greater than half that of the boiler shell. The arrangement of the grate and bridge is evident from the diagram. After passing the bridge the flame and gases travel along through the internal cylinder B, till they reach the back end of the boiler; they then return to the front again by the two side flues *m*, *m'*, and thence back again to the chimney by the bottom flue *n*.

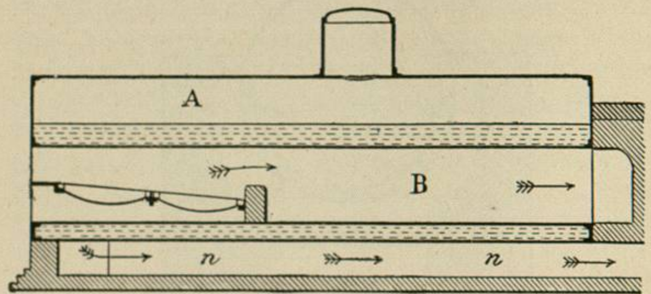

Fig. 154.

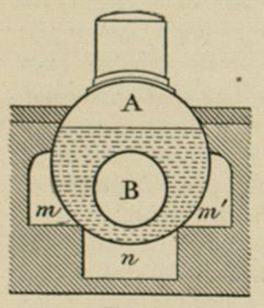

Fig. 155.

In this form of boiler the heating surface exceeds that of the last described by an amount equal to the area of the internal flue, while the internal capacity is diminished by its cubic contents; hence for boilers of equal external dimensions the ratio of heating surface to mass of water to be heated is greatly increased. Boilers of this sort can, however, never be made of as small diameters as the plain cylindrical sort on account of the necessity of finding room inside, below the water level, for the furnace and flue. The disadvantage attending the deposits in the plain cylindrical type is, to a great extent, got over in the Cornish boiler; for the bottom, where the deposit chiefly takes place, is the coolest, instead of being the hottest, part of the heating surface.

The internal flue in the Cornish system is the hottest portion of the boiler, and consequently undergoes a greater linear expansion than the outside shell. The result is a tendency to bulge out the ends, and when the boiler is out of use the flue returns to its normal size, and thus has a tendency to work loose from the ends to which it is riveted. If the ends are too rigid to move, a very serious strain comes on the joints of the flue. To remedy this the latter is often made up of a number of short cylindrical lengths jointed together by being riveted to a ring, the section of which is shown in fig. 156. This ring is intended to serve as a spring, and to allow the ends *a*, *a'* to approach or recede from each other, when undergoing change of temperature. It also serves to stiffen the flue against the pressure from the outside, which tends to collapse it. Another way of effecting the same end is shown in the section of the Lancashire boiler, fig 159.

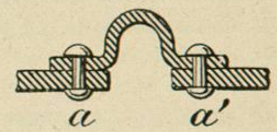

Fig. 156.

Even while in use, the flue of a Cornish boiler is liable to undergo great changes in temperature, according to the state of the fire. When this latter is very low, or when fresh fuel has been thrown on, the temperature is a minimum, and reaches a maximum again when the fresh fuel commences to burn fiercely.

Lancashire boiler.—To remedy this inconvenience, and also in order to attain a more perfect combustion, Fairbairn contrived the double-flued, or Lancashire boiler, the arrangement of the furnaces of which is shown in transverse section in fig. 160. It will be observed that there are two internal furnaces instead of one, as in the Cornish type. These furnaces are sometimes each continued as a separate flue to the other end of the boiler, as shown in fig. 160; but as a rule they merge into one internal flue. They are supposed to be fired alternately, and the smoke and unburnt gases issuing from the fresh fuel are ignited in the flue by the hot air proceeding from the other furnace, the fuel in which is in a state of incandescence. Thus all violent changes of temperature in the flue are avoided, and the waste of fuel due to unburnt smoke is avoided, if the firing is properly conducted.

The disadvantage of the Lancashire boiler is the difficulty of finding adequate room for the two furnaces without unduly increasing the diameter of the shell. Low furnaces are extremely unfavourable to complete combustion, the comparatively cold crown plates, where they are in contact with the water of the boiler, extinguishing the flames from the fuel when they are just formed, while the narrow space between the fuel and the crown does not permit of the proper quantity of air being supplied above the fuel to complete the combustion of the gases as they arise. On the other hand, though this type of boiler favours the distillation of the fuel and the formation of smoke, it supplies the means of completing the combustion afterwards by means of the hot air from the second furnace.

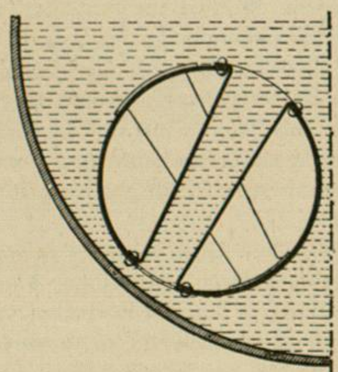

Fig. 157.

Another disadvantage which the Lancashire boiler has in common with all steam generators having circular internal furnaces, is the danger to which the flues are exposed of collapsing, because of the pressure which they have to sustain from without. There are many ways of getting over this evil.

In the Galloway form of boiler the flue is sustained and stiffened by the introduction of numerous conical tubes, flanged at the two ends and riveted across the flue. These tubes, a sketch of two of which is given in fig. 157, are in free communication with the water of the boiler, and, besides acting as stiffeners, they also serve to increase the heating surface and to promote circulation. Other methods of strengthening the flues have already been described under the head of Cornish boilers.

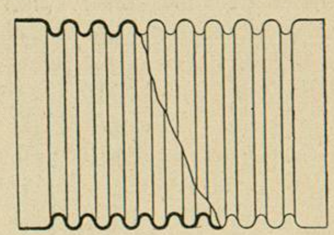

Fig. 158.

Mr. Fox of Leeds corrugates the flues in the manner shown in fig. 158. This plan increases the resisting power of the flues enormously, and, moreover, increases the heating surface and provides for the contraction and expansion of the flue.

The annexed illustrations give all the principal details of a Lancashire boiler fitted with Galloway tubes. Fig. 159 represents a longitudinal section, and fig. 160 shows to a larger scale, an end view of the front of the boiler with its fittings, and also a transverse section. The arrangement of the furnaces, flues, and the Galloway tubes *a a a* is sufficiently obvious from the drawings. The usual length of these boilers is 27 feet, though they are occasionally made as short as 21 feet.

The minimum diameter of the furnaces is 33 inches, and in order to contain these comfortably the diameter of the boiler should not be less than 7 feet. The ends of the boiler are flat, and are prevented from bulging outwards by being held in place by the furnaces and flues, which stay the two ends together, and also by the so-called gusset stays, *e*, fig. 159, which are explained in greater detail on page 397. Great care should be taken to keep the lower ends of the gusset stays 8 or 9 inches away from the nearest points of furnaces and flues, otherwise when the latter expand under

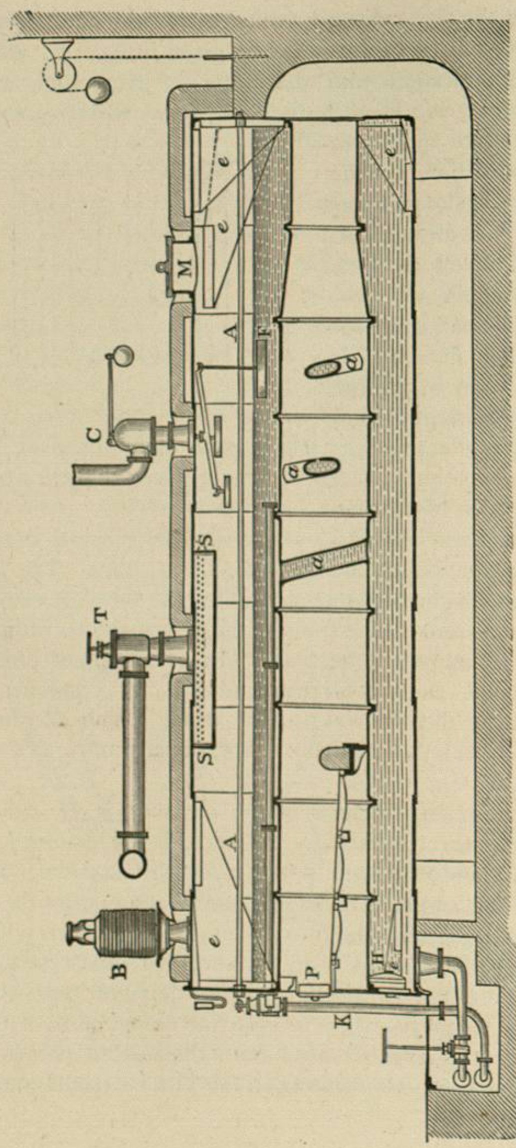

Fig. 159.

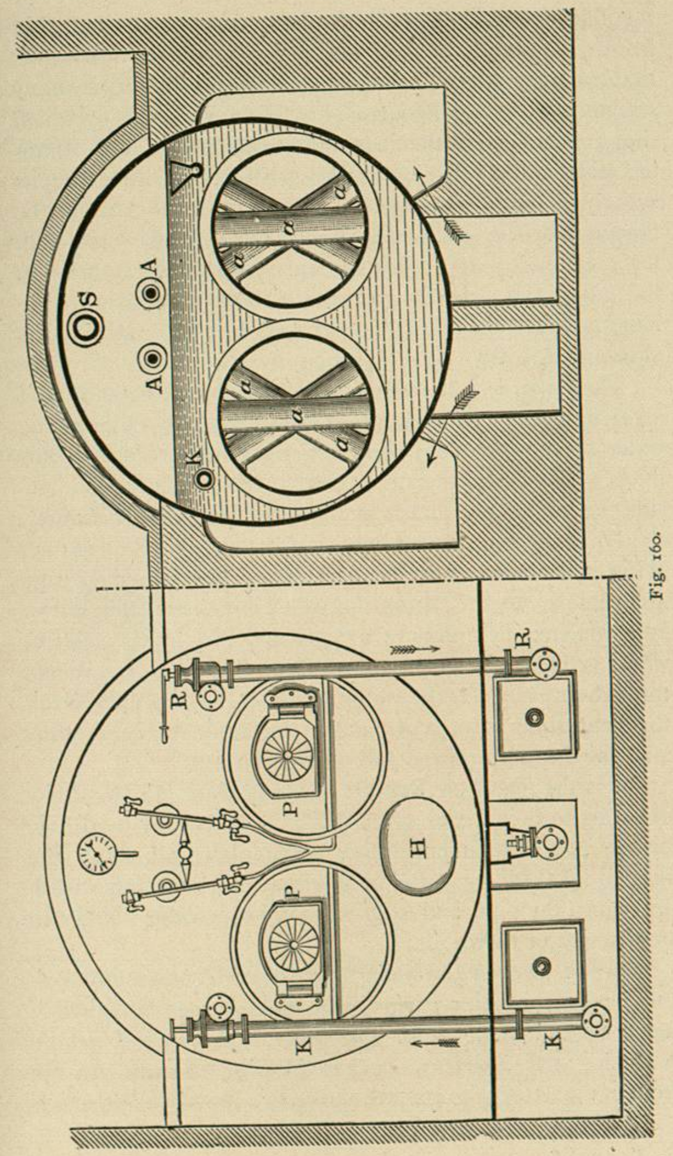

Fig. 160.

the influence of the heat the boiler ends will be so stiff, that instead of slightly bulging out to accommodate themselves to the increased length of the flues, they will be very severely strained in the neighbourhood of the angle irons by which they are fastened to the flues. The result of this local straining will be the opening of the grain of the iron, and its subsequent rapid corrosion. For the same reason the thickness of the end plates should not exceed a half inch for pressures up to 75 lbs. per square inch. In addition to the gusset stays, the flat ends of the boilers frequently have longitudinal rods to tie them together. One of these is shown at AA, fig. 159.

The steam is collected in the pipe S, which is perforated all along the top so as to admit the steam, and exclude the water spray which may rise from the surface during ebullition. The steam thence passes to the stop-valve T, outside the boiler, and thence by the steam pipes to the engines.

There are two safety valves on the top of the boiler, one, B (fig. 159), being of the dead weight type explained on page 404, and the other, C, being a so-called low-water safety valve. It is attached by means of a lever and rod to the float F, which ordinarily rests on the surface of the water. When, through any neglect, the water sinks below its proper level, the float sinks also, and causes the valve to open, thus allowing steam to escape and giving an alarm.

M is the man-hole, with its covering plate, which admits of access to the interior of the boiler, and H is the mud-hole by which the sediment which accumulates all along the bottom is raked out. Below the front end and underneath are shown the pipe and stop-valve by which the boiler can be emptied or blown off.

On the front of the boiler (fig. 160) are shown the pressure gauge, the water gauges, and the furnace doors, which are described in detail on pages 401, 407, 413. K is the seed-pipe; RR, a pipe and cock for blowing off scum. In the front of the setting, fig. 160, are shown two iron doors by which

access may be gained to the lower external flues for clearing purposes.

In the Lancashire boiler it is considered advisable to take the products of combustion, after they leave the internal flues, along the bottom of the boiler, and then back to the chimney by the sides. When this plan is adopted the bottom is kept hotter than would otherwise be the case, and circulation is promoted, which prevents the coldest water from accumulating at the bottom. If this precaution be neglected, the boiler is very apt to strain locally, from the fact of the top and sides being hotter, and consequently expanding more than the bottom. The result is that the lower portions of the transverse seams of rivets give way.

The principal dimensions and other particulars of the boiler shown in figs. 159 and 160 are as follows :—

Steam pressure	75 lbs. per sq. inch
Length	27 feet
Diameter	7 ,,
Weight (total)	$15\frac{1}{2}$ tons
Shell plates	$\frac{7}{16}$ inch
Furnace diameter	33 inches
Furnace plates	$\frac{3}{8}$ inch
Grate area	33 sq. feet
Heating surface :—	
In furnace and flues . . .	450 ,,
In Galloway pipes . . .	30 ,,
In external flues . . .	370 ,,
Total. . . .	850 ,,

Fuel consumption, 17 to 23 lbs. of coal per sq. ft. of grate per hour.

Water evaporated per lb. of coal, at and from 212°, from $10\frac{1}{2}$ to 11 lbs. with the help of a feed-heater.

Tubulous Boilers.

The above term is applied to a class of boilers in which the water is contained in a series of tubes, of comparatively small diameter, which communicate with one another and with a common steam-chamber. The flame and hot gases from the furnace circulate between the tubes, and are usually guided by baffle plates or partitions, so as to act equally on all portions of the tubes. There are many varieties of this type of boiler. Fig. 161 illustrates Root's patent boiler. Each tube is screwed at either end into a square cast-iron head, and each of these heads has two

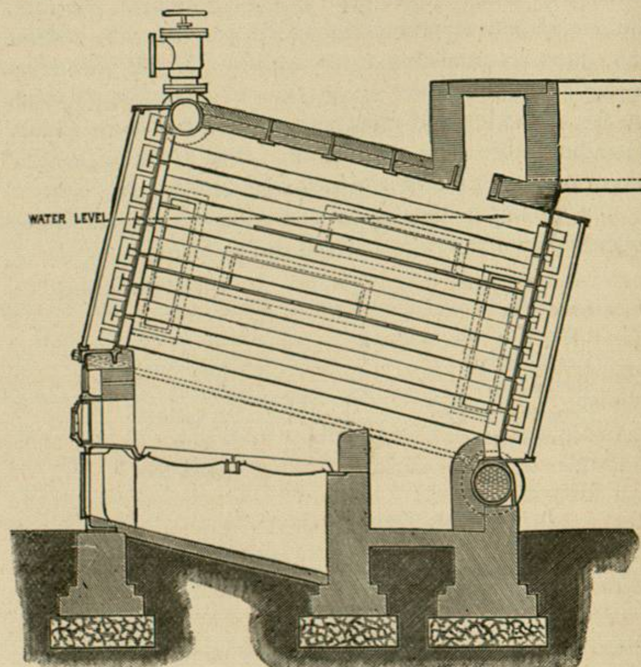

Fig. 161.

openings, one communicating with the tube below, and the other with the tube above. The communication is effected by means of hollow cast-iron caps shown at the ends of the tubes. The caps have openings in them corresponding with the openings in the tube heads to which they are bolted, the joints being made by india-rubber washers.

Locomotive Boilers.

The essential features of locomotive boilers are dictated by the duties which they have to perform under peculiar conditions. The size and weight are limited by the fact that the boiler has to be transported rapidly from place to place, and also that it has to fit in between the frames of the locomotive; while, at the same time, the pressure of the steam has to be very great, in order that with comparatively small cylinders the engine may develope great power; moreover, the quantity of water which has to be evaporated in a given time is very considerable. To fulfil these latter conditions a large quantity of coal must be burned on a fire-grate of limited area; hence intense combustion is necessary under a forced blast. To utilise advantageously the heat thus generated, a large heating surface must be provided, and this can only be obtained by passing the products of combustion through a great number of tubes of small diameter. The manner in which these conditions are carried out in practice will be best understood by reference to the accompanying illustrations (figs. 162 to 165). Fig. 162 is a longitudinal vertical section of a boiler of a modern locomotive. Fig. 163 is a vertical transverse section, half through the fire-box, and half through the cylindrical body of the boiler showing the tubes in section. Fig. 164 is half a section through the smoke box and funnel, and half an elevation of the front end of the locomotive, showing the smoke-box door. Fig. 165 is a horizontal section through the fire-box, showing some of the fire-bars in plan. The furnace (figs. 162, 163, 165), or fire-box as it is called, is a box-shaped casing of copper. In horizontal plan the fire-box is also rect-angular, the width in this example being 40 inches, and the length from front to back 60 inches, and the height from top of fire-bars to crown $64\frac{1}{2}$ inches. The fire-bars B usually form the bottom of the box, though in some boilers there is a water space provided with two openings for the admission of air below the bars. The lower edge of the furnace door is about

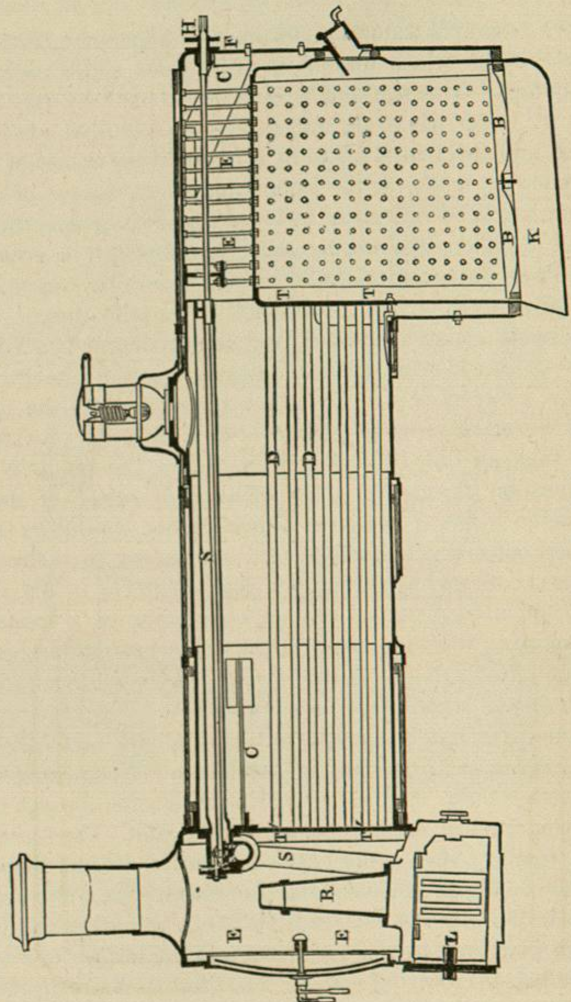

Fig. 162.

30 inches from the grate. Within the fire-box and below the tubes a bridge or arch of fire-brick is often built, which serves

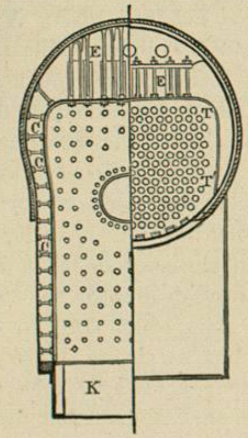

Fig. 163.

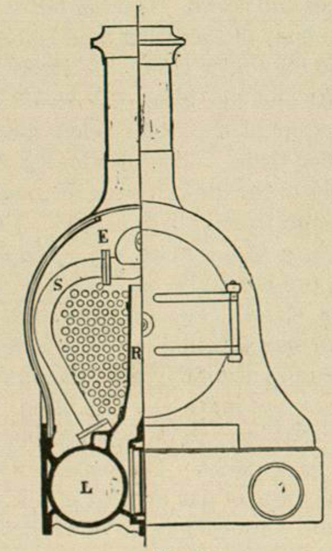

Fig. 164.

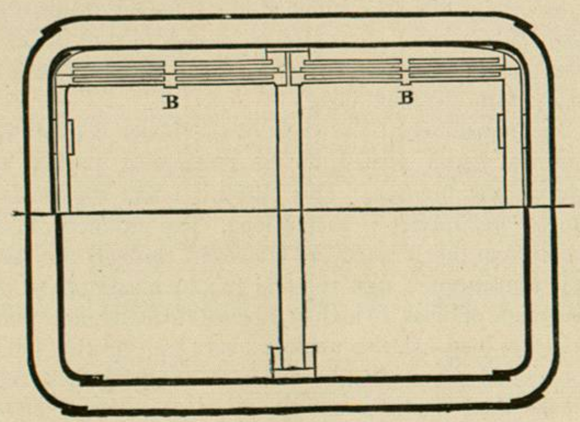

Fig. 165.

to deflect the products of combustion, which would otherwise rush direct into the tubes, and causes them to impinge on the sides and crown. The fire-box is enclosed completely within the body of the boiler, and consequently the four sides, and also the top or crown, are available as heating surface. The sides and top, being flat, would quickly collapse under the pressure of the steam unless special provision were made to stiffen them. The plan invariably adopted is to connect the sides of the fire-box with the outside shell of the boiler by a number of short bolts or stays CCC, screwed and riveted into each, as shown in fig. 163. The shell of the boiler exterior to the fire-box is also in plan a rectangular box made of wrought iron plates. The tendency of the steam being to bulge the shell outwards, and the sides of the fire-box inwards, the two pressures neutralise each other in the stays, which latter are of course put into a state of tension. They are clearly shown in the drawing, and are spaced about four inches apart all over the flat surfaces. The portion of the shell immediately over the crown of the fire-box is not flat, but semi-circular. It would consequently be often inconvenient to stay these two surfaces together in the manner described. The crown of the fire-box is therefore stiffened in a different manner, and usually by means of stout girders, though in the case of the boiler under description, the crown is supported by stays EE hanging from the shell plate.

The remainder of the shell of the boiler consists of a cylindrical barrel united to the rectangular portion surrounding the fire-box. This barrel is 4 feet $2\frac{3}{16}$ inches in diameter and 10 feet 11 inches long. The products of combustion from the furnace are conveyed through the barrel to the smoke-box E, figs. 162 and 164, by means of 195 thin tubes, made of brass, $1\frac{3}{4}$ inch in external diameter, and 10 feet $11\frac{1}{8}$ inches long. In this manner a very large heating surface is obtained. Care must be taken in designing these tubes to make their diameter sufficiently large to carry off the products of combustion with ease. In some of the earlier

locomotive boilers, the diameter was made too small, with the object of getting as many tubes as possible into the available space, and thus increasing the heating surface; but it was found that the narrow tubes offered a most serious impediment to the escape of the smoke and gases, and they were moreover, on account of their small diameter, very liable to become choked by soot, so that this plan had to be avoided. It was formerly the custom to make the tubes much longer than shown in fig. 162, with the object of gaining heating surface; but modern experience has shown that the last three or four feet next the smoke-box were of little or no use, because, by the time the products of combustion reached this part of the heating surface, their temperature was so reduced that but little additional heat could be abstracted from them. The tubes, in addition to acting as flues and heating surface, fulfil also the function of stays to the flat end of the barrel of the boiler, and the portion of the fire-box opposite to it. They always tend to work loose and consequently to leak at the tube plates (T,T, fig. 162), because they expand and contract more than the outside shell. They must therefore be very securely fastened. This is accomplished either by riveting the ends over the tube-plates, and driving in ring ferrules, or else by expanding the tube immediately behind the tube plates by an instrument specially made for this purpose. In addition to the staying power derived from the tubes, the smoke-box tube plate and the front shell plate F are stayed together by several long rods, or else the ends are strengthened by gusset stays CCC. In the boiler under consideration the heating surface given by the tubes is 964 square feet in area, while the sides and crown of the fire-box, or the direct heating surface, as it is called, is 101 square feet. The grate area is 16 square feet.

The forced draught in a locomotive boiler is obtained by causing the steam from the cylinders after it has done its work to be discharged into the chimney by means of a pipe

R (figs. 162, 164) called the blast-pipe. The lower portion of the blast-pipe consists of two branches, one in communication with the exhaust port of each cylinder. One of these branches and one cylinder L are shown in section, fig. 164. The most advantageous position for the mouth of the blast-pipe is some few inches below the base of the funnel. As each puff of steam from the blast-pipe escapes up the chimney, it forces the air out in front of it, causing a partial vacuum which can only be supplied by the air rushing through the furnace and tubes. The greater the body of steam escaping at each puff, and the more rapid the succession of puffs, the more violent is the action of the blast-pipe in producing a draught, and consequently this contrivance regulates the consumption of fuel and the evaporation of water, to a certain extent automatically, because when the engine is working its hardest, and using most steam, the blast is at the same time most efficacious. The blast-pipe is perhaps the most distinctive feature of the locomotive boiler, and the one which alone has rendered it possible to obtain large quantities of steam from so small a generator.

The chamber E (figs. 162, 164) into which the smoke and other products of combustion issue on leaving the tubes is called the smoke-box. It is provided with a door in front, for giving access to the interior and to the tubes. The chimney is placed on the top of the smoke-box. The steam is either collected in a dome, on the top of the barrel, and which contains the mouth of the steam pipe S, leading to the cylinders ; or else, as in the case of fig. 162, a perforated pipe, S, is used, which runs along the top of the steam space in the barrel of the boiler. Unless these precautions were taken, the steam would carry over quantities of spray into the cylinders ; in other words, the boiler would prime. Priming, besides being a great inconvenience, is also a source of waste of heat, for the hot water carried over into the cylinders is incapable of doing work itself, and, moreover, lowers

the temperature of the steam in contact with it, and in this way may indirectly become a most prolific source of waste.

On account of the oscillations to which the boilers of locomotive engines are subject, weighted safety valves are inadmissible, and springs are used instead to hold the valves in place. A spring safety valve is described on p. 406.

Marine Boilers.

The boilers used on board steamships are of two principal types. The older sort used for steam of comparatively low pressure, viz. up to 35 lbs. per square inch, is usually made of flat plates stayed together, after the manner of the exterior and interior fire-boxes of a locomotive boiler. Modern high-pressure marine boilers, constructed for steam of 60 to 150 lbs. per square inch, are circular or oval in cross section, and are fitted with cylindrical interior furnaces and flues like land boilers.

Figs. 166, 167 represent the general arrangement of the older type of marine boiler, in longitudinal and transverse sections. A A, fig. 167, are the grate bars ; B, the furnace door ; D, the ashpit. After passing the bridge the hot air and flame enter a large chamber E, called the back up-take, thence they return through the tubes *eee*, to the front up-take F and the chimney. The heating surface consists of the sides and crown of the furnace, the sides of the back up-take and the tubes. The front up-take F is provided with doors G for giving access to the tubes and chimney for cleaning and repairs. The outside shell of this type of boiler is rectangular box-shaped. Some of the stays are represented at *a a a* in both views.

The general arrangements and construction of this type of boiler are rendered clear by the illustrations. As the form of the boiler contributes nothing to its strength, the latter is maintained by staying all the opposite surfaces together in