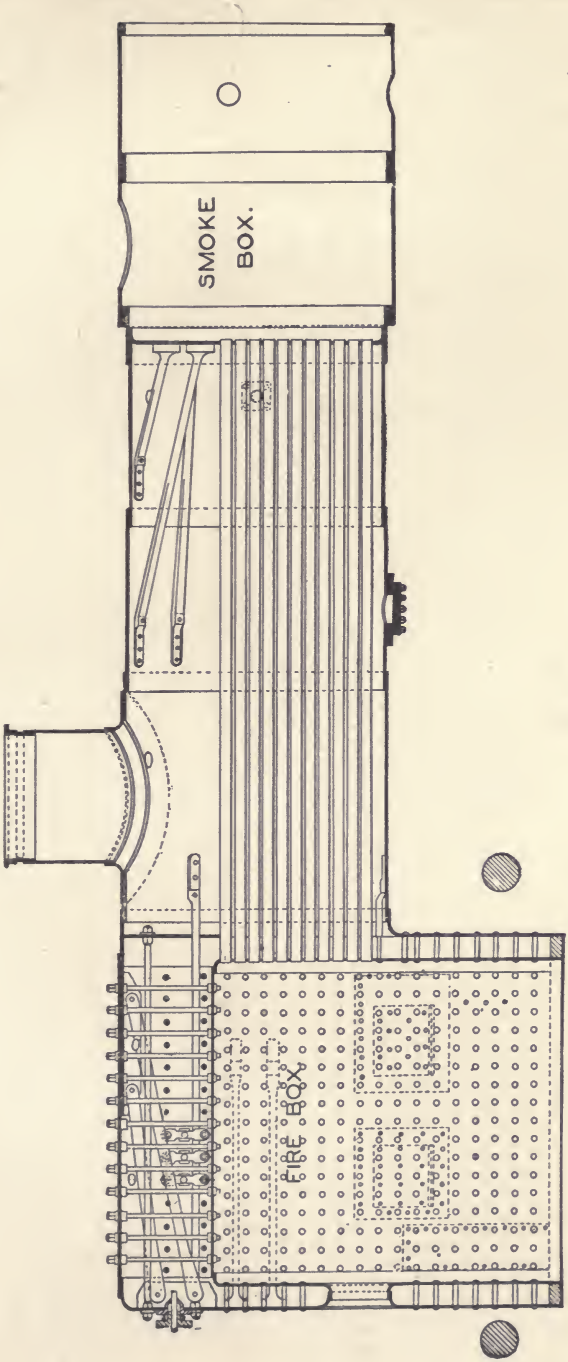


Fig. 29.

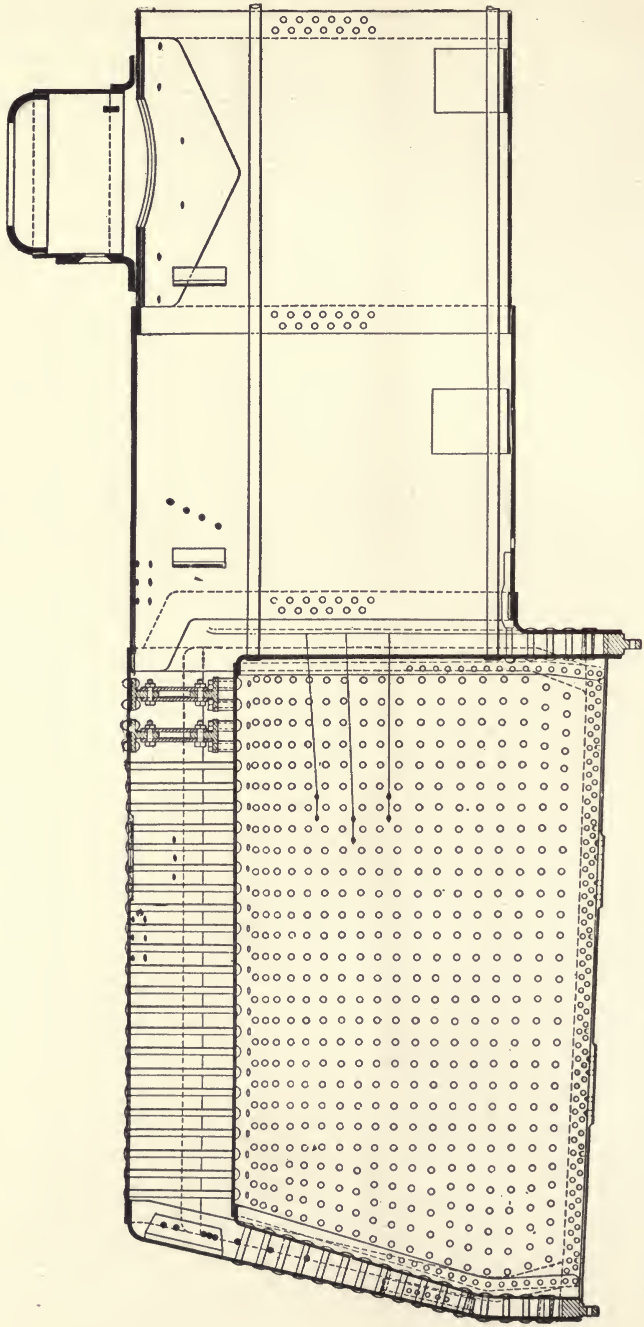


Fig. 30.

Like the vertical boiler there is an inner and an outer fire box, the inner having the same shape as the outer, except that the top is flat. The external fire box is connected to the inner by short screw stays. The space between is called the water leg. The flat top is stayed by girders or crown stays. These are sometimes attached to the shell by sling stays. The lower portions of the tube sheets are held in place by the tubes; the upper portions are stayed by diagonal stays.

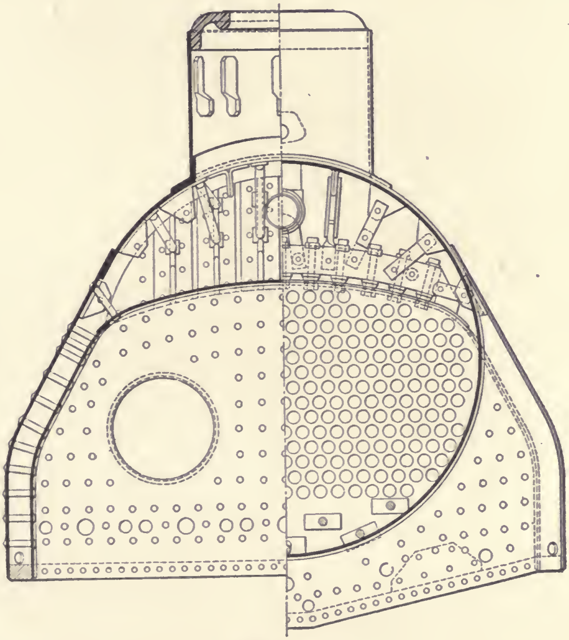


Fig. 31.

The chief differences in the various forms of locomotive boilers are the shape of the fire box and the location of the grate. Locomotive boilers are either straight top or wagon top. The wagon top boiler, see Fig. 28, has a cone-shaped portion by means of which the boiler is larger at the fire-box end. This construction is to give a greater steam space. The increase in size of boilers has raised the top so high above the rails that the wagon top is not now used extensively; the straight top, see Fig. 29, is more common.

Belpaire Boiler. The shell and fire tubes of this type of boiler are practically the same as in any other fire-box boiler; the peculiarity lies in the fire box. The inner and outer fire-box plates are horizontal at the top, and the sides of the outer fire-box are continued so that the space above the crown sheet is rectangular in section. The advantage of this construction is that the staybolts holding the crown sheets and side sheets can be placed at right angles to the sheets. This reduces the tendency to bending when under pressure.

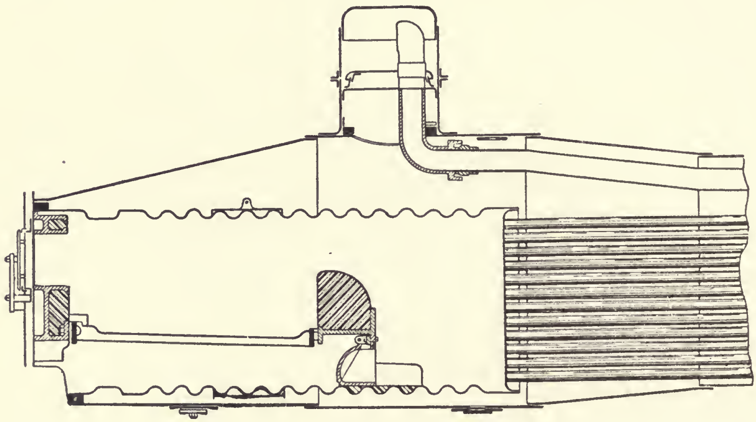


Fig. 32.

Wootten Boiler. In this type also, the fire box is the chief portion to be considered. The size of the locomotive fire box is limited. With older types the width was limited to less than three feet and the length to less than seven feet. This was because of the frames and the distance between the axles. By placing the fire box above the axles, the width was increased by an amount equal to the thickness of the frames or about seven inches, and the length increased to about eleven feet. By raising the fire box still more and placing it above the driving wheels, the width can be still further increased.

A broad, shallow fire box is required if anthracite coal is used. The Wootten fire box, shown in Fig. 30 and 31, is very wide and is placed on top of the driving wheels. Formerly, a combustion chamber was placed between the end of the grate and the tubes, but as it was found to be unnecessary, it is not now used.

Lentz Boiler. The object of the design shown in Fig. 32 is to avoid the use of stays. To do this no flat plates are used, except the tube sheets and these are stayed by the tubes. The fire-box is in the form of a corrugated flue similar to those in internally-fired, return-tube boilers. As this is circular it requires no stays. The shell is circular and shaped as shown in the illustration. This type has been much used in Europe, but a few have been built in this country.

FIRE-BOX BOILER FOR STATIONARY WORK.

The fire-box boiler, usually called the locomotive boiler, is often used for stationary work, traction engines, and for vessels of light draft. This type of boiler, slightly modified, is sometimes

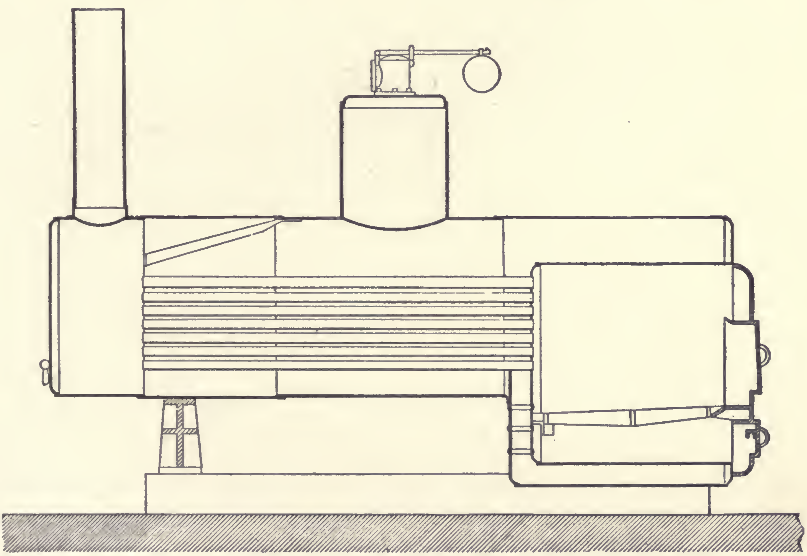


Fig. 33.

used for generating the steam for heating buildings. It is economical and durable when used with natural draft. The chief differences in construction are larger tubes because of the draft, and the changes due to method of support. A common form is shown in Fig. 33. This type has been built in large sizes for high pressure, but when so made is expensive.

PECULIAR FORMS.

Fire-Tube Boilers, but differing from those described.

Return Tubular as Stationary. Boilers of the form shown in Fig. 34 resemble the locomotive, fire-box type, but in addition have return tubes. The hot gases reach the uptake by means of these tubes instead of passing to the chimney from the smoke-box end. Thus they combine the advantages of the fire-box type and the return-tube type without the brick furnace. The water surrounds the furnace on all sides except the front. They are built in sizes from 12 to 70 horse-power. As Fig. 34 shows the construction so clearly, further description is unnecessary.

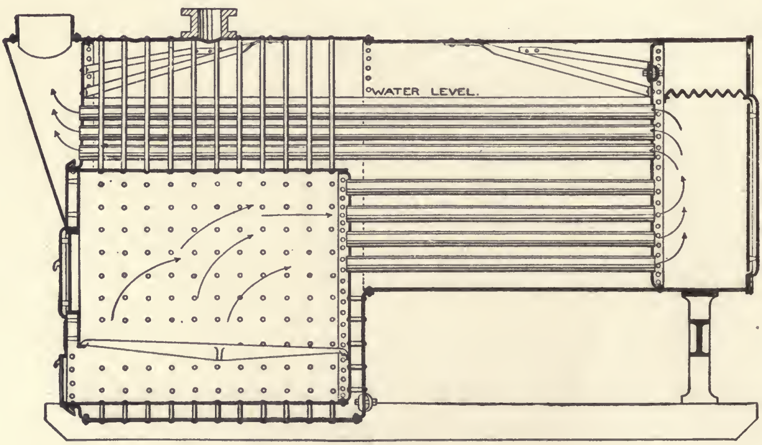


Fig. 34.

The Cochrane Vertical Boiler is somewhat like the return-tube boiler in point of arrangement of heating surface. This boiler is shown in section in Fig. 35. The hot gases pass from the furnace to the combustion chamber, then through the tubes to the uptake. The heating surface consists of tubes and the plates of the fire box which is surrounded by water except the bottom. The crown of the boiler and of the fire box, being hemispherical, require no staying. The hemispherical crown also allows a large steam space. The flat plates (the tube plates) are held together by the tubes.

The Shapley Boiler, shown in Fig. 36, may be called a return-flue vertical boiler. The upper portion is a reservoir for water and steam and the lower contains the fire box. The crown sheet of the fire box is stayed to the top by through stays. The hot gases from the fire rise in the fire box, pass through short horizontal tubes to an annular space. This annular space is connected to the flue at the base by vertical tubes passing through the water space.

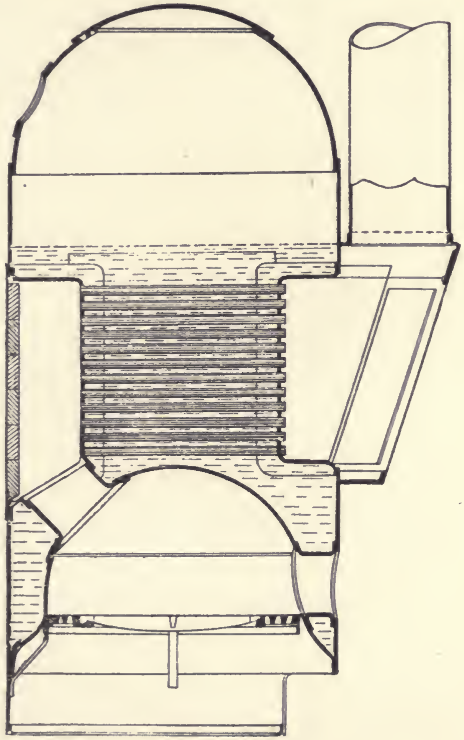


Fig. 35.

This boiler has a large combustion chamber; the fire box is surrounded by water, and the crown sheet and tubes are removed from the intense heat of the fire. This arrangement increases the heating surface, allows complete combustion and results in a durable boiler. The base is partially filled with water so that any sparks carried over will be quenched.

Robb-Mumford. This boiler resembles the through-tube internally-fired boiler (see Fig. 27) in that the fire is within a corrugated flue and the tubes lead from this flue to the rear of the boiler.

The Robb-Mumford boiler consists of two cylindrical drums or shells, connected at each end by a neck. See Fig 37. The upper drum is a steam and water drum, the water level being at about the middle. The lower shell is larger and is inclined about one inch in twelve to increase the circulation, and facilitate washing out. In this lower shell is the corrugated flue containing the grate. The fire tubes nearly fill the remaining portion of the shell as shown.

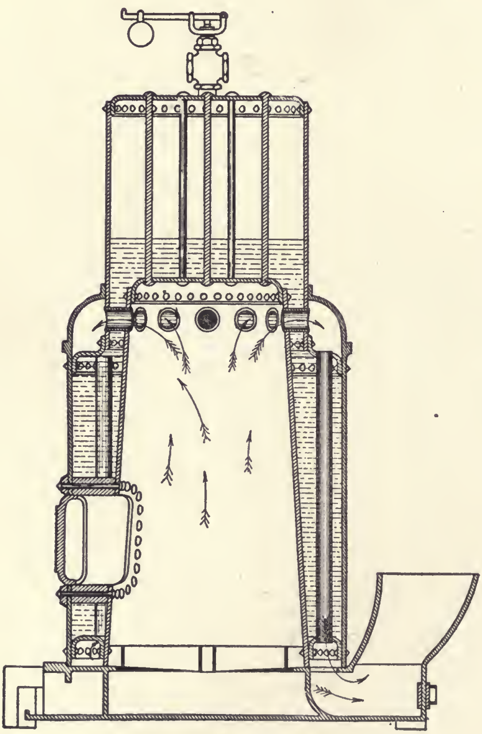


Fig. 36.

The furnace, in which the coal is burned, is surrounded by water; the hot gases pass through the tubes to the rear, return between the lower and upper shells and escape to the chimney from the front of the boiler. The steel casing keeps the gases in contact with the drums. The water circulation is shown by the arrows. The mixture of water and steam enters the upper drum; the steam here separates from the water which flows down the neck at the forward end. A semicircular baffle plate directs this water around the furnace to the bottom. The feed water enters at the rear of the steam and water drum.

As compared with the multitubular boiler one can readily see that the drums can be made much thinner on account of the small diameter. The tubes are short, straight, and easily cleaned. The internal furnace does away with much of the loss from leakage. As the water is well subdivided, steam can be raised rapidly and there is little danger of a disastrous explosion.

Directurn. The Begg's "Directurn" boiler (Fig. 38) is, in brief, a horizontal, externally-fired, multitubular boiler in which tubes conduct hot gases through the space behind the bridge.

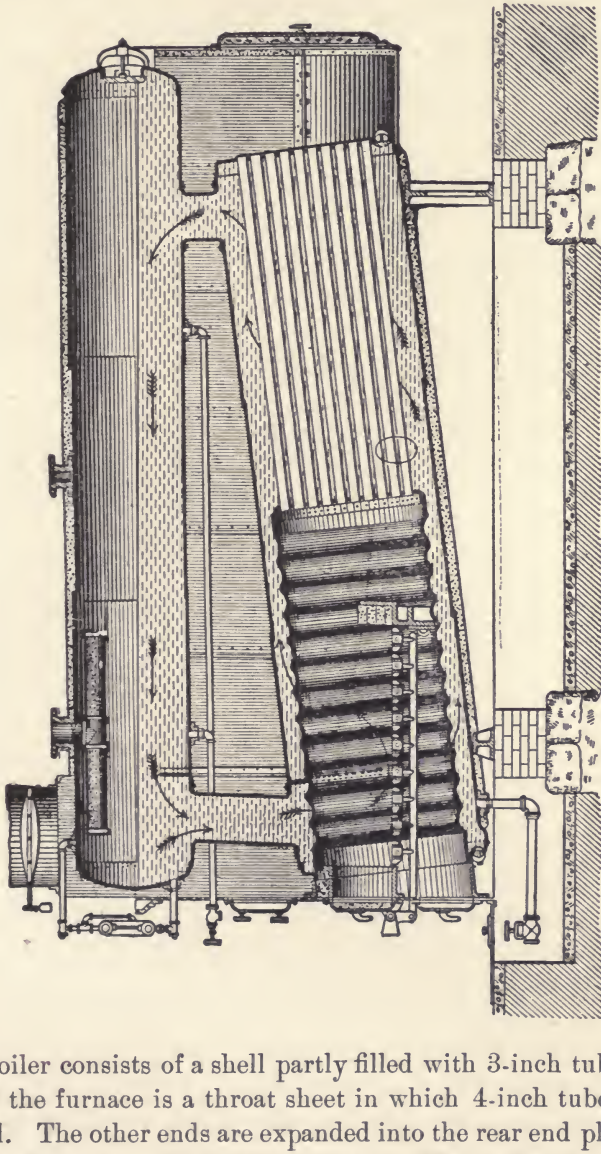


Fig. 37.

This boiler consists of a shell partly filled with 3-inch tubes. The rear of the furnace is a throat sheet in which 4-inch tubes are expanded. The other ends are expanded into the rear end plate which is made large enough for the purpose. The boiler is encased in steel plates lined with fire brick which is held in place by rods passing through the notches as shown. The manhole for entering the boiler is placed in the front head instead of in the shell as is frequently done.

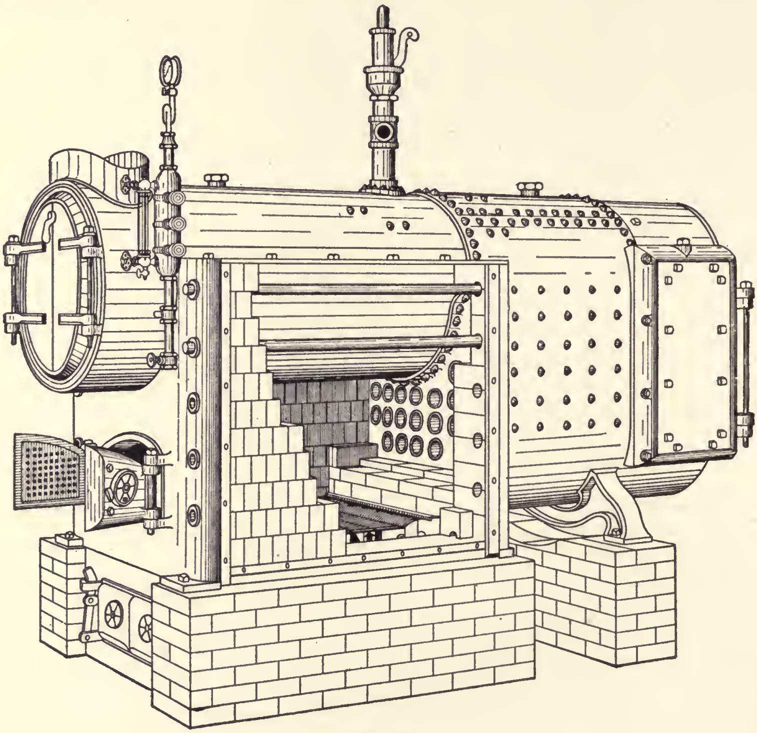


Fig. 38.

WATER-TUBE BOILERS.

The water-tube boiler differs essentially from the fire-tube. The names indicate the chief point of difference. In the fire-tube boiler, the tubes, which are surrounded with water, conduct the hot gases to the smoke box. In the water-tube, the tubes are filled with water, and the hot gases pass over and among them on their way to the chimney.

Although flue boilers and the tubular types were introduced at an earlier period than the water-tube, yet the last-named type is not a new form of steam generator. About a century ago, John Stevens invented a water-tube boiler and fitted it to a steamboat.

This boiler (Fig. 39) was a combination of small tubes connected. at one end to a reservoir. Thus the "porcupine" was one of the earliest forms. At various times since then, many ideas have been worked out both for marine and stationary boilers. During the last fifteen years, however, the water-tube boiler has been steadily growing in favor, the chief reasons being—the necessity of higher steam pressures, greater reliability of materials, greater skill in design and workmanship, and more intelligent management.

It is not within the province of this instruction paper to discuss the relative merits of fire-tube and water-tube boilers, but a careful, impartial consideration seems to show that as far as economy of running is concerned there is but little difference. The fire-tube boiler is reliable and can be handled by those possessing comparatively little knowledge of engineering. Its chief defect seems to be the disastrous results following an explosion. The water-tube boiler, on the other hand, is safe, and suited to higher pressures, but requires greater care in management.

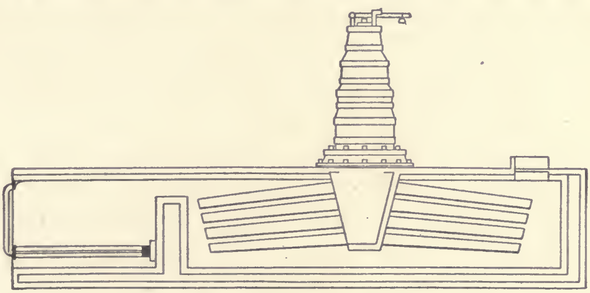


Fig. 39. Stevens Boiler.

Before discussing these boilers in detail, let us consider briefly the salient points.

Safety. Probably the greatest advantage claimed for the water-tube boiler is its safety. The boiler contains much less water than does the flue or tubular boiler and the water is divided into small masses, thus minimizing serious results in case of rupture. On account of the shape and arrangement of parts, the circulation is usually good, and no part exposed to the fire can be uncovered while there is any water in the boiler. The tubes cannot become overheated until the boiler is empty and with an empty boiler there cannot be a serious explosion.

Rapidity in Raising Steam. The many small streams into which the water is divided as it passes through the furnace greatly facilitate the absorption of heat. Because of the small streams and the rapid circulation, the water is converted into steam in a very short time. Several hours (usually five to seven) are required to raise steam to working pressure in a tubular boiler, while in many water-tube boilers, steam can be raised to over 200 pounds pressure in less than half an hour.

Durability. Most water-tube boilers are so designed that no seams are exposed to the fire or hot gases. The seams are the weakest part of a boiler, and as strains due to unequal expansion concentrate at such points, leaks or even ruptures are liable to occur. In the water-tube boiler, the joints between tubes and tube sheets are not in the direct path of the hot gases.

Loss of Heat. The loss of heat will evidently be reduced to a minimum if the heating surfaces are such that the heat readily passes through to the water. The small diameter of the water tubes (2 to 4 inches) allows the use of thin metal which does not hinder the transmission of heat. The rapid circulation in the water-tube boiler prevents the accumulation of sediment which is a poor conductor of heat.

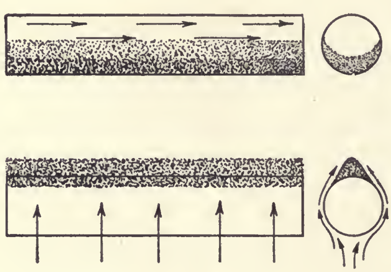


Fig. 40.

Still further, dust and dirt does not readily collect on the convex surface of water tubes, but the *inside* of fire tubes soon become choked with soot unless cleaned frequently. See Fig. 40.

Less Weight. It is a well-known fact that a cylinder of large diameter must be much thicker than one of small diameter when the internal pressure is the same. The thickness of the shell of a fire-tube stationary boiler is not excessive, because of the moderate diameter; but in the return-tube marine boiler, the shell plates for 250 pounds pressure would be about $1\frac{7}{8}$ inches thick. The difficulty of working such thick plates and their great weight render the cylindrical boiler unsuitable for high pressures. The small tubes and drums of the water-tube boiler may be made quite thin even for very high pressures. In general, it may be said that for the same capacity and pressure, the weight of a water-tube boiler is only about two-thirds that of a fire-tube.

CLASSIFICATIONS.

Many attempts have been made to classify water-tube boilers. By some writers a classification based on circulation, or on the principle of operation, is claimed to be superior to any division according to construction. Therefore, they divide them into classes as follows—boilers with limited circulation; boilers with free circulation; boilers with accelerated circulation.

In the first part of this Instruction Paper, is given a classification according to features of construction. No classification is altogether satisfactory because boilers overlap into other divisions; a water-tube boiler may be sectional, of the double-tube type, have horizontal tubes, straight tubes, and free circulation. In order to have some sort of classification, and as no discussion will be entered into regarding relative merits, the classification given on page 6 will be here adopted and followed as closely as conditions will permit.

Water-tube boilers are divided into two great classes—horizontal and vertical. Under these heads come sectional and non-sectional, straight-tube and curved-tube, and single-tube and double-tube. If the tubes are nearly horizontal, such as is the case of the Babcock and Wilcox, Root, etc., the boiler will be called horizontal. If the tubes are vertical, or nearly so, as in the Wickes, Stirling, etc., the boiler will be classed as vertical.

Although most boilers can be classified as outlined on page 6, there are a few of such peculiar construction and arrangement that they must be placed by themselves under "Peculiar Forms." These are described without any further attempt at classification.

As it is impossible to discuss all makes of boilers, a few representative forms will be considered as types of their respective classes. No attempt will be made to choose any make as being the best, because many conditions must be considered in selecting a boiler. The boilers described, except in a few cases, are now used extensively in either stationary or marine work.

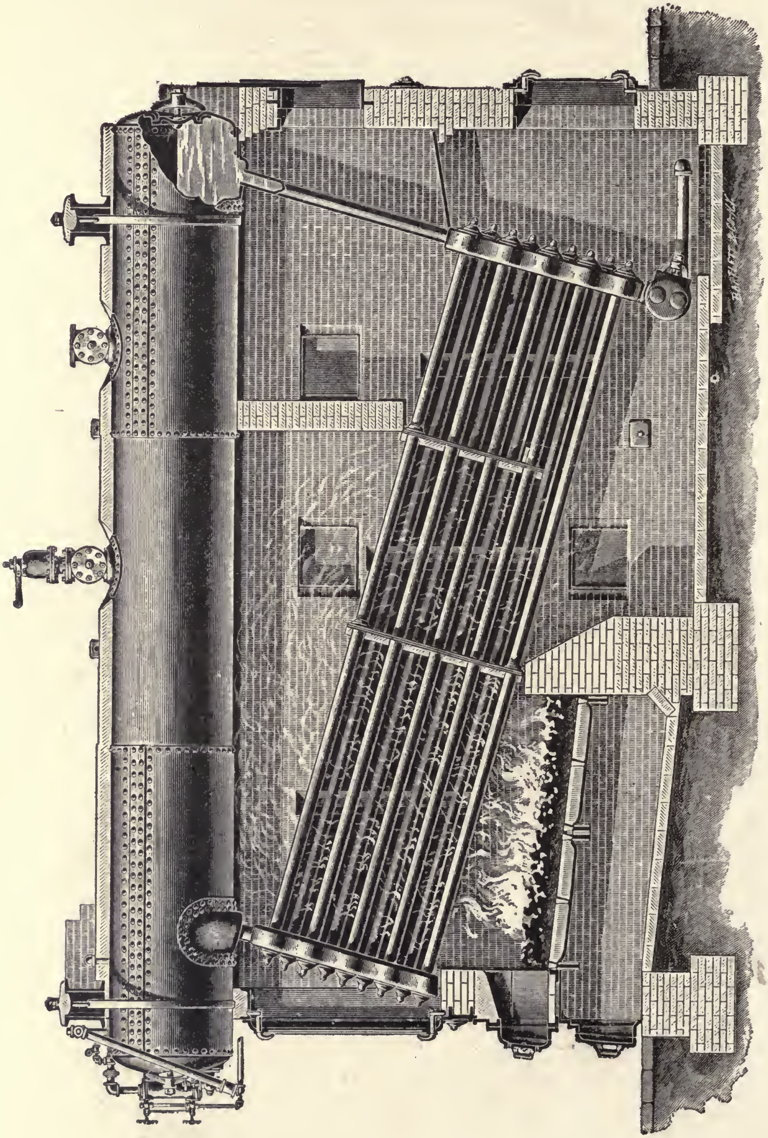


Fig. 41.

HORIZONTAL WATER-TUBE BOILERS.

BABCOCK AND WILCOX.

Water Tubes Nearly Horizontal—Steam and Water Drum Horizontal—Straight-Tube—Single-Tube—Sectional.

Construction. This boiler consists of a large number of lap-welded, wrought-iron, 4-inch tubes connected to each other and to a horizontal steam and water drum. The arrangement of the parts is shown in Fig. 41 which is a side view of a much-used form of this boiler. Each tube is expanded into a forging of the form shown in Fig. 42.

The tubes in a vertical row enter one piece and this vertical row is independent of the others, as shown in Fig. 43. Thus it is readily seen that this is a sectional boiler. Fig. 43 shows also the "staggered" arrangement of the tubes. In the back side of the front header, and in the front side of the rear header, holes are drilled into which are expanded the water tubes. In the front side of the header a flanged hole opposite each tube is fitted with a hand-hole plate. The details of construction are shown in Fig. 44. The tops of the headers are connected to the steam and water drum by short tubes and the same construction is used for connecting the mud drum to the rear header.

Fig. 42.

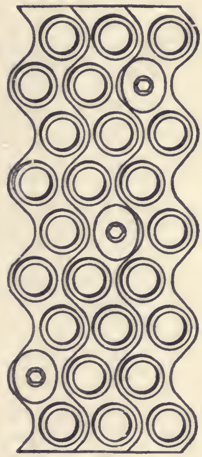


Fig. 43.

Operation. The grate is at the front end of the boiler under the higher end of the tubes. The hot gases from the fire are guided by division plates and bridges, so that after rising from the grate they pass between the tubes to the combustion chamber, which is under the steam and water drum; the gases then pass downward among the tubes, and after rising a second time pass off to the chimney. In this way, the direction of the currents of hot gases is at all times almost at right angles to the tubes, thus impinging upon them instead of passing parallel to the heating surfaces, as in the case of fire tubes. As the gases impinge three times against the staggered tubes, the heating surface is very efficient.

Circulation. The feed water enters the steam and water drum through the pipe shown in Fig. 44. It is thus heated before it mixes with the hot water in the boiler. As the water in the tubes becomes heated, it rises to the higher end where it is

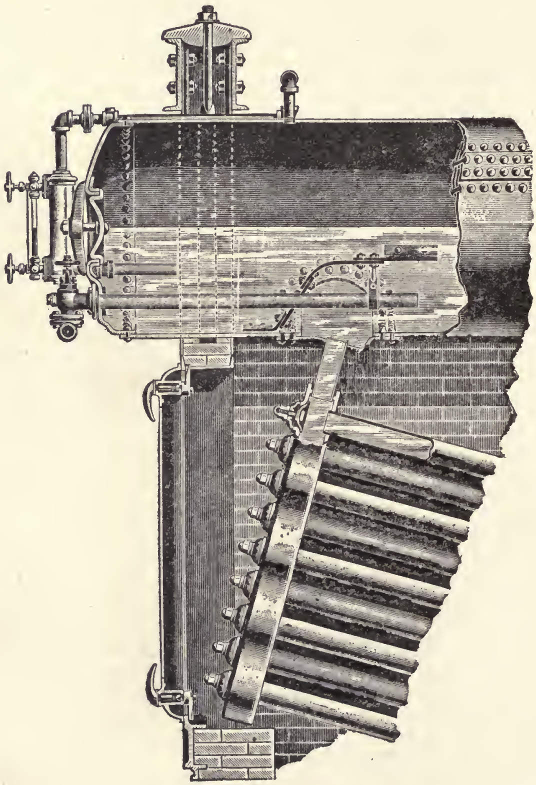


Fig. 44.

partly converted into steam; a column of water and steam rises through the header to the drum in which the steam and water become separated. The cooler water at the rear of the steam and water drum flows down into the lower end of the tubes and as it becomes heated rises. Thus there is a continuous circulation.

Steam is taken from the rear end of the steam and water drum. The solid matter in the water is not deposited on the tubes because of the rapid circulation; it falls to the mud drum from which it is blown out.

The marine form of this boiler has a cross drum, that is, the drum is at right angles to the tubes instead of parallel to them. It is similar in form to the cross-drum types used for stationary work. This form is used in case there is not sufficient head room.

ROOT.

Water Tubes Nearly Horizontal—Steam and Water Drums Horizontal —Straight-Tube—Single-Tube—Sectional.

The above brief outline indicates that the Root water-tube boiler is, in its main features, like the Babcock and Wilcox. In fact the difference is in detail of construction only. Fig. 46 shows the general appearance when a part of the brickwork is removed. It will be seen that there is a large steam drum (cross type) at the top in addition to the small steam and water drum over each section.

Construction. The Root water-tube boiler is composed of 4-inch lap-welded wrought-iron tubes. These tubes are expanded into cast iron headers as shown in A, Fig. 45. A vertical section is formed by placing one pair upon another as shown at B, Fig. 45. One tube of each pair is connected to one above it by a flexible bend, by means of which is obtained an uninterrupted circulation from the bottom to the top of the section. A metallic packing ring (see C, D, and E, Fig. 45) insures a tight joint between the bend and the header. F, Fig. 45, shows an enlarged end of a bend.

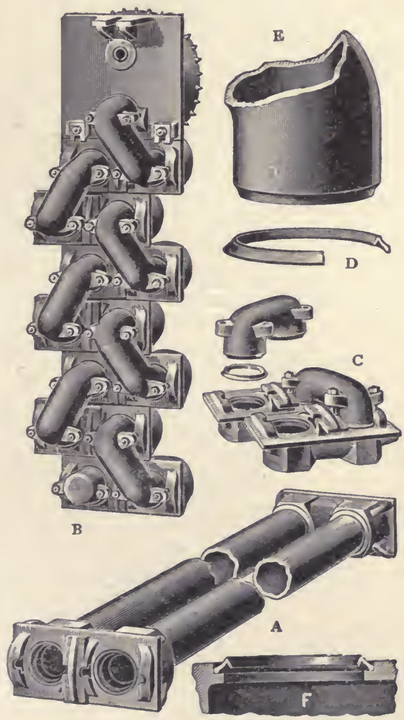


Fig. 45

To form the boiler several of these vertical sections are placed side by side. These vertical rows are not rigidly connected because the lower tubes being nearer the fire expand more than those above.

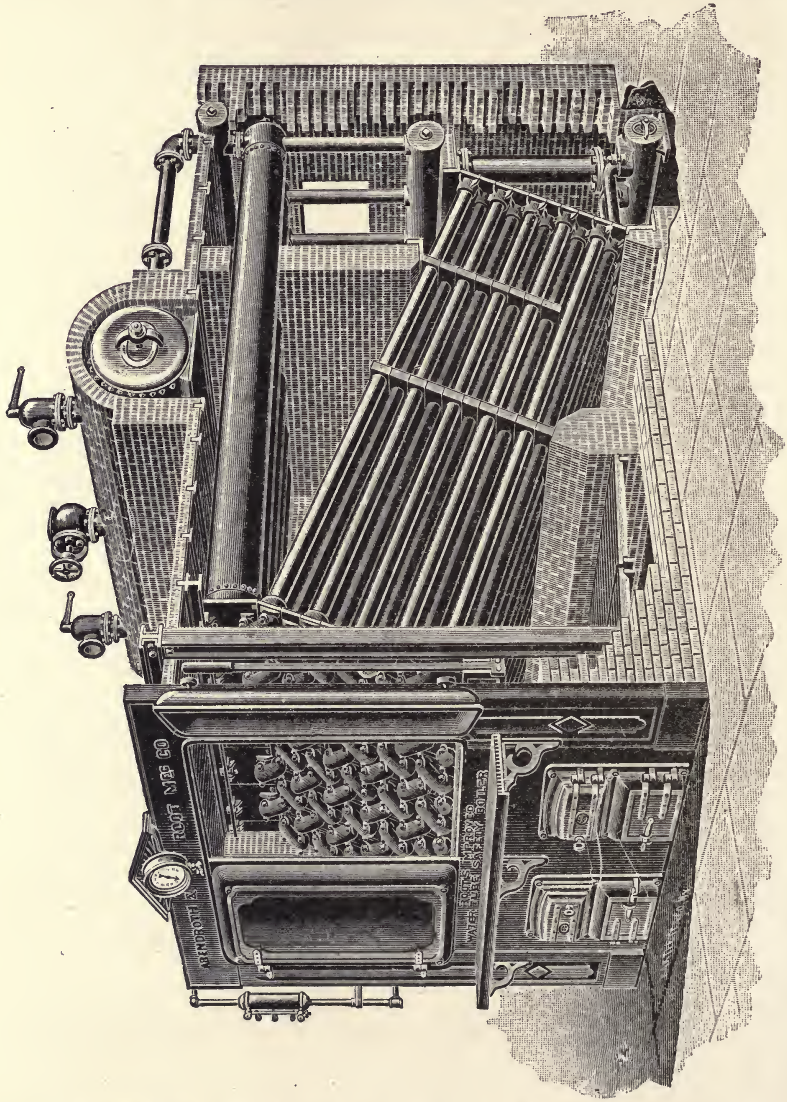


Fig. 46.

Circulation. Each section has its overhead drum into which the water and steam is discharged from the tubes. At the rear of the boiler and at the end of each steam and water drum, a vertical pipe leads to a cross drum beneath; this drum is a common reservoir for all the sections. The feed water enters this drum and meets the hot water coming from above. The mixing of the water results in a temperature which prevents any trouble from unequal expansion. The cross drum (reservoir) is also connected by vertical pipes to another drum which is below and parallel to it; this is the mud drum. From the feed reservoir, the mixture of feed and circulating water descends to the mud drum in which the solid impurities are left. The circulating water then flows from the top of the mud drum into the lower end of the tubes. As these tubes are surrounded by hot gases, the water becomes heated and rises through the tubes to the steam and water drums. This heated water contains bubbles of steam which leave the water and collect in the steam drum. The water flows through the steam and water drum and descends to meet the entering feed water. The water level is at about the middle of the steam and water drums.

The hot gases from the fire pass among the tubes three times in practically the same manner as in the Babcock and Wilcox boiler.

WORTHINGTON.

Water Tubes Nearly Horizontal—Steam and Water Drum Horizontal —Straight-Tube—Single-Tube—Sectional.

Construction. This form of boiler is much the same in principle and operation as the Babcock & Wilcox boiler, but the parts are differently proportioned and arranged; see Fig. 47. The furnace extends under the entire boiler, and the tubes are set over it close together in oppositely inclined series. No flame walls or baffle plates are used.

Boilers up to 125 H. P. are usually made to fire at the end as shown in Fig. 47, in which the tubes extend across the furnace viewed from the front, and the steam and water drum is at right angles to the tubes. In the *side-fired* boilers the tubes extend from front to back, and the steam and water drum from side to side; this arrangement is better adapted for large units and for setting in battery. The tubes of each vertical row are expanded into straight headers which contain seven or eight tubes. See Fig. 48. Opposite each tube is a hand hole. These headers are arranged close together, forming the boiler enclosure.

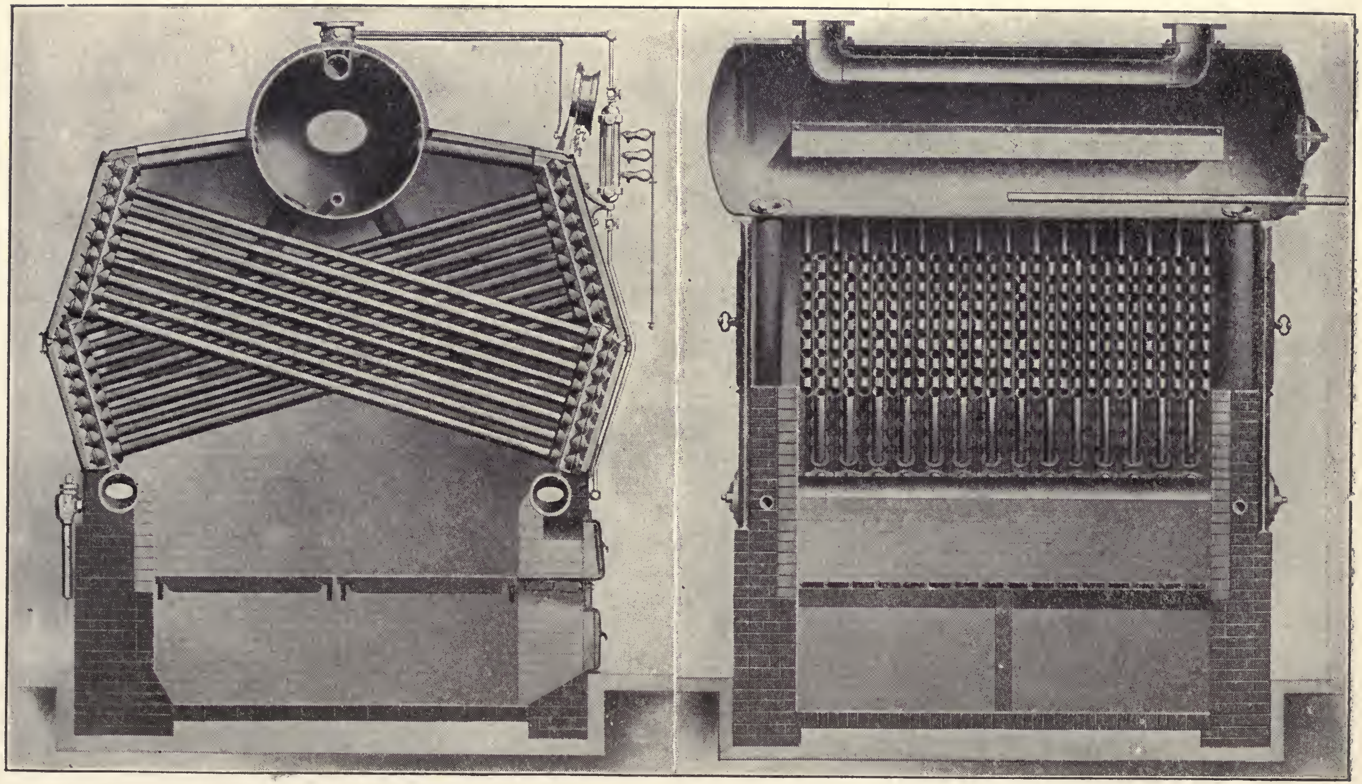
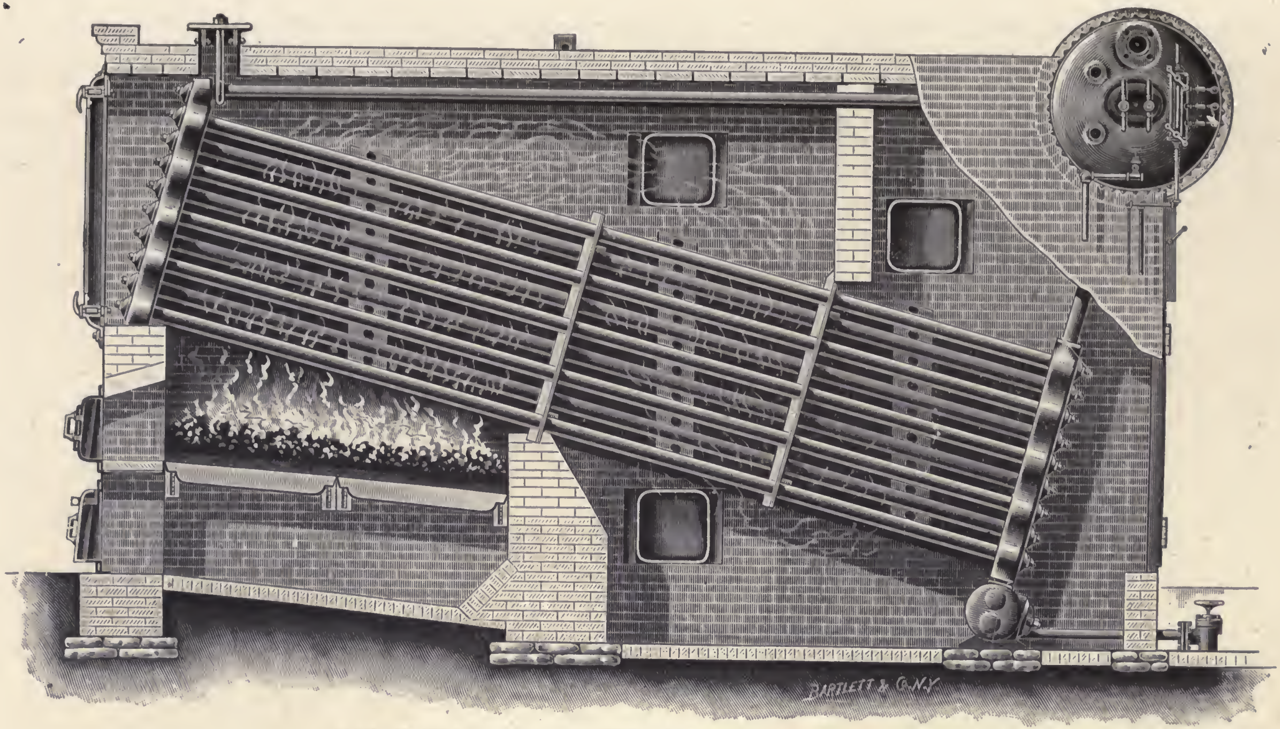
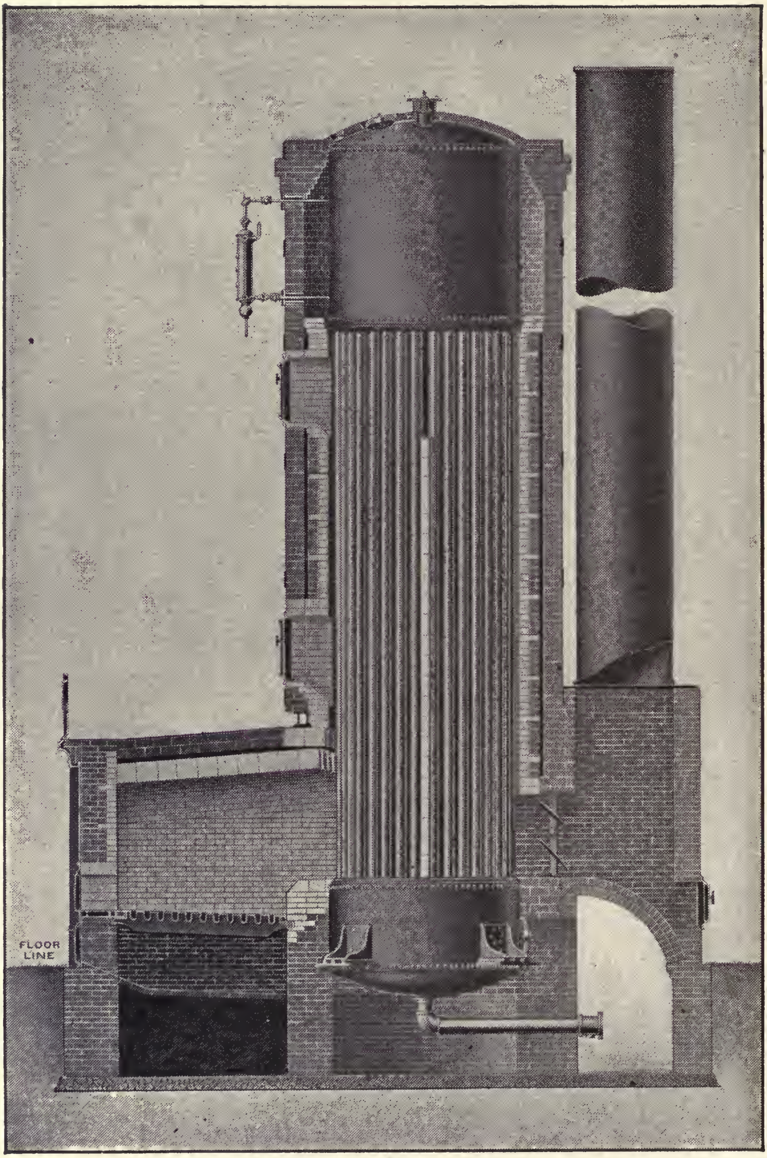


Fig. 47.



Side View of Cross Drum Type of Babcock and Wilcox Boiler.



THE WICKES VERTICAL WATER TUBE BOILER.

Circulation. The feed water enters the steam and water drum and the circulation carries it down to the mud drums through large circulating tubes which are outside of the furnace. See Fig. 48. From the mud drum it enters the lower series of headers and rises through the inclined tubes over the fire into the upper headers.

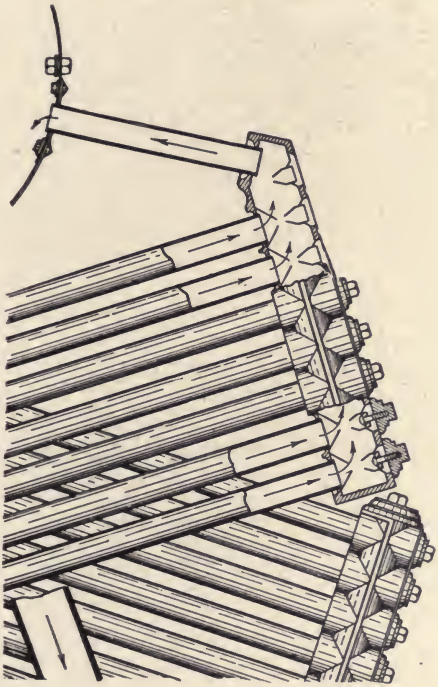


Fig. 48.

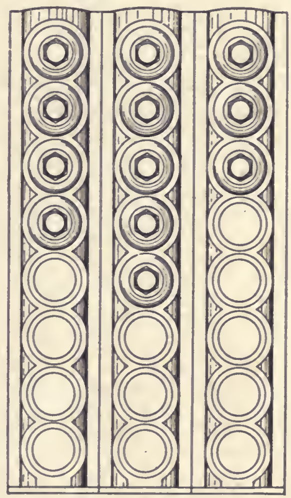


Fig. 49.

The water now containing bubbles of steam enters the steam and water drum by means of short tubes shown in Figs. 47 and 48.

The covering for this boiler is an iron casing, no brick being used except to enclose or line the furnace.

HEINE.

Water Tubes Nearly Horizontal—Steam and Water Drum Parallel to Tubes—Straight-Tube—Single-Tube—Non-Sectional.

Construction. The Heine water-tube boiler is not a sectional boiler. Instead of being expanded into small headers grouped to form a boiler, all the tubes are expanded into the inside plates of

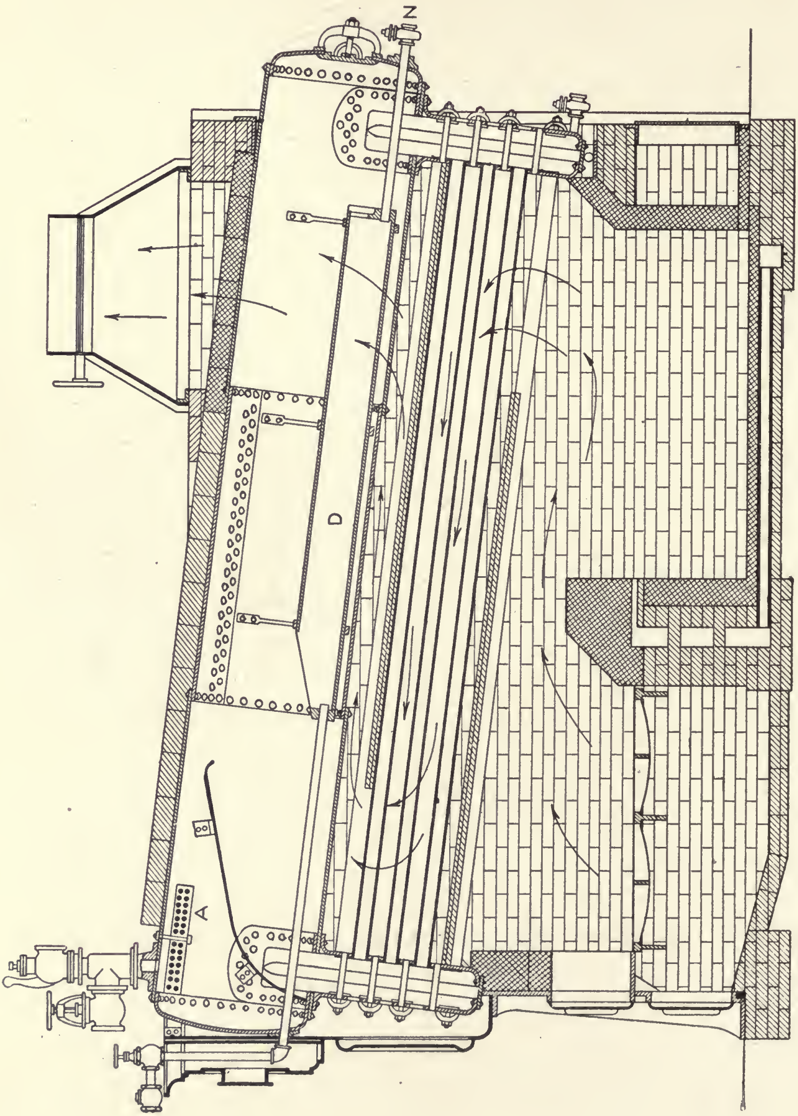


Fig. 51.

a water leg at each end. The construction of this water leg is shown in Fig. 50. It is composed of two parallel plates flanged and riveted to a butt strap. The plates are strengthened by short hollow screw stays similar to those used in the water-leg construction of fire-box boilers. At the top, the water leg is curved and joined to the steam and water drum by riveting. Opposite each tube is a hand hole for cleaning or replacing a defective tube.

Circulation. The feed water enters at the front of the steam and water drum and flows into the mud drum D, from which it passes to the rear header with much less velocity. The water is warmed while passing through the pipe leading to the mud drum, and as it flows slowly through the mud drum it deposits its sediment. The accumulated sediment is blown off by means of the blow-off pipe N. The water, as it becomes heated in the mud drum, rises and passes to the front of the mud drum, from which it flows in a thin sheet to the rear of the steam and water drum and to the rear water leg. From the rear water leg, it enters the tubes in which it is partially converted into steam. The mixture of steam and water enters the higher end of the drum from the water leg, and as there is but a thin layer of water in the steam and water drum, the steam readily rises through it. A deflection plate prevents water from being carried to the perforated steam pipe A.

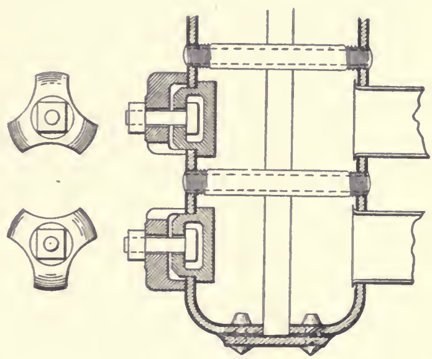


Fig. 50.

The flow of hot gases from the fire is directed by light tile placed on the upper and lower rows of tubes as shown in Fig. 51. The hot gases flow nearly parallel with the tubes instead of across them as in the Babcock and Wilcox.

ATLAS.

Water Tubes Nearly Horizontal—Steam and Water Drums (Cross Type) Horizontal—Straight-Tube—Single-Tube—Non-Sectional.

This make of water-tube boiler does not need a full description as Figs. 52 and 53 show both the general arrangement of

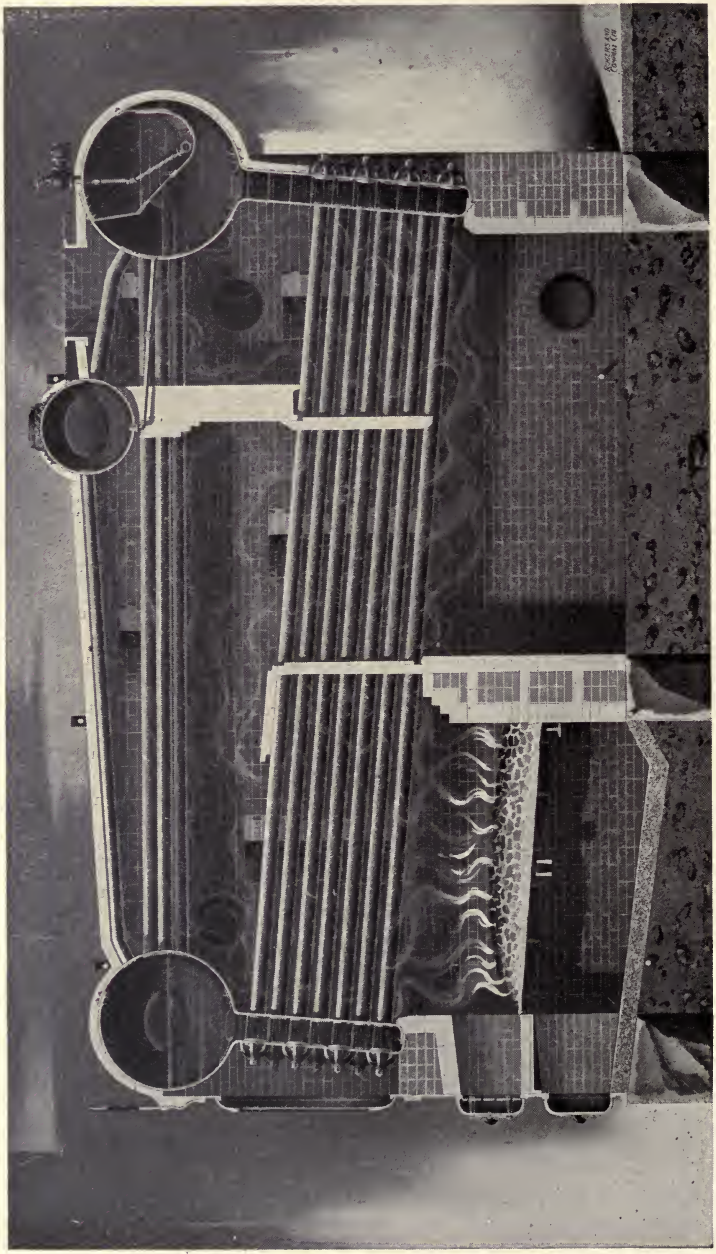


Fig. 52.

parts and the details of water-leg construction. The general description of the Heine boiler is applicable to this type. A few points of difference, however, should be pointed out.

There are three drums running crosswise the tubes. The front and rear drums are made of the same plates as the water legs. This is shown in the illustrations. The reasons for this method of construction are that it gives a "throat" area of about 80 per cent of the area of the leg and prevents all seams from coming in contact with the furnace gases. The two drums are connected on the water line by equalizing tubes. In the rear drum, a water purifier receives the feed water which passes down the rear leg, then through the tubes to the front leg. In the last portion of the tubes, much of the water is converted into steam which flows through the front drum and the superheating tubes to the small upper drum. The water flows through the equalizing tubes to the rear drum and joins the current of feed water.

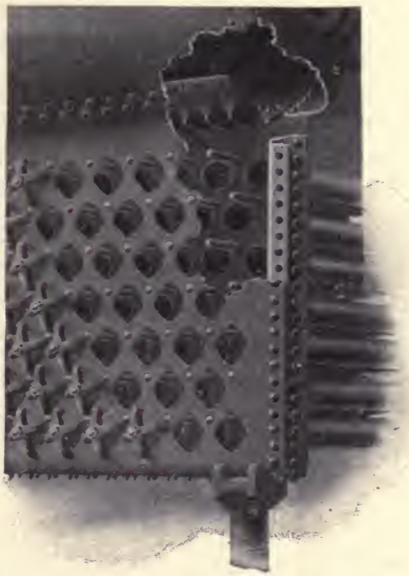


Fig. 53.

The front drum is made 36 inches in diameter, the middle drum 24 inches, and the rear drum 42 inches. The tubes are 4 inches in diameter and the longest are 18 feet in length.

MOSHER.

Water Tubes Nearly Horizontal—Steam and Water Drums (Cross Types) Horizontal—Curved-Tube—Single-Tube—Non-Sectional.

The chief differences in appearance between this boiler and those already described are shorter tubes, making a more compact boiler, and the curved tubes. This type is more often used in

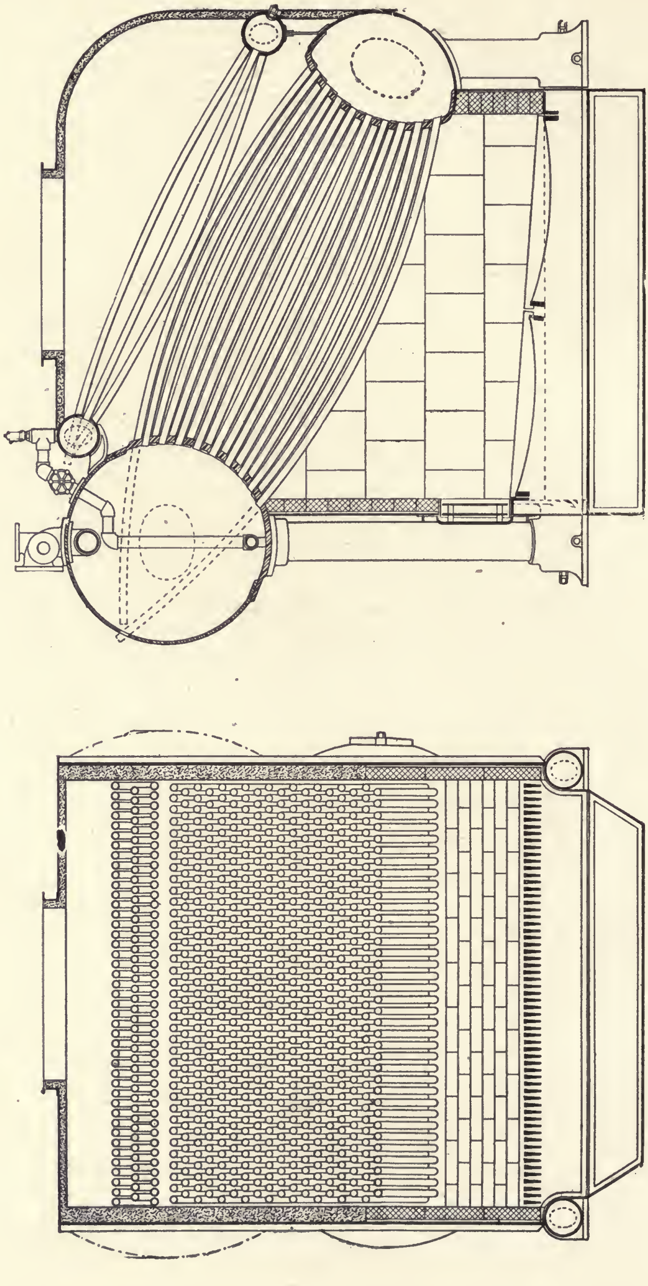


Fig. 54.

marine than in stationary work. The boiler consists of a large steam and water drum connected to a smaller water drum by slightly curved tubes. The steam drum is supported by two large circulating pipes (one at each end) which are connected by other pipes to the water drum. Thus the circulation is down these pipes

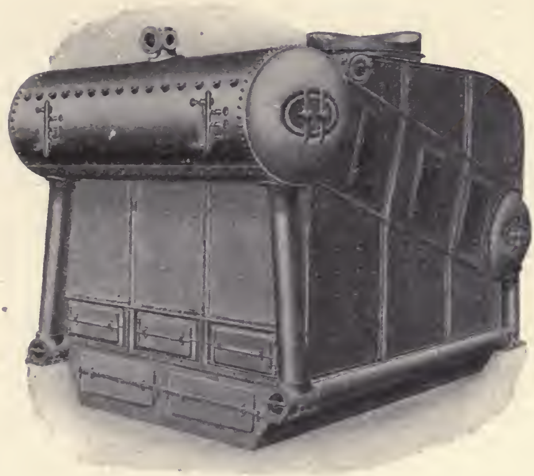


Fig. 55.

and along the pipe at the bottom (see Fig. 55), up to the water drum and from thence to the steam drum by the tubes which are in contact with the hot gases.

The feed-water heater, shown in Fig. 54, consists of two small drums connected by tubes. The parallel dotted lines in the steam drum of Fig. 54 show how tubes are removed and replaced. Fig. 55 shows the row of plugs for this purpose. These plugs are illustrated in Fig. 56. Each plug is a conical-headed bolt, having a short piece of copper tube, a washer, and a nut. The conical head and the copper tube are inserted in the hole until the washer is in contact with the outer surface of the drum. The nut is then screwed up, thereby flaring the end of the copper tubing as shown.

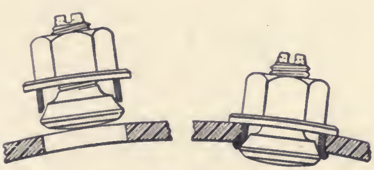


Fig. 56.

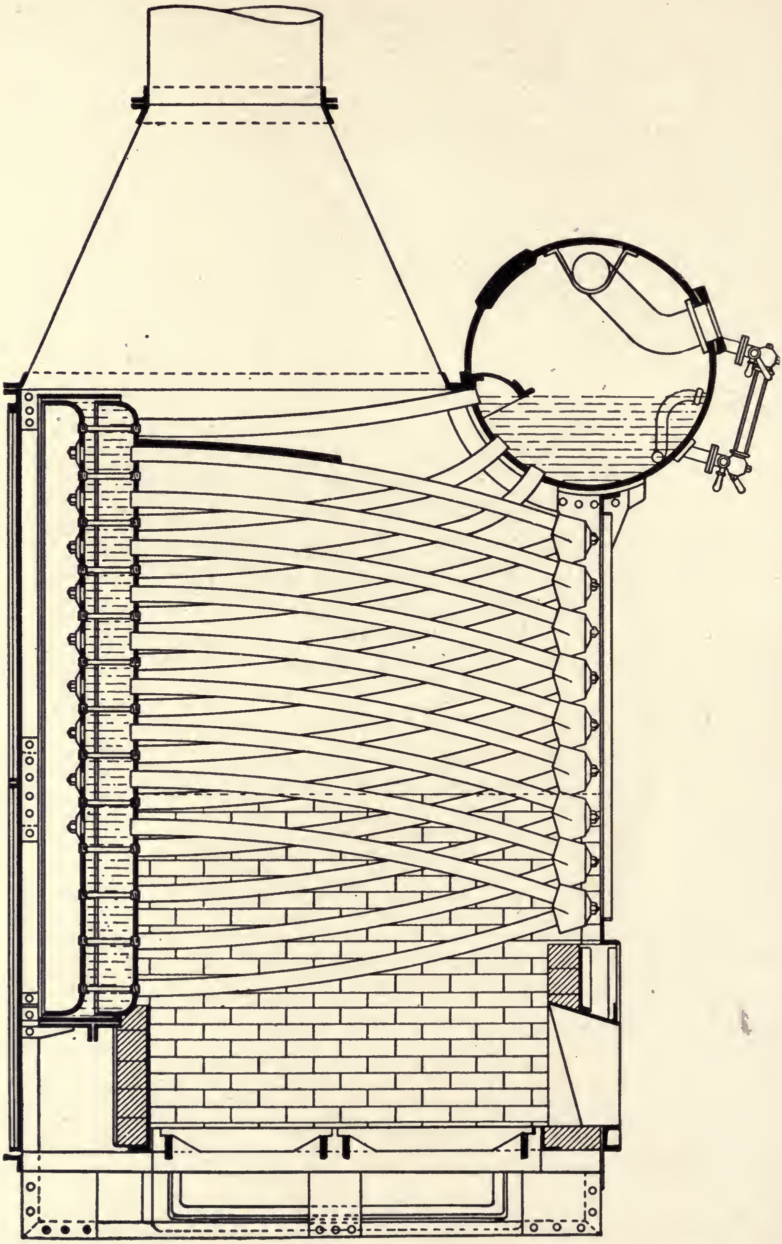


Fig. 57.

The steam pressure on the conical head increases the tightness of the joint.

THORNYCROFT-MARSHALL.

Water Tubes Nearly Horizontal—Steam and Water Drum (Cross Type) Horizontal—Curved-Tube—Single-Tube—Non-Sectional.

The Thornycroft-Marshall non-sectional boiler consists of a large horizontal steam and water drum, a vertical water box or header, and the generating tubes. Like the Mosher, the tubes are curved slightly, but the header is a distinct difference.

The general features of construction are shown in Fig. 57. The steam and water drum, sometimes called the separator barrel, is simply a cylinder with dished ends. The water level is about one-third the diameter of the cylinder. The tubes, which are $3\frac{1}{4}$ inches in diameter, are connected in pairs to a junction box at one end and to a water box or header at the other end. Thus each pair forms a unit, but the two tubes of the unit are not in the same vertical plane. The upper tube enters the header as high as possible and the lower ones enter low down, thus giving considerable upward slope. From near the top of the water box, three rows of tubes lead to the separator barrel as shown in Fig. 58. The water box is very simple, the flat plates are stayed by short hollow screw stay-bolts. The junction boxes are not restrained in any way; this construction, combined with the slight curve of the tubes, allows free expansion. The slight curve also allows the tubes to enter the separator barrel and the water box at right angles so that they may be expanded in-place.

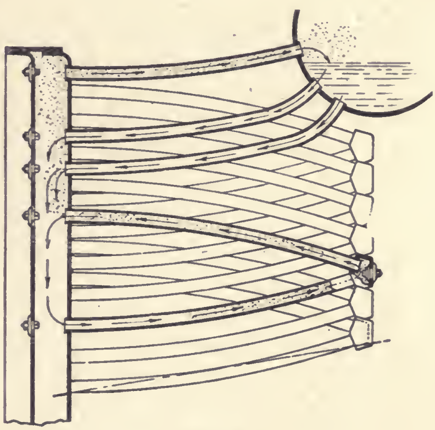


Fig. 58.

Circulation. The feed water enters the steam and water drum and then passes to the water box through the two lower sets of tubes. See Fig. 58. The water enters the lower ends of the various pairs

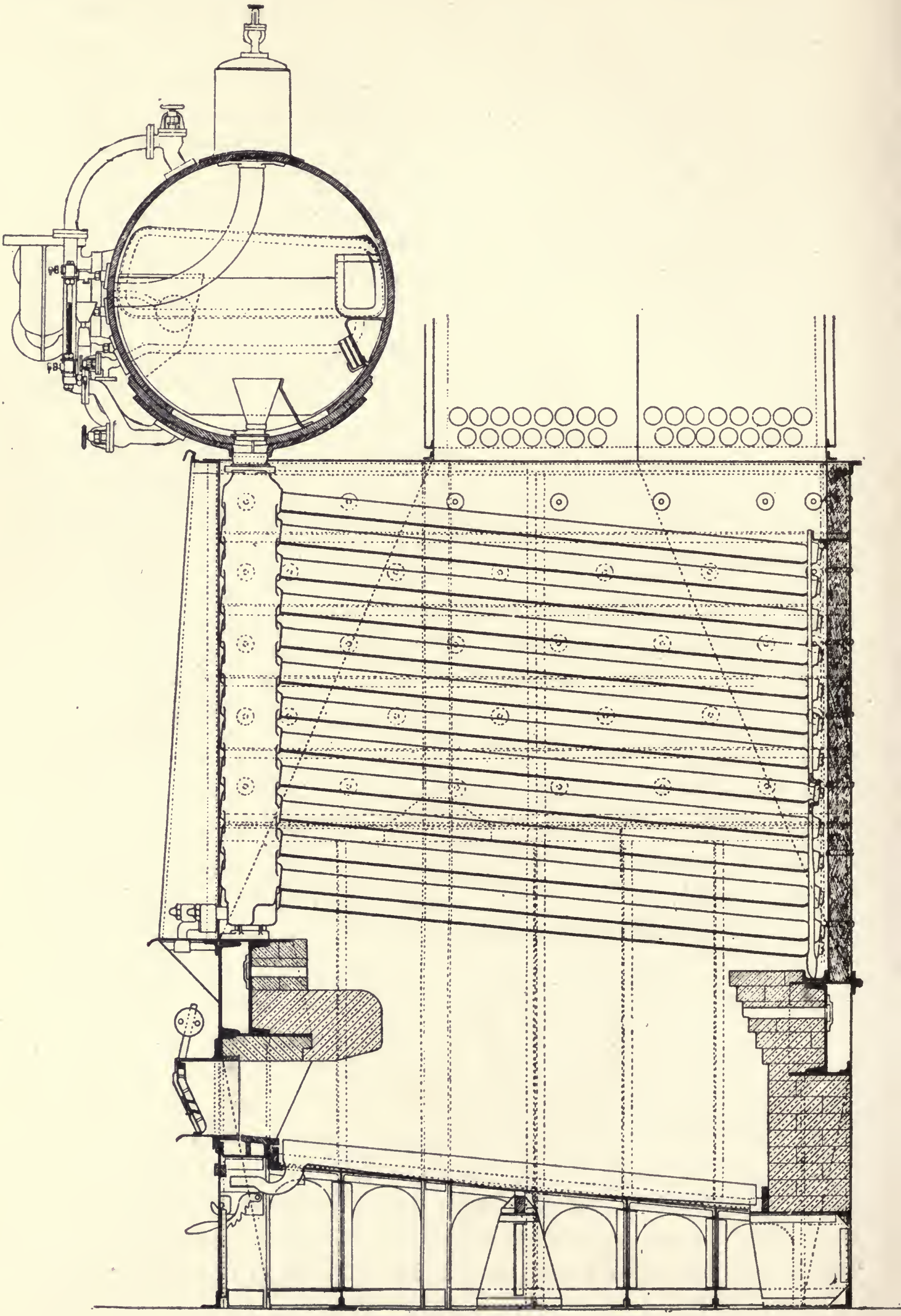


Fig. 59.

of tubes, as shown in Fig. 58, and rises in the tubes while in contact with the hot gases from the furnace. The mixture of steam and hot water then enters the header from which it passes to the steam and water drum by means of the highest row of tubes. The difference in height of the two tubes of a unit insures good circulation. A baffle plate prevents the water from splashing to the steam pipe.

The hot gases pass upward among the tubes which cross so frequently that they take almost all the heat from them.

NICLAUSSE.

Water Tubes Nearly Horizontal—Steam Drum Horizontal—Straight-Tube—Double-Tube—Sectional.

This boiler differs essentially from those already described in that it is of the *double-tube* type. In general, it consists of a number of elements which form a vertical header, to which tubes are connected. The tubes are set at an angle of about 6 degrees to the horizontal. Above the elements is a transverse steam and water drum which is in communication with the headers. The general arrangement of parts is shown in Fig. 59.

Construction. The interesting features of this type of boiler

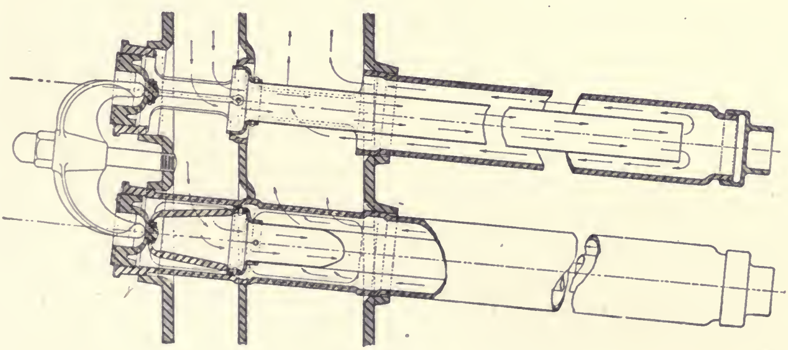


Fig. 60.

are the design and construction of the tubes and headers. To increase the circulation the principle of the "Field" tube is employed. In this construction, the outer, or generating, tubes ($3\frac{1}{4}$ inches in diameter) are closed at one end. Each generating tube contains an inner circulating tube which is $1\frac{19}{32}$ inches in diameter.

This tube is open at both ends. The closed ends of the generating tubes are supported by resting in holes in a plate or rack at the rear of the boiler. The forward end of the circulating tube is attached to a cap which screws into the outer end of the generating tube. A recess in this cap provides a bearing for an arch bar which spans two tubes, keeps them in place, and is itself secured by a nut on a bolt which is screwed into the header. See Fig. 60.

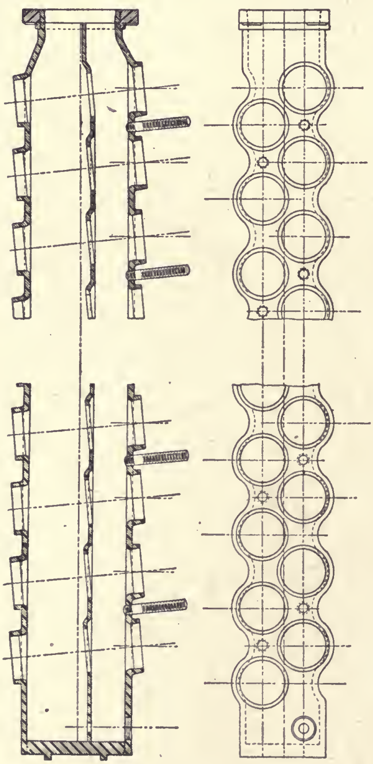


Fig. 61.

The front end of the generating tubes is of peculiar shape. To allow the water to enter the circulating tubes, and to fasten the tubes to the header without expanding them, each generating tube is provided at the open end with two cone-shaped portions; these are about eight inches apart. The first cone fits into a taper hole flanged outward in the front face of the header, and the second cone fits a similar hole in the rear face of the header. Both the holes and tubes are ground to the same size and taper. About midway between the cones, a third expanded portion occupies the tube hole in the diaphragm or middle plate of the header. See Fig. 60. The portion of the tube within the header is called the "lantern". At this point the tube is cut away so that water may freely enter the tube, the openings being above and below. In Fig. 60, the upper tube is in its normal position, but the lower tube has been turned through 90 degrees to show the construction.

To stand high steam pressures, the elements of the headers are made of wrought steel and are sinuous in shape. Fig. 61 shows the shape of the header and the positions of the tubes.

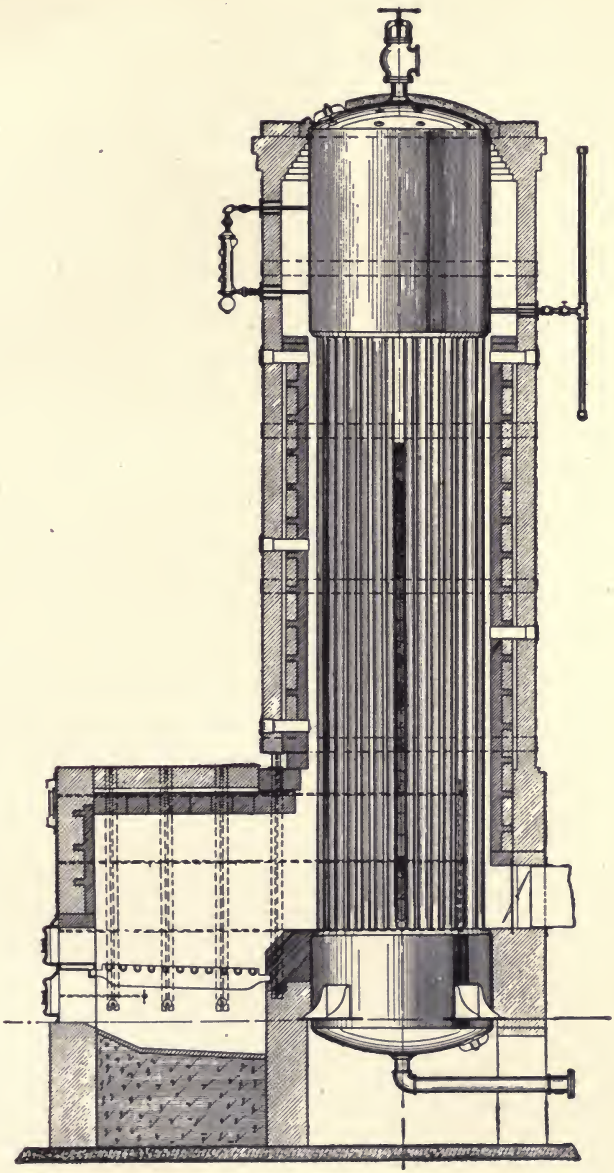


Fig. 62.

Each element contains 24 tubes in two vertical rows of 12 each. In the middle of the headers, there is a diaphragm for dividing the interior. The front passage serves as a "downcomer" for the water, and the rear is the "upcomer", or riser, for the mixture of steam and water.

The lower ends of the headers are closed, and the upper ends flanged to connect with the steam and water drum, which is 42 inches in diameter.

Circulation. Fig. 60 gives an idea of the direction of circulation. Water from the drum descends in the front compartment of the header, flows into the circulating tubes, *which communicate with the front compartment only*, and after flowing the length of the circulating tubes, enters the generating tubes. The water then comes back through the annular spaces in the generating tubes to the rear compartment of the header, because the *generating tubes communicate with the rear compartment only;* while in the annular space it is partially evaporated. The mixture of steam and water then rises to the drum.

VERTICAL WATER-TUBE BOILERS.

WICKES.

Water Tubes Vertical—Straight-Tube—Single-Tube—Non-Sectional.

Let us now consider a water-tube boiler having vertical tubes. Fig. 62 shows the general arrangement of the parts of the Wickes vertical water-tube boiler. At the top is a cylindrical steam and water drum into which the upper ends of the vertical tubes are expanded. At the bottom is a cylindrical mud drum of the same diameter as the upper drum. The tubes are straight and plumb when in position; they are arranged in parallel rows with a clear space between rows to admit a small hoe to remove any soot that may accumulate on the tube sheet of the mud drum.

The tubes are divided into two compartments by heavy fire-brick tile. The tubes in the section next the furnace are called "risers"; those in the rear are the "downcomers," because the heated water rises to the steam drum through the front tubes, and the cooler water flows down those in the rear. The feed water is introduced into the upper drum. The direction of flow of hot

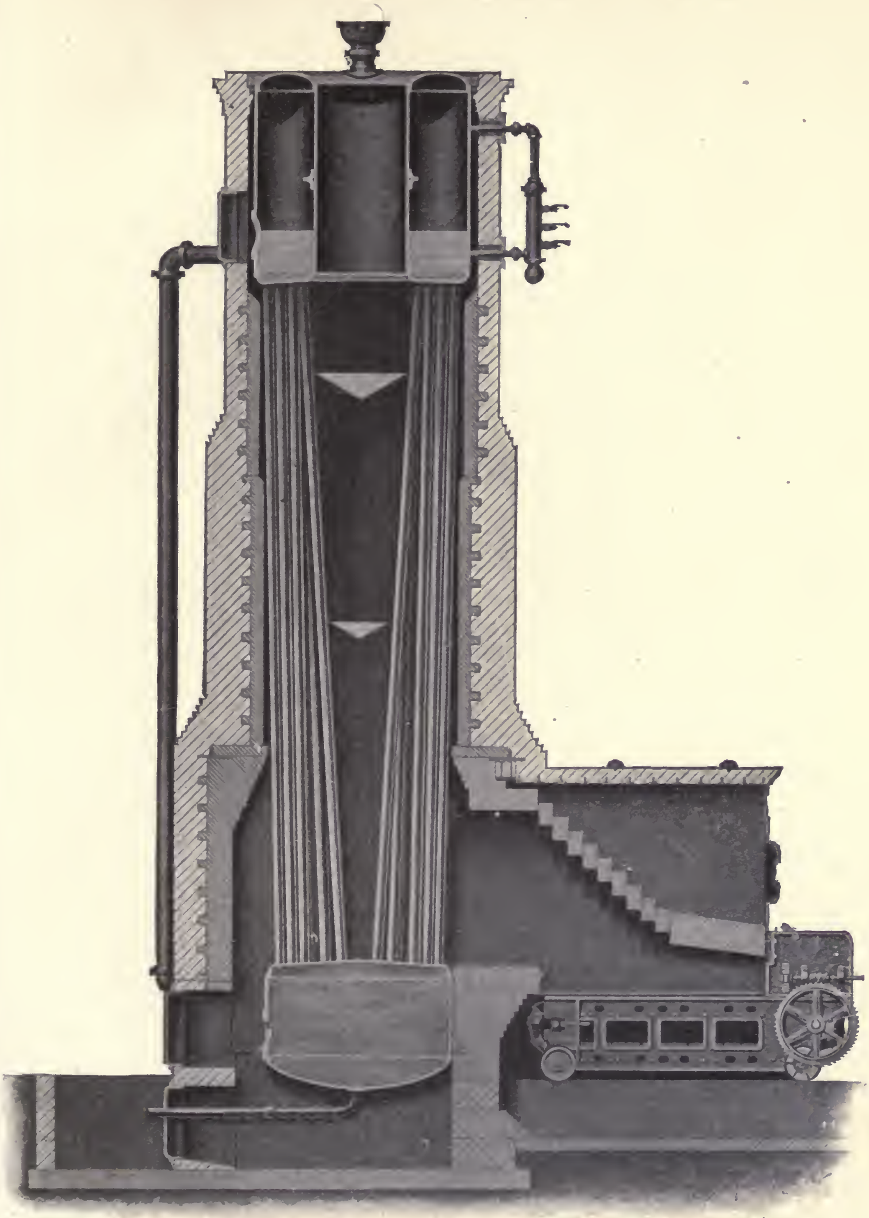


Fig. 63.

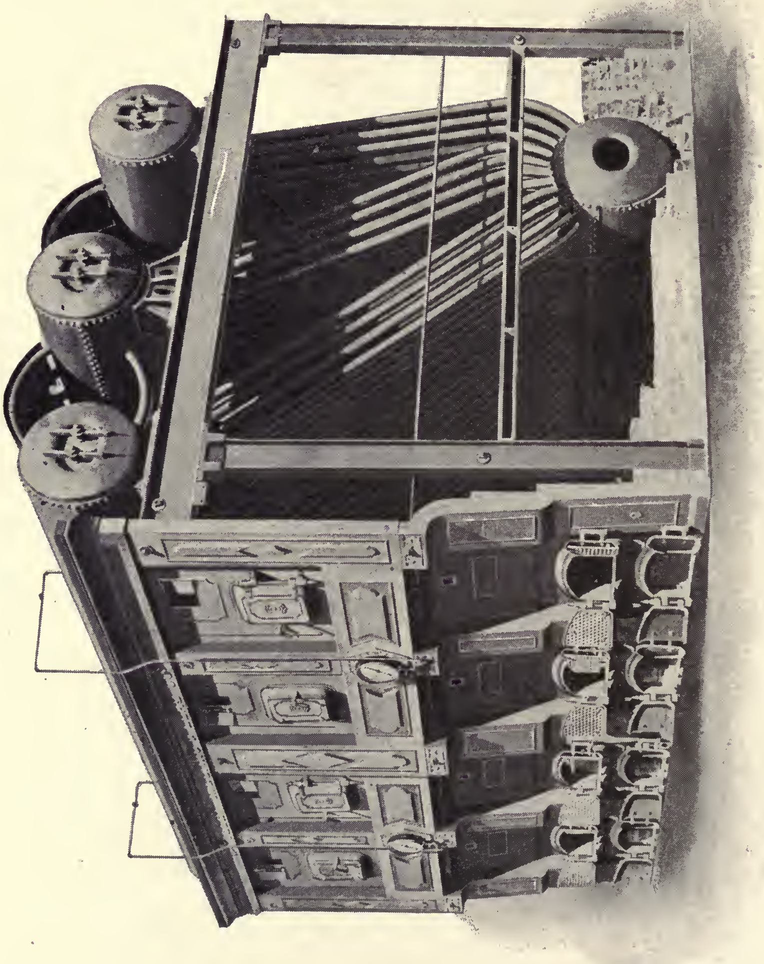


Fig. 64.

gases is the same as that of the water. A baffle plate in the steam and water drum directs the water to the downcomers.

The furnace is external and built entirely of brick. The hot gases from the fire come in contact with the tubes without passing through a combustion chamber.

CAHALL.

Annular Steam and Water Drum—Water Tubes Vertical—Straight-Tube—Single-Tube—Non-Sectional.

The Cahall vertical water-tube boiler consists of an annular steam and water drum, a cylindrical mud drum, and 4-inch vertical tubes. The generating tubes connect these two drums and are placed within the brick setting. An external circulating pipe also connects the two drums. As this pipe is filled with comparatively cool water and the generating tubes with a mixture of hot water and steam, the circulation is positive and rapid. The feed water enters the steam and water drum, flows down the external pipe to the mud drum and then rises in the generating tubes to the steam and water drum.

The fire is in a brick furnace at one side of the boiler as shown in Fig. 63. The hot gases rise among the tubes. The annular form of the steam drum makes the central space conical; in this space several deflecting plates, or baffles, cause the hot gases to flow out among the tubes. After heating the water in the tubes the hot gases pass through the opening in the steam and water drum coming in contact with the metal containing the steam This thoroughly dries the steam and in many cases slightly super heats it.

The steam drum and also the mud drum are equipped with swinging manheads. The steam drum also has several handholes for use in removing and replacing tubes.

STIRLING.

Water Tubes Nearly Vertical—Steam and Water Drums Horizontal—Curved-Tubes—Single-Tube—Non-Sectional.

The Stirling boiler, shown in Fig. 64, consists of three cylindrical steam and water drums at the top, and a mud drum at the bottom. The lower drum is connected to the upper drums by three sets of tubes which are curved slightly at the ends. The curved tubes allow for expansion and make it possible to have the tubes enter the drums radially.

The feed water enters the rear steam and water drum and coming in contact with the hot gases just before they enter the uptake, becomes gradually warmed. This heating causes most of the sediment to fall to the mud drum from which it may be blown out at intervals. The mud drum is protected from the intense heat of the furnace by the bridge wall.

Each set of tubes are separated from the others by partition walls or baffles of fire-brick tile so that the gases from the furnace pass along the entire length among the first set of tubes; they are then guided downward among the second set and after rising again among the tubes of the third set, escape to the chimney. By thus having a long passage a large proportion of the heat is taken from the gases before they go to the chimney. The fire-brick arch just above the furnace insures an even distribution of the gases and promotes combustion; the arch heats the entering air to a high temperature, thus reducing the liability of chilling the tubes by an inrush of cold air.

Steam is taken from the middle drum which is set a little higher than the others in order to obtain more steam space and drier steam. The boiler is surrounded on the rear and two sides by the brick setting; the front is of cast iron or of pressed steel. Numerous openings in the brickwork allow entrance for cleaning.

This type of boiler is flexible and adapted to cramped places as it can be made broad with little height or high with small floor area. All parts are either cylindrical or spherical in shape and of wrought metal. The curved tubes reduce the strains resulting from unequal expansion and contraction.

MILNE.

Water Tubes Vertical—Steam and Water Drum Horizontal—Curved-Tube—Single-Tube—Non-Sectional.

This boiler (Fig. 65) is in many respects similar to the Stirling (Fig. 64), but an inspection of the two illustrations will show several differences. In the Milne boiler there is but one steam and water drum and the tubes are vertical with a slight curve at

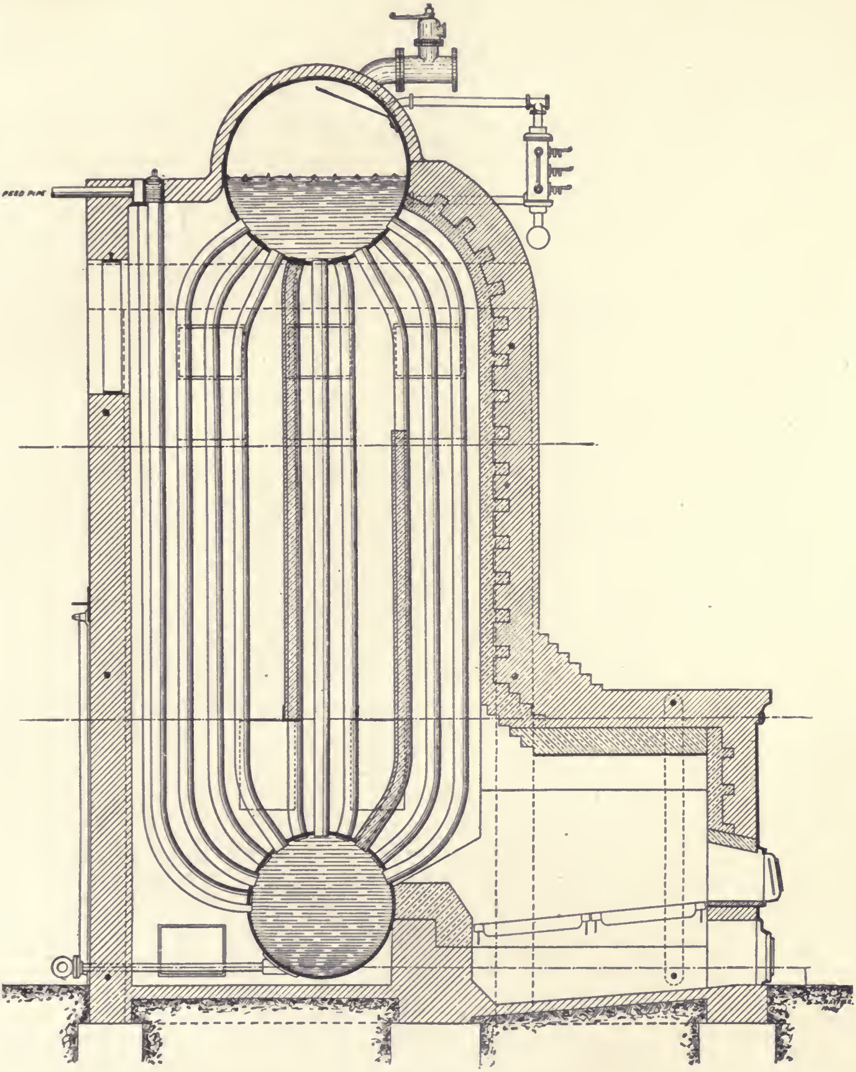


Fig. 65.

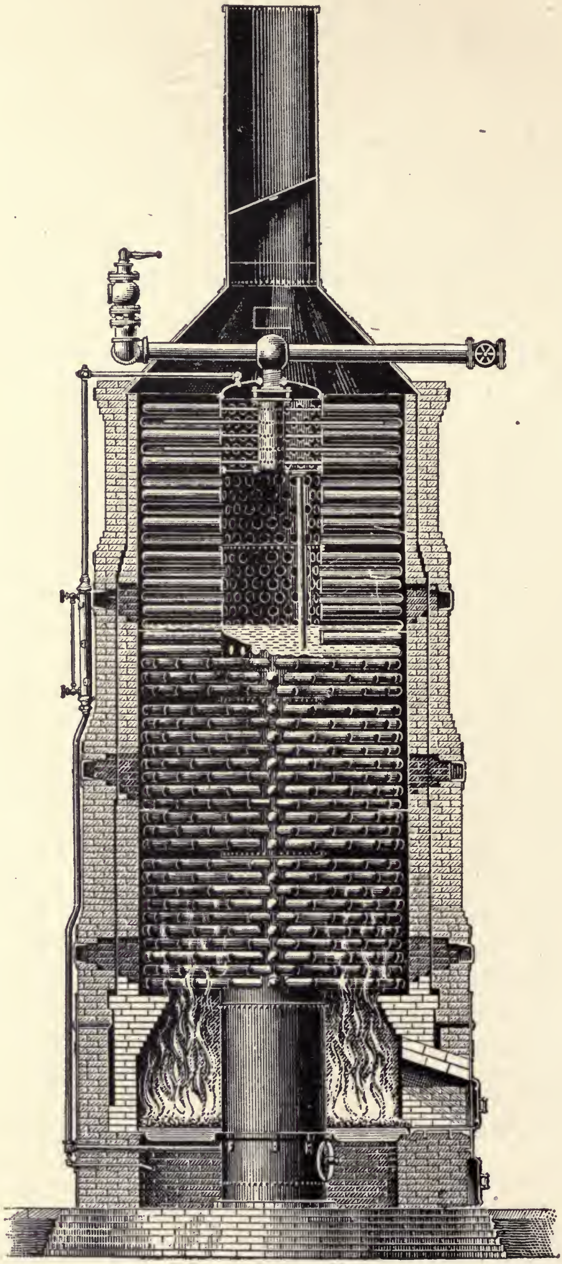


Fig. 66.

the ends. The hot gases are guided by division plates or tile so that they traverse 65 feet of tube-heating surface before they enter the flue. The tubes, being vertical, do not become covered with fine ash, nor do they become clogged with sediment and scale.

Circulation. The feed water enters the row of tubes at the extreme left and flows downward to the mud drum. It then rises as it becomes heated in the hotest generating tubes and enters the steam drum as steam and water. This method of feeding keeps the cold feed water out of the steam drum, and as the cold tubes containing the feed are placed in the path of the escaping gases, but little heat escapes to the chimney.

PECULIAR FORMS.

HAZELTON OR PORCUPINE.

Water Tubes Horizontal—Steam and Water Drum Vertical—Straight-Tube—Single-Tube.

The Hazelton water-tube boiler differs in many ways from the boilers thus far described. Like most water-tube boilers it consists of a steam and water drum and water tubes, but the central standpipe is vertical and the short horizontal tubes radiate from the central drum. According to our classification it is not a vertical water-tube boiler because the tubes are horizontal, also, it is not a horizontal boiler as in general appearance it is vertical.

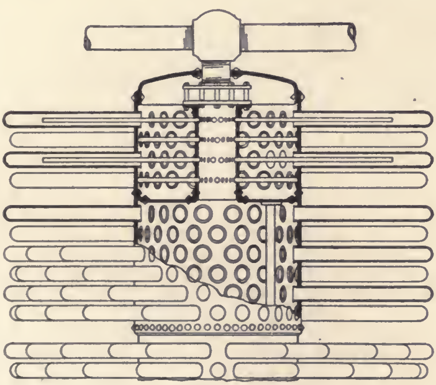


Fig. 67.

The grate is circular and formed around the central drum which rests on a circular cast-iron foundation. Above the grate, the central drum forms part of the heating surface and is the steam reservoir; below the grate it is the mud drum, which may be entered by means of a manhole just below the grate. As shown in Fig. 66, the standpipe above the fire is provided with radial tubes. The appearance of these tubes gives the name "porcupine".

The standpipe is about three feet in diameter for large boilers. The tubes are about four inches in diameter, and two and one-half feet long, the number varying with the capacity of the boiler. The outer ends of the tubes are closed and hemispherical, and the inner ends expanded into the standpipe. These tubes are free to expand and contract without bringing any strain on the boiler.

Steam is taken from the top of the central drum. To get dry steam, small pipes are inserted as shown in Fig. 67. The steam passes up into the small tube at the top of the standpipe and then through the small pipes to the ends of the generating tubes. It then flows back through the generating tubes to the annular space and from thence to the steam pipe. The feed pipe enters the mud

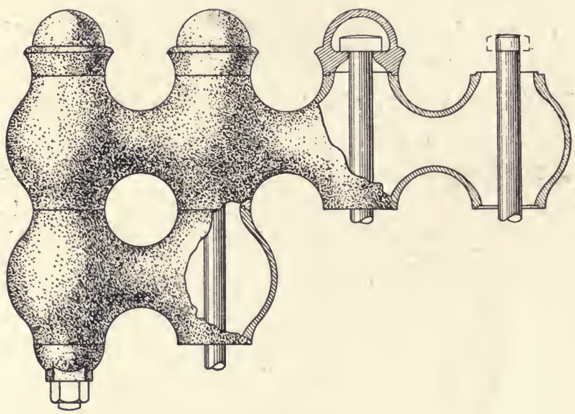


Fig. 68.

drum and extends upward nearly to the water line; it then returns nearly to the level of the grate, terminating in a spraying nozzle.

This type of boiler may be enclosed in a brick setting as shown in Fig. 66 or by a sheet steel covering lined with fire brick.

HARRISON.

Sectional—Hollow Cast-Iron Spheres Instead of Tubes.

All boilers thus far described have employed tubes as a means of dividing the water into small masses in order to make the heating surfaces more effective. In the Harrison Safety Boiler (Fig. 69) tubes are not used; instead, the water is contained in hollow cast-iron spheres, called units. These units, see Fig. 68, are arranged in vertical rows, called slabs, which are suspended side by side, about one inch apart, from an iron framework. The brickwork setting is merely a covering to keep the hot gases in contact with the units; it does not support the boiler, and can be repaired without disturbing the units.

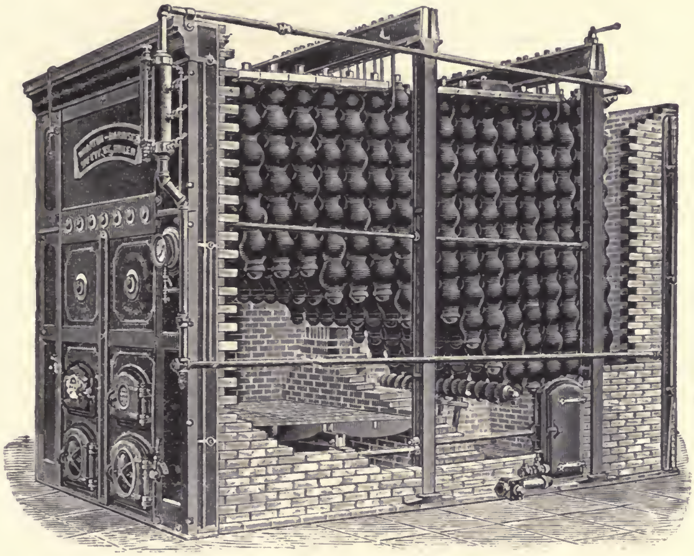


Fig. 69.

The use of units in place of tubes combines great strength and a large heating surface. They are strong because small and spherical and on account of the division of the water into small masses, the heating surface is effective. The units are held together by long bolts which pass through the centers as shown in Fig. 68. The machined faces make a steam-tight joint without packing. This boiler requires the same fittings as other boilers.

The great advantage of this boiler is safety. From the construction, it is apparent that rupture cannot extend beyond the unit; thus disastrous explosions cannot occur. They are claimed to be durable, economical, rapid steamers, and easily handled. The capacity can be increased by merely adding more slabs.

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