The above tables, and figs. 172 to 174, extracted from Mr. Unwin's work, give the proportions, together with the efficiency of riveted joints—that is to say, the ratio of their strength to that of the solid plate, for iron and steel plates, and for single and double riveting. Fig. 172 illustrates a single riveted lap joint; fig. 173 a similar butt joint, in both single and double shear—that is to say, with single and double cover plates. Fig. 174 shows a double riveted lap joint of the usual dimensions. All dimensions are given in terms of the diameter of the rivet as unit. See also App., Examples 140 *et seqq.*

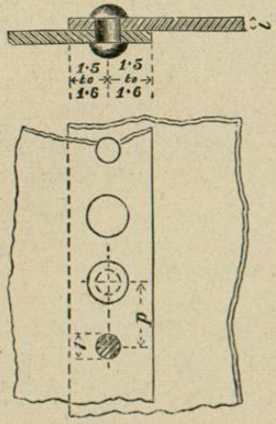

Fig. 172.

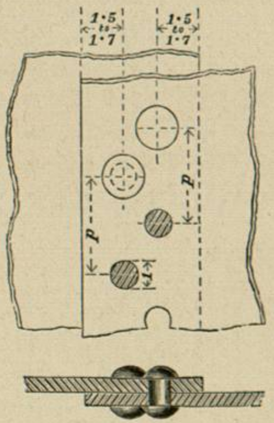

Fig. 174.

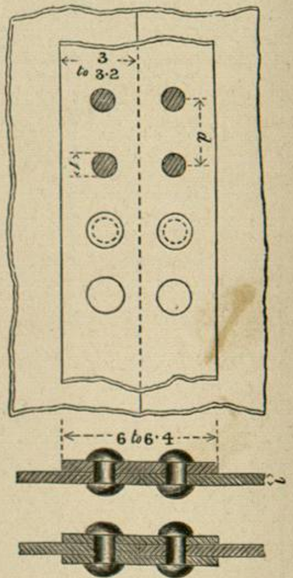

Fig. 173.

Hollow cylinder pressed from without.—The strength of cylinders pressed from without is much more difficult to determine than when they are pressed from within. Theoretically the metal would for similar pressures be in a state of compression equal to the tension as determined above. There is, however, a great practical difference between the two cases. When a cylinder is pressed from without, unless it is of a mathematically perfect shape, and perfectly homogeneous in strength, the pressure tends to change its shape, so that it may yield by deformation long before the limit of the crushing strength of the metal is approached. Thus it is frequently found that internal furnace flues give way by collapsing. On the other hand, when pressed from within, the tendency of the pressure is to keep the cylinder in shape, so that it can only give way when the metal yields. The standard experiments on the strength of cylinders to resist external pressure were those made by Fairbairn thirty-three years ago, under conditions widely different from those now common. The results arrived at by Fairbairn were as follows: The strength varies inversely as the length of the cylinder, inversely also as the diameter, and directly as the square of the thickness of the metal. The following formula is given by Rankine to determine the collapsing pressure of such cylinders:—

$$P = 806000\frac{t^2}{Ld},$$

when P is the pressure in pounds per square inch, t the thickness of the sides in inches, d the diameter in inches, and L the length in feet.

In order to obviate the weakness of long flues, rings of angle or tee iron are riveted round them at fixed intervals, as shown in fig. 175, or else the joints are made as represented in fig. 156, or as shown in the furnace of the boiler in fig. 159. The strength in these cases, according to Fairbairn, is to be calculated on the supposition that the length is equal to the distance between two consecutive rings.

Fig. 175.

Those portions of cylindrical flues which do not contain the furnace are very successfully strengthened by means of Galloway's tubes, described on p. 364. The method of strengthening the furnaces themselves which appears to be most successful is the plan of corrugating the plates introduced by Mr. Fox (fig. 158), and now much used in the furnaces of high-pressure marine boilers. This system has been already described, see p. 365.

Staying of flat surfaces.—When boilers are formed principally of flat plates, like low-pressure marine boilers, or the fire-boxes of locomotive boilers, the form contributes nothing to the strength, which must, therefore, be provided for by staying the opposite surfaces together. Fig. 176 shows the arrangement of the stays in a locomotive fire-box. They are usually pitched about 4 inches from centre to centre, and are fastened into the opposite plates by screwing, as shown, the heads being riveted over. Each stay has to bear the pressure of steam on a square *aa*, and the sectional area of the stay must be so chosen that the tensile strength will be sufficient to bear this strain with the proper factor of safety. Thus if a be the area of the section of the stay in inches, and a' that of the square of plate which it supports, P the pressure of the steam per square inch, and t the tensile strength of the stay, we must have—

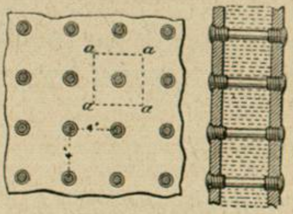

Fig. 176.

$$a'P = at, \text{ or } a = \frac{a'P}{t}.$$

It is usual to allow a factor of safety of eight for locomotive boilers, while in marine boilers the factor is from nine to ten, a large margin of strength being necessary on account of the liability of the stays to corrosion.

If the spaces between the stays are too great, or the plate too thin, there is a danger of the structure yielding through the plate bulging outwards between the points of attachment of the stays, thus allowing the latter to draw through the screwed holes made in the plates. Rankine recommends that if the material of the plate is equal in strength to that of the stay, the thickness of the plate should equal half the diameter of the stay; and that if the material of the plate be weaker, its thickness should be proportionately increased.

The flat ends of cylindrical boilers are usually stayed to the cylindrical portions by triangular plates of iron, called gusset stays (see figs. 159, 162, 177). Gusset stays should never be brought too close to any internal flues riveted to the flat ends for the reasons explained on p. 365. The two opposite ends are also stayed together by long bar stays, running the whole length of the boiler. It is dangerous, however, to trust too much to the latter class of stays; for, in consequence of the alternate expansion and contraction which takes place every time the boiler is heated and cooled, they have a tendency to work loose at the joints; and if the portion of the boiler in which they are situated should happen to be hotter than the outside shell, they have a tendency to droop, and are then perfectly useless.

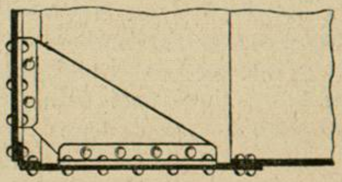

Fig. 177.

In designing boilers with stayed surfaces care should be taken that the opposite plates connected by any system of stays should, as far as possible, be of equal area, otherwise there is sure to be an unequal distribution of load in the stays, some receiving more than their proper share, and, moreover, the least supported plate is exposed to the danger of buckling.

THE EFFECTS OF UNEQUAL EXPANSION AND CONTRACTION IN STRAINING A BOILER.

If every portion of a boiler were, when heated, raised to exactly the same temperature, and if the same description of metal were used throughout the entire structure, there would of course be no strains set up by the change of temperature, because all the parts would expand and contract proportionately to their dimensions. In the majority of boilers, however, the various portions are at very different temperatures, and the more highly heated parts expand to a greater extent than the remainder, thus distorting the shape of the boiler, and inducing sometimes very serious strains. Take, for instance, the internal furnace and flue of a Cornish boiler : this portion, containing, as it does, the fire, is considerably hotter than the outside shell, and consequently expands more. One of two things must then happen : either the flat ends of the boiler must bulge out, or if these are too rigid to yield, or are stayed too stiffly, the whole of the metal of the flue will be put into a state of compression, the effects of which are sometimes most conspicuously seen in the joints.[1] Again, the flue, though hotter on the whole than the rest of the boiler, is not itself uniformly heated, the upper portions above the fire-bars being at a higher temperature than the lower. The result of this is to twist the flue out of shape, provided the ends of the boiler can yield, the flue cambering up towards the top of the shell. If the ends were quite rigid the top of the flue would be put into compression, and the bottom in tension.

The outside shells are also subject to considerable differences of temperature, caused by the top of the boiler being filled with hot steam, while the bottom contains water, often not much warmer than the feed. In the case of Cornish and Lancashire boilers with external return flues, this difference in temperature is compensated for, and sometimes more than compensated for, by the high temperature of the hot gases circulating underneath, but in the case of boilers having no external heating surface there may be a considerable difference in temperature, unless means are taken to circulate the water.

In estimating the intensity of the strains due to temperature it should be borne in mind that one degree of rise in temperature elongates a bar of ordinary boiler iron by the same amount as would a tensile stress of the intensity of about 190 lbs. per square inch. Hence such a bar, if held rigidly at the ends, so that these could not move, and then heated ten degrees, would be subjected to a force of compression equal to 1900 lbs. per square inch. Similarly, if cooled ten degrees below the normal temperature, it would be subjected to a tensile stress of the same amount.

MATERIALS OF CONSTRUCTION.

The metals principally used in the construction of boilers are wrought iron, mild steel, copper, and brass. Copper is used almost exclusively for the inner fire-boxes of locomotive furnaces, on account of its great conductivity, and the property which it possesses of resisting the intense temperature of combustion usual in this class of boiler. The use of brass is limited to the tubes, but even these are now often made of steel or iron.

Wrought iron has till lately been the principal metal used in the structure of boilers, but it is now rapidly being superseded by mild steel. The advantages of mild steel are very great. Its strength to resist strains of tension and compression is considerably greater than that of iron, thus

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[1] See also page 363.

enabling lesser scantlings to do the work. Its ductility is greater, its structure more homogeneous, and its quality more uniform; while its power to resist corrosion, when proper precautions are taken, is reported on most favourably by those who have had the best practical opportunities of watching its behaviour in use. The only drawback which retarded its general introduction was a certain difficulty which the boiler-makers experienced in working the new metal safely into shape, especially when at a black heat; but this difficulty has to a great extent been got over with increased experience.

The following table gives the approximate numerical value of the tensile strength of the three metals. It must be understood that samples of the same metal vary so much that nothing but approximate or rough average values can be given.

Name of Metal	Tensile Strength, lbs. per sq. inch	
	With grain	Across grain
Best Lowmoor plate	58,487	55,033
Ordinary wrought-iron boiler plate . .	50,000	46,500
Mild Siemen's steel plates, average . .	64,600	64,500
Brass tubes	80,000	—
Copper plates.	30,000	—
Copper bolts	36,000	—

Lloyd's rules for marine boilers require that when the material of the shell plates is mild steel it shall have a tensile strength of not less than 26 tons and not more than 30 tons per square inch of section, and the ultimate elongation of a test piece 8 inches in length after fracture, must be not less than 20 per cent. of the original length.

The Board of Trade rules for steel marine boilers require that the tensile strength of plates not exposed to flame should be about 28 tons and should not exceed 32 tons per square inch of section. The tensile strength of furnace, flanging and combustion box plates should range from 26 tons to 30 tons per square inch.

Fittings of Boilers.

The principal parts of boilers which now remain to be considered are furnace doors and grates, safety valves, pressure and water gauges, feeding apparatus, and feed heaters.

Furnace Doors.—The chief points to be considered in the design of furnace doors are to prevent the radiation of heat through them, and to provide for the admission of air above the burning fuel in order to aid in the consumption of smoke and unburnt gases. In all cases where the doors are exposed to very rough usage—such, for instance, as in locomotive and marine boilers—the means for admitting air must be of the simplest, and consist generally of simple perforations, as shown in fig. 178, which represents a front view and section of the furnace door of a locomotive boiler. The heat from the burning fuel is prevented from radiating through the perforations in the outer door by attaching to it a second or baffle plate *a*, at a distance of about 1½ inch, the holes in which do not coincide in direction with those of the door proper. By the constant entry of cold air from the outside the greater part of any heat which may be communicated to the door by radiation or conduction is returned to the furnace.

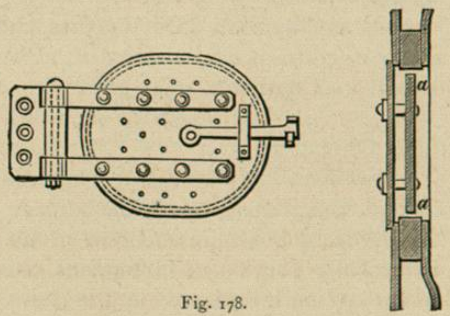

Fig. 178.

Doors similar to the above provide for the constant admission of limited quantities of fresh air above the fuel. In actual practice, however, air is only needed above the fire for a few minutes after fresh fuel has been thrown on the grate, and is then required in considerable quantities. In the case of land boilers, the furnace doors of which undergo comparatively mild treatment, it is possible to introduce the necessary complications for effecting the above objects. Fig. 160 shows an arrangement in common use in Cornish and Lancashire boilers, and consists of a number of radial slits in the outer door plate, which can be closed or opened at will in the same manner as an ordinary window ventilator. Other and more complicated arrangements have been frequently devised which work admirably so long as they remain in order, but the frequent banging to which furnace doors are subjected, even in factory boilers, soon deranges delicate mechanism.

Furnace doors should be kept as small as is compatible with the proper distribution of the fuel over the grate area, as otherwise the great rush of cold air, when the door is opened, rapidly cools down the flues, and does considerable injury to tube plates, crowns of furnaces, &c. For this reason it is desirable, when grates are over forty inches in width, to have two doors to each furnace, which can be fired alternately.

Dead-plate and Fire-bars.—The dead-plate is a flat plate of iron immediately inside the furnace door, and which is used in many boilers in order to insure the combustion of the volatile portions of bituminous coal. When the fresh fuel is laid on it is placed on the dead-plate instead of on the grate. In this position the coal is coked, the volatile hydrocarbons being driven off by the radiated heat from the incandescent fuel, and ignited as they pass over the latter by the surplus air coming through the grate, or by a special admission through the furnace door. As soon as the coking process is complete the fuel is pushed forward from the dead-plate over the fire-bars. Dead-plates are also frequently used where anthracite coal is burned, as this fuel is apt to crack and splinter into small pieces if thrown fresh on to the grate without having been previously warmed through.

The grate consists of a number of cast-iron bars, called fire-bars, which are supported on wrought-iron bearers. Innumerable forms of fire-bars have been contrived to meet the cases of special kinds of fuel. The type in common use is represented in fig. 179, which shows a side view and a section of a single bar, and a plan of three bars in position Each bar is, in fact, a small girder, the top surface of which is wider than the bottom. On each bar are cast lugs, the width of which determines the size of the interstices for the passage of air. In marine boilers the usual width of the bar on the top surface is 1¼ inch, tapering down to one-third of this size at the bottom. The interstice varies in width according to the character of the fuel. For anthracite ½ inch is a maximum, while for caking coals ¾ inch is often used. For long furnaces the bars are usually made in two lengths, with a bearer in the middle of the grate. In the Lancashire boiler, illustrated in fig. 159, the bars are in three lengths of two feet each. They are ¾ inch wide on the top, and spaced ⅜ inch apart. In locomotive boilers the bars are generally in one length. As a rule long grates are set with a considerable slope towards the bridge, in order to facilitate the distribution of the fuel. A slope of an inch

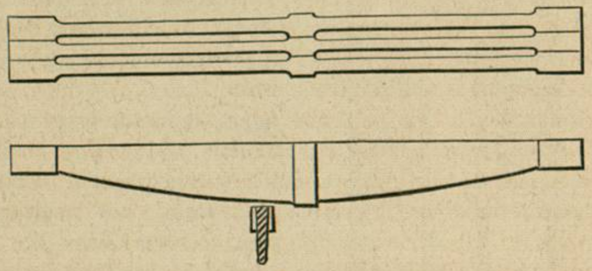

Fig. 179.

to the foot is the rule. The grates of locomotive engines are nearly always flat.

Safety valves.—The safety valve is a circular valve seated on the outside of the boiler, and weighted to such an extent that when the pressure of the steam exceeds a certain point, the valve is lifted from its seating and allows the steam to escape. Safety valves can be loaded directly with weights, in which case they are called dead-weight valves, or the load can be transmitted to the valve by a lever. Again, the end of the lever is sometimes held down by a simple weight attached to it, a plan commonly adopted in land boilers; while sometimes, as in the case of locomotive and marine boilers, the lever is weighted by means of a spring, the tension of which can be adjusted.

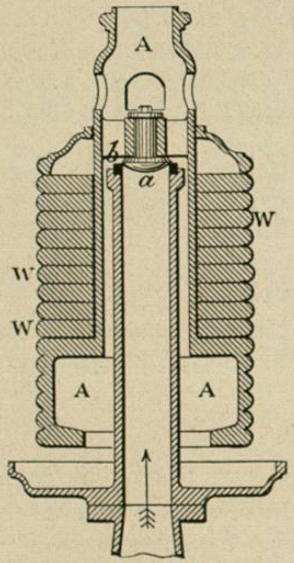

Fig. 180.

Fig. 180 shows a form of dead-weight safety valve, where *a* is the valve which rests on the seating *b*.

The valve is attached to the circular casting AAA, so that both rise and fall together. The weights WW, &c., are disposed on the casting in rings, which can be adjusted to the desired blow-off pressure. Owing to the centre of gravity of the casting and weights being below the valve, the latter requires no guides to keep it in position. This is a great advantage, as guides frequently stick, and prevent the valve from acting. Another advantage of this form of valve is that it is difficult to tamper with. For instance, a four-inch valve, intended to blow off at 100 lbs. per square inch, would require weights of 11 cwt., which occupy a considerable bulk. An unauthorised addition of a few pounds to such a mass would make no appreciable addition to the blowing-off pressure, while any effectual increment of weight would be immediately noticed. It is quite different with the lever safety valve, about to be described. A small addition to the weight at the end of the lever is multiplied several times at the valve.

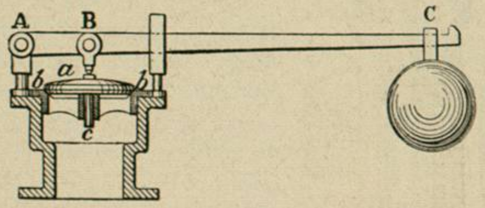

Fig. 181.

The second form of safety valve is shown in fig. 181 Here the load is attached to the end C of the lever ABC, the fulcrum of which is at A.

Calling the weight W,

the weight of the lever w,

the weight of the valve, w',

the distance of the centre of gravity of the lever from A, l,

$$w' + W\frac{AC}{AB} + w\frac{l}{AB}$$

is the pressure brought to bear on the seat *bb* of the valve *a*. The effective pressure on the valve, and consequently the blowing-off pressure in the boiler, can be regulated, within certain limits, by sliding the weight W along the arm of the lever. In locomotive engines the weight would, on account of the oscillations, be inadmissible, and a spring is used to hold down the end of the lever. The pressure on the valve can be regulated by altering the tension of the spring.

A valve much used in locomotives is shown in fig. 182. It is called, after the name of its inventor, Ramsbottom's patent safety valve. It consists really of two valves AA, placed side by side, at a little distance apart. A cross-piece B bears upon each valve, and to the cross-piece is attached a powerful spiral spring D, the lower end of which is so fixed at C that its tension can be adjusted by means of a set screw at E which is out of reach of the engine driver. Before the valves can rise they have to overcome the resistance of the spring, to which the pressure is communicated by means of the cross-piece B. The spring is attached to the cross-piece below the bearing points of the cross-piece on the valves. If one of the valves should rise from its seating before the other, the spring leans a little towards this latter, easing the pressure on it, and allowing it to open. The rise of the valves from the seating is much greater with these directly loaded valves than when the pressure is transmitted through a lever, and thus the steam escapes with much greater rapidity.

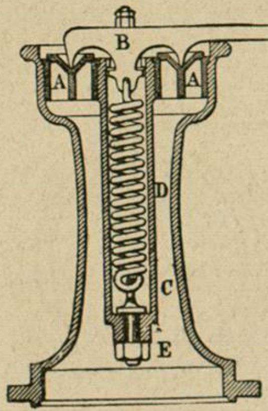

Fig. 182.

Every boiler should be provided with two safety valves, one of which should be put beyond the control of the attendant. The size of the opening depends of course upon the steam-producing power of the boiler, the object to be attained being to reduce the pressure within the boiler to its normal point as quickly as possible. The following rule is given by Rankine for valves having a lift of one-twentieth of their own diameter. Let a = area of valve; A = area of heating surface in square

feet; P = pressure of steam in pounds per square inch. Then—

$$a = \frac{A}{3P}.$$

The Board of Trade rule for marine boilers is to allow half a square inch of safety valve for every square foot of fire-grate area.

Pressure Gauges.—These instruments are used for showing the pressure at which the steam happens to be within the boiler. The one in most common use is Bourdon's, and is illustrated in fig. 183. It consists of a bent metal tube *aa*, which is put in connection with the interior of the boiler by means of the pipe *b*, which is provided with a stopcock. The tube *aa* is elliptical in cross section, as shown at A. The effect of internal pressure on the tube is to tend to transform the elliptical into a circular cross section. This, however, cannot be done without partially unbending or straightening the tube *aa*; that is to say, the effect of internal pressure is ultimately to straighten the tube, and the greater the pressure the more the tube is unbent, and consequently the more the free end *c* is moved from its normal position. The free end is connected by means of a link with an index like the hand of a watch, either directly, or else through the medium of a small rack and pinion, which multiplies the motion of the index; and when the free end of the tube moves under the influence of pressure, the end of the index describes an arc of a circle. By placing a dial behind the

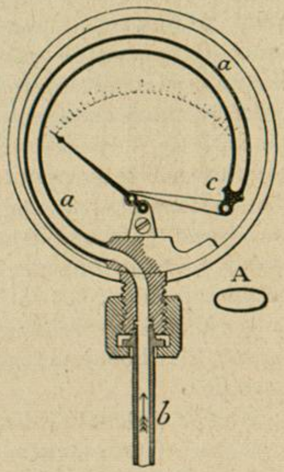

Fig 183.

index, and graduating the former experimentally, so that a given position of the needle corresponds with a given pressure in the tube, we obtain an exact pressure gauge. The experimental division of the circumference of the dial is made by connecting the Bourdon gauge with a mercurial syphon gauge and a force-pump. The force-pump is then worked, so that the syphon gauge registers successive increments of pressure of one pound per square inch, and at each of these a mark is made on the dial of the Bourdon gauge opposite the position of the index finger. These gauges should be tested from time to time by a mercurial gauge, as they are apt to get out of order, in consequence of water lodging in the end of the bent tube and corroding the latter. It may easily be known when they are out of order by raising the pressure of the steam in the boiler, and watching till it commences to blow off at the safety valve, and then noting the position of the index finger. The pressure registered by the finger should of course then correspond with the known blow-off pressure of the valves; if it does not, one or other or both of these instruments must be out of order: but the safety valve is usually kept in order; therefore when this is the case, and a disagreement occurs, the Bourdon gauge may be presumed to need correction.

Feeding Apparatus.—The water of a boiler is replenished by means of force-pumps or injectors, or by both. For safety's sake every boiler ought to have two feeds, in order to avoid accidents when one of them gets out of order. Pumps for feeding are of two principal kinds, viz. those driven by a crank or eccentric on the main axle of the engine, and those which are connected direct to a separate small engine, which is only employed for pumping purposes: these latter are called donkey engines. The feed-pumps of land boilers are usually made large enough to supply, if kept continuously at work, from two to two and a half times the quantity of water actually consumed by the engine.

In old-fashioned marine boilers, where the engine is not provided with a surface condenser, the pumps had to be made still larger, in order to allow for the waste occasioned by the discharge of brine from the boilers. The pumps themselves, being ordinary force-pumps, require no special description.

Injectors.—The injector, which was invented by Giffard, is in many respects the most peculiar and interesting apparatus connected with the steam engine. It is an instrument which converts the energy of the heat in the steam into mechanical work without the aid of any moving mechanism whatever. Before describing it, it is necessary to notice the difference between the velocity of steam escaping from a boiler, and water escaping from the same vessel under the same pressure of steam. The velocity of the water is, in accordance with a well-known law of hydrodynamics, and neglecting the effect of friction, the same as it would acquire by falling down a height equal to the length of the column of water which would produce the same pressure as the steam. Thus, let the pressure of the steam in the boiler be five atmospheres above that of the external air; the pressure of one atmosphere will balance the weight of a column of water 33·9 feet in height; therefore five atmospheres will balance a column of 169·5 feet. The velocity acquired by falling down this height would be about 104 feet per second. This, therefore, would be approximately the velocity of efflux of the *water* from the boiler.

The velocity of efflux of the steam is much greater, although the pressure is the same. It would be impossible in the limits of this chapter to give an account of the theory of the flow of gases and of saturated steam. It must be enough to mention that for the pressures usual in land boilers the velocity of the steam is from 16 to 18 times greater than that of the water.

Suppose now that some of the steam were discharged from a boiler through a pipe at this high velocity, and that while in the act of discharge it were condensed suddenly by