CHAPTER V.

PROPORTION OF BOILERS.

HEATING AND FIRE GRATE SURFACE.

252. *Q.*—What are the considerations which must chiefly be attended to in settling the proportions of boilers?

A.—In the first place there must be sufficient grate surface to enable the quantity of coal requisite for the production of the steam to be conveniently burnt, taking into account the intensity of the draught; and in the next place there must be a sufficient flue surface readily to absorb the heat thus produced, so that there may be no needless waste of heat by the chimney. The flues, moreover, must have such an area, and the chimney must be of such dimensions, as will enable a suitable draught through the fire to be maintained; and finally the boiler must be made capable of containing such supplies of water and steam as will obviate inconvenient fluctuations in the water level, and abate the risk of water being carried over into the engine with the steam. With all these conditions the boiler must be as light and compact as possible, and must be so contrived as to be capable of being cleaned and repaired with facility.

253. *Q.*—Supposing, then, that you had to proportion a boiler, which should be capable of supplying steam sufficient to propel a steam vessel or railway train at a given speed, or to perform any other given work, how would you proceed?

A.—I would first ascertain the resistance which had to be overcome, and the velocity with which it was necessary to overcome it. I should then be in a position to know what pressure and volume of steam were required to overcome the resistance at the prescribed rate of motion; and, finally, I should allow a sufficient heating and fire grate surface in the boiler according to the kind of boiler it was, to furnish the requisite quantity of steam, or, in other words, to evaporate the requisite quantity of water.

254. *Q.*—Will you state the amount of heating surface and grate surface necessary to evaporate a given quantity of water?

A.—The number of square feet of heating or flue surface, required to evaporate a cubic foot of water per hour, is about 70 square feet in Cornish boilers, 8 to 11 square feet in land and marine boilers, and 5 or 6 square feet in locomotive boilers. The number of square feet of heating surface per square foot of fire grate, is from 13 to 15 square feet in wagon boilers; about 40 square feet in Cornish boilers; and from 50 to 90 square feet in locomotive boilers. About 80 square feet in locomotives is a very good proportion.

255. *Q.*—What is the heating surface of boilers per horse power?

A.—About 9 square feet of flue and furnace surface per horse power is the usual proportion in wagon boilers, reckoning the total surface as effective surface, if the boilers be of a considerable size; but in the case of small boilers the proportion is larger. The total heating surface of a two horse power wagon boiler is, according to Boulton and Watt's proportions, 30 square feet, or 15 ft. per horse power; whereas, in the case of a 45 horse power boiler the total heating surface is 438 square feet, or 9·6 ft. per horse power. In marine boilers nearly the same proportions obtain. The original boilers of the Great Western steamer, by Messrs. Maudslay, were proportioned with about 10 square feet of flue and furnace surface per horse power, reckoning the total amount as effective; but in the boilers of the Retribution, by the same makers, but of larger size, a somewhat smaller proportion of heating surface was adopted. Boulton and Watt have found that in their marine flue boilers, 9 square feet of flue and furnace surface are requisite to boil off a cubic foot of water per hour, which is the proportion of heating surface that is allowed in their land boilers per horse power; but inasmuch as in most modern engines, and especially in marine engines, the nominal considerably exceeds the actual power, they allow 11 or 12 square feet of heating surface per nominal horse power in their marine boilers, and they reckon as effective heating surface the tops of the flues, and the whole of the sides of the flues, but not the bottoms. For their land engines they still retain Mr. Watt's standard of power, which makes the actual and the nominal power identical; and an actual horse power is the equivalent of a cubic foot of water raised into steam every hour.

256. *Q.*—What is the proper proportion of fire grate per horse power?

A.—Boulton and Watt allow 0·64 of a square foot area of grate bars per nominal horse power in their marine boilers, and a good effect arises from this proportion; but sometimes so large an area of fire grate cannot be conveniently got, and the proportion of half a square foot per horse power, which is the proportion adopted in the original boiler of the Great Western, seems to answer very well in engines working with a moderate pressure, and with some expansion; and this proportion is now very widely adopted. With this allowance, there will be 22 to 24 square feet of heating surface per square foot of fire grate; and if the consumption of fuel be taken at 6 lbs. per nominal horse power per hour, there will be about 12 lbs. of coal consumed per hour on each square foot of grate. The furnaces should not be more than 6 ft. long, as, if much longer than this, it will be impossible to work them properly for any considerable length of time, as they will become choked with clinker at the back ends.

257. *Q.*—What quantity of fuel is usually consumed per hour on each square foot of fire grate?

A.—The quantity of fuel burned on each square foot of fire grate per hour, varies very much in different boilers; in wagon boilers it is from 10 to 13 lbs.; in Cornish boilers from 3½ to 4 lbs.; and in locomotive boilers from 80 to 150 lbs.; but about 1 cwt. per hour is a good proportion in locomotives, as has been already explained.

CALORIMETER AND VENT.

258. *Q.*—In what manner are the proper sectional area and the proper capacity of the flue of a boiler determined?

A.—The proper collective area for the escape of the smoke and flame over the furnace bridges in marine boilers is 19 square inches per nominal horse power, according to Boulton and Watt's practice, and for the sectional area of the flue they allow 18 square inches per horse power. The sectional area of the flue in square inches is what is termed the *calorimeter* of the boiler, and the calorimeter divided by the length of the flue in feet is what is termed the *vent.* In marine flue boilers of good construction the vent varies between the limits of 20 and 25, according to the size of the boiler and other circumstances—the largest boilers having generally the largest vents; and the calorimeter divided by the vent will give the length of the flue in feet. The flues of all flue boilers diminish in their calorimeter as they approach the chimney, as the smoke contracts in its volume in proportion as it parts with its heat.

259. *Q.*—Is the method of determining the dimensions of a boiler flue, by a reference to its vent and calorimeter, the method generally pursued?

A.—It is Boulton and Watt's method; but some very satisfactory boilers have been made by allowing a proportion of 0·6 of a square foot of fire grate per nominal horse power, and making the sectional area of the flue at the largest part $\frac{1}{7}$th of the area of fire grate, and at the smallest part, where it enters the chimney, $\frac{1}{11}$th of the area of the fire grate. These proportions are retained whether the boiler is flue or tubular, and from 14 to 16 square feet of tube surface is allowed per nominal horse power.

260. *Q.*—Are the proportions of vent and calorimeter, taken by Boulton and Watt for marine flue boilers, applicable also to wagon and tubular boilers?

A.—No. In wagon and tubular boilers very different proportions prevail, yet the proportions of every kind of boiler are determinable on the same general principle. In wagon boilers the proportion of the perimeter of the flue which is effective as heating surface, is to the total perimeter as 1 to 3, or, in some cases as 1 to 2·5; and with any given area of flue, therefore, the length of the flue must be from 3 to 2·5 times greater than would be necessary if the total surface were effective, else the requisite quantity of heating surface will not be obtained. If, then, the vent be the calorimeter, divided by the length, and the length be made 3 or 2·5 times greater, the vent must become 3 or 2·5 times less; and in wagon boilers accordingly, the vent varies from 8 to 11 instead of from 21 to 25, as in the case of marine flue boilers. In tubular marine boilers the calorimeter is usually made only about half the amount allowed by Boulton and Watt for marine flue boilers, or, in other words, the collective sectional area of the tubes, for the transmission of the smoke, is from 8 to 9 square inches per nominal horse power. It is better, however, to make the sectional area larger than this, and to work the boiler with the damper sufficiently closed to prevent the smoke and flame from rushing exclusively through a few of the tubes.

261. *Q.*—What are the ordinary dimensions of the flue in wagon boilers?

A.—In Boulton and Watt's 45 horse wagon boiler the area of flue is 18 square inches per horse power, but the area per horse power increases very rapidly as the size of the boiler becomes less, and amounts to about 80 square inches per horse power in a boiler of 2 horse power. Some such increase is obviously inevitable, if a similar form of flue be retained in the larger and smaller powers, and at the same time the elongation of the flue in the same proportion as the increase of any other dimension is prevented; but in the smaller class of wagon boilers the consideration of facility of cleaning the flues is also operative in inducing a large proportion of sectional area. Boulton and Watt's 2 horse power wagon boiler has 30 square feet of surface, and the flue is 18 inches high above the level of the boiler bottom, by 9 inches wide; while their 12 horse wagon boiler has 118 square feet of heating surface, and the dimensions of the flue similarly measured are 36 inches by 13 inches. The width of the smaller flue, if similarly proportioned to the larger one, would be 6½ inches, instead of 9 inches, and, by assuming this dimension, we should have the same proportion of sectional area per square foot of heating surface in both boilers. The length of flue in the 2 horse boiler is 19·5 ft., and in the 12 horse boiler 39 ft., so that the length and height of the flue are increased in the same proportion.

262. *Q.*—Will you give an example of the proportions of a flue, in the case of a marine boiler?

A.—The Nile steamer, with engines of 110 horse power by Boulton and Watt, is supplied with steam by two boilers, which are, therefore, of 55 horses power each. The height of the flue winding within the boiler is 60 inches, and its mean width 16½ inches, making a sectional area or calorimeter of 990 square inches, or 18 square inches per horse power of the boiler. The length of the flue is 39 ft., making the vent 25, which is the vent proper for large boilers. In the Dee and Solway steamers, by Scott and Sinclair, the calorimeter is only 9·72 square inches per horse power; in the Eagle, by Caird, 11·9; in the Thames and Medway, by Maudslay, 11·34, and in a great number of other cases it does not rise above 12 square inches per horse power; but the engines of most of these vessels are intended to operate to a certain extent expansively, and the boilers are less powerful in evaporating efficacy on that account.

263. *Q.*—Then the chief difference in the proportions established by Boulton and Watt, and those followed by the other manufacturers you have mentioned is, that Boulton and Watt set a more powerful boiler to do the same work?

A.—That is the main difference. The proportion which one part of the boiler bears to another part is very similar in the cases cited, but the proportion of boiler relatively to the size of the engine varies very materially. Thus the calorimeter *of each boiler* of the Dee and Solway is 1296 square inches; of the Eagle, 1548 square inches; and of the Thames and Medway, 1134 square inches; and the length of flue is 57, 60, and 52 ft. in the boilers respectively, which makes the respective vents $22\frac{1}{2}$, 25, and 21. Taking then the boiler of the Eagle for comparison with the boiler of the Nile, as it has the same vent, it will be seen that the proportions of the two are almost identical, for 990 is to 1548 as 39 is to 60, nearly; but Messrs. Boulton and Watt would not have set a boiler like that of the Eagle to do so much work.

264. *Q.*—Then the evaporating power of the boiler varies as the sectional area of the flue?

A.—The evaporating power varies as the square root of the area of the flue, if the length of the flue remain the same; but it varies as the area simply, if the length of the flue be increased in the same proportion as its other dimensions. The evaporating power of a boiler is referable to the amount of its heating surface, and the amount of heating surface in any flue or tube is proportional to the product of the length of the tube and the square root of its sectional area, multiplied by a certain quantity that is constant for each particular form. But in similar tubes the length is proportional to the square root of the sectional area; therefore, in similar tubes, the amount of heating surface is proportional to the sectional area. On this area also depends the quantity of hot air passing through the flue, supposing the intensity of the draught to remain unaffected, and the quantity of hot air or smoke passing through the flue should vary in the same ratio as the quantity of surface.

265. *Q.*—A boiler, therefore, to exert four times the power, should have four times the extent of heating surface, and four times the sectional area of flue for the transmission of the smoke?

A.—Yes; and if the same form of flue is to be retained, it should be of twice the diameter and twice the length; or twice the height and width if rectangular, and twice the length. As then the diameter or square root of the area increases in the same ratio as the length, the square root of the area divided by the length ought to be a constant quantity in each type of boiler, in order that the same proportions of flue may be retained; and in wagon boilers without an internal flue, the height in inches of the flue encircling the boiler divided by the length of the flue in feet will be 1 very nearly. Instead of the square root of the area, the effective perimeter, or outline of that part of the cross section of the flue which is effective in generating steam, may be taken; and the effective perimeter divided by the length ought to be a constant quantity in similar forms of flues and with the same velocity of draught, whatever the size of the flue may be.

266. *Q.*—Will this proportion alter if the form of the flue be changed?

A.—It is clear, that with any given area of flue, to increase the perimeter by adopting a different shape is tantamount to a diminution of the length of the flue; and, if the perimeter be diminished, the length of the flue must at the same time be increased, else it will be impossible to obtain the necessary amount of heating surface. In Boulton and Watt's wagon boilers, the sectional area of the flue in square inches per square foot of heating surface is 5·4 in the two horse boiler; in the three horse it is 4·74; in the four horse, 4·35; six horse, 3·75; eight horse, 4·33; ten horse, 3·96; twelve horse, 3·63; eighteen horse, 3·17; thirty horse, 2·52; and in the forty-five horse boiler, 2·05 square inches. Taking the amount of heating surface in the 45 horse boiler at 9 square feet per horse power, we obtain 18 square inches of sectional area of flue per horse power, which is also Boulton and Watt's proportion of sectional area for marine boilers with internal flues.

267. *Q.*—If to increase the perimeter of a flue is virtually to diminish the length, then a tubular boiler where the perimeter is in effect greatly extended ought to have but a short length of tube?

A.—The flue of the Nile steamer if reduced to the cylindrical form would be 35½ inches in diameter to have the same area; but it would then require to be made 47¾ feet long, to have the same amount of heating surface, excluding the bottom as non-effective. Supposing that with these proportions the heat is sufficiently extracted from the smoke, then every tube of a tubular boiler in which the same draught existed ought to have very nearly the same proportions.

268. *Q.*—But what are the best proportions of the parts of tubular boilers relatively with one another?

A.—The proper relative proportions of the parts of tubular boilers may easily be ascertained by a reference to the settled proportions of flue boilers; for the same general principles are operative in both cases. In the Nile steamer each boiler of 55 horse power has about 497 square feet of flue surface or 9 square feet per horse power, reckoning the total surface as effective. The area of the flue, which is rectangular is 990 square inches, therefore the area is equal to that of a tube 35½ inches in diameter; and such a tube, to have a heating surface of 497 square feet, must be 53·4 feet or 640·8 inches in length. The length, therefore, of the tube, will be about 18 times its diameter, and with the same velocity of draught these proportions must obtain, whatever the absolute dimensions of the tube may be. With a calorimeter, therefore, of 18 square inches per horse power, the length of a tube 3 inches diameter must not exceed 4 feet 6 inches, since the heat will be sufficiently extracted from the smoke in this length, if the smoke only travels at the velocity due to a calorimeter of 18 square inches per horse power.

269. *Q.*—Is this, then, the maximum length of flue which can be used in tubular boilers with advantage?

A.—By no means. The tubes of tubular boilers are almost always more than 4 feet 6 inches long, but then the calorimeter is almost always less than 18 square inches per horse power—generally about two thirds of this. Indeed, tubular boilers with a large calorimeter are not found to be so satisfactory as where the calorimeter is small, partly from the propensity of the smoke in such cases to pass through a few of the tubes instead of the whole of them, and partly from the deposit of soot which takes place when the draught is sluggish. It is a very confusing practice, however, to speak of nominal horse power in connection with boilers, since that is a quantity quite indeterminate.

EVAPORATIVE POWER OF BOILERS.

270. *Q.*—The main thing after all in boilers is their evaporative powers?

A.—The proportions of tubular boilers, as of all boilers, should obviously have reference to the evaporation required, whereas the demand upon the boiler for steam is very often reckoned contingent upon the nominal horse power of the engine; and as the nominal power of an engine is a conventional quantity by no means in uniform proportion to the actual quantity of steam consumed, perplexing complications as to the proper proportions of boilers have in consequence sprung up, to which most of the failures in that department of engineering may be imputed. It is highly expedient, therefore, in planning boilers for any particular engine, to consider exclusively the actual power required to be produced, and to apportion the capabilities of the boiler accordingly.

271. *Q.*—In other words you would recommend the inquiry to be restricted to the mode of evaporating a given number of cubic feet of water in the hour, instead of embracing the problem how an engine of a given nominal power was to be supplied with steam?

A.—I would first, as I have already stated, consider the actual power required to be produced, and then fix the amount of expansion to be adopted. If the engine had to work up to three times its nominal power, as is now common in marine engines, I should either increase correspondingly the quantity of evaporating surface in the boiler, or adopt such an amount of expansion as would increase threefold the efficacy of the steam, or combine in a modified manner both of these arrangements. Reckoning the evaporation of a cubic foot of water in the hour as equivalent to an actual horse power, and allowing a square yard or 9 square feet as the proper proportion of flue surface to evaporate a cubic foot of water in the hour, it is clear that I must either give 27 square feet of heating surface in the boiler to have a trebled power without expansion, or I must cut off the steam at one seventh of the stroke to obtain a threefold power without increasing the quantity of heating surface. By cutting off the steam, however, at one third of the stroke, a heating surface of 13½ square feet will give a threefold power, and it will usually be the most judicious course to carry the expansion as far as possible, and then to add the proportion of heating surface necessary to make good the deficiency still found to exist.

272. *Q.*—But is it certain that a cubic foot of water evaporated in the hour is equivalent to an actual horse power?

A.—An actual horse power as fixed by Watt is 33,000 lbs. raised one foot high in the minute; and in Watt's 40 horse power engine, with a 31½ inch cylinder, 7 feet stroke, and making 17½ strokes a minute, the effective pressure is 6·92 lbs. on the square inch clear of all deductions. Now, as a horse power is 33,000 lbs. raised one foot high, and as there are 6·92 lbs, on the square inch, it is clear that 33,000 divided by 6·92, or 4768 square inches with 6·92 lbs. on each if lifted 1 foot or 12 inches high, will also be equal to a horse power. But 4768 square inches multiplied by 12 inches in height is 57224·4 cubic inches, or 33·1 cubic feet, and this is the quantity of steam which must be expended per minute to produce an actual horse power.

273. *Q.*—But are 33 cubic feet of steam expended per minute equivalent to a cubic foot of water expended in the hour?

A.—Not precisely, but nearly so. A cubic foot of water produces 1669 cubic feet of steam of the atmospheric density of 15 lbs. per square inch, whereas a consumption of 33 cubic feet of steam in the minute is 1980 cubic feet in the hour. In Watt's engines about one tenth was reckoned as loss in filling the waste spaces at the top and bottom of the cylinder, making 1872 cubic feet as the quantity consumed per hour without this waste; and in modern engines the waste at the ends of the cylinder is inconsiderable.

274. *Q*—What power was generated by a cubic foot of water in the case of the Albion Mill engines when working without expansion?

A.—In the Albion Mill engines when working without expansion, it was found that 1 lb. of water in the shape of steam raised 28,489 lbs. 1 foot high. A cubic foot of water, therefore, or 62½ lbs., if consumed in the hour, would raise 1780562·5 lbs. one foot high in the hour, or would raise 29,676 lbs. one foot high in a minute; and if to this we add one tenth for waste at the ends of the cylinder, a waste which hardly exists in modern engines, we have 32,643 lbs. raised one foot high in the minute, or a horse power very nearly. In some cases the approximation appears still nearer. Thus, in a 40 horse engine working without expansion, Watt found that ·674 feet of water were evaporated from the boiler per minute, which is just a cubic foot per horse power per hour; but it is not certain in this case that the nominal and actual power were precisely identical. It will be quite safe, however, to reckon an actual horse power as producible by the evaporation of a cubic foot of water in the hour in the case of engines working without expansion; and for boiling off this quantity in flue or wagon boilers, about 8 lbs. of coal will be required and 9 square feet of flue surface.

MODERN MARINE AND LOCOMOTIVE BOILERS.

275. *Q.*—These proportions appear chiefly to refer to old boilers. I wish you to state what are the proportions of modern flue and tubular marine boilers.

A.—In modern marine boilers the area of fire grate is less than in Mr. Watt's original boilers, where it was one square foot to nine square feet of heating surface. The heat in the furnace is consequently more intense, and a somewhat less amount of surface suffices to evaporate a cubic foot of water. In Boulton and Watt's modern flue boilers they allow for the evaporation of a cubic foot of water 8 square feet of heating surface, 70 square inches of fire grate, 13 square inches sectional area of flues, 6 square inches sectional area of chimney, 14 square inches area over furnace bridges, ratio of area of flue to area of fire grate 1 to 5·4. To evaporate a cubic foot of water per hour in tubular boilers, the proportions are—heating surface 9 square feet, fire grate 70 square inches, sectional area of tubes 10 square inches, sectional area of back uptake 12 square inches, sectional area of front uptake 10 square inches, sectional area of chimney 7 square inches, ratio of diameter of tube to length of tube $\frac{1}{28}$th to $\frac{1}{30}$th, cubical content of boiler exclusive of steam chest 6·5 cubic feet, cubical content of steam chest 1·5 cubic feet.

276. *Q.*—These proportions do not apply to locomotive boilers?

A.—Not at all. In locomotive boilers the draught is maintained by the projection of the waste steam which escapes from the cylinders up the chimney, and the draught is much more powerful and the combustion much more rapid than in cases in which the combustion is maintained by the natural draught of a chimney, except indeed the chimney be of very unusual temperature and height. The proportions proper for locomotive boilers will be seen by the dimensions of a few locomotives of approved construction, which have been found to give satisfactory results in practice, and which are recorded in the following Table:

	NAME OF ENGINE.			
	Great Britain.	Pallas.	Snake.	Sphinx.
Diameter of cylinder.......	18 in.	15 in.	$14\frac{1}{4}$ in.	18 in.
Length of stroke	24 in.	20 in.	21 in.	24 in.
Diameter of driving wheel..	8 ft.	6 ft.	$6\frac{1}{2}$ ft.	5 ft.
Inside length of fire box....	53 in.	55 in.	$41\frac{1}{2}$ in.	44 in.
Inside width of fire box.....	63 in.	42 in.	$43\frac{1}{4}$ in.	$39\frac{1}{2}$ in.
Height of fire box above bars	63 in.	52 in.	$48\frac{1}{2}$ in.	$55\frac{1}{2}$ in.
Number of fire bars........	29	....	32	16
Thickness of fire bars.......	$\frac{3}{4}$ in.	$1\frac{3}{4}$ in.	$\frac{5}{8}$ in.	1 in.
Number of tubes...........	305	134	181	142
Outside diameter of tubes...	2 in.	2 in.	$1\frac{7}{8}$ in.	$2\frac{1}{3}$ in.
Length of tubes...........	11 ft. 3 in.	10 ft. 6 in.	10 ft. $3\frac{1}{3}$ in.	14 ft. $3\frac{1}{4}$ in.
Space between tubes.......	$\frac{1}{2}$ in.	$\frac{3}{4}$ in.	$\frac{1}{8}$ in.	
Inside diameter of ferules...	$1\frac{9}{16}$ in.	$1\frac{1}{2}$ in.	$1\frac{5}{16}$ in.	$1\frac{4}{5}$ in.
Diameter of chimney.......	17 in.	15 in.	13 in.	$15\frac{1}{2}$ in.
Diameter of blast orifice....	$5\frac{1}{2}$ in.	$4\frac{4}{5}$ in.	$4\frac{1}{2}$ in.	$4\frac{3}{4}$ in.
Area of fire grate..........	21 sq. ft.	16·04 sq. ft.	12·4 sq. ft.	10·56 sq. ft.
Area of air space of grate...	11·4 sq. ft.	4·08 sq. ft.	5·54 sq. ft.	5 sq. ft.
Area of tubes.............	5·46 sq. ft.	2·40 sq. ft.	2·8 sq. ft.	2·92 sq. ft.
Area through ferules.......	4 sq. ft.	1·64 sq. ft.	2 sq. ft.	2·04 sq. ft.
Area of chimney..........	1·77 sq. ft.	1·23 sq. ft.	·921 sq. ft.	1·31 sq. ft.
Area of blast orifice........	23·76 sq. in.	16·8 sq. in.	14·18 sq. in.	17·7 sq. in.
Heating surface of tubes....	1627 sq. ft.	668·7 sq. ft.	823 sq. ft.	864·8 sq. ft.

THE BLAST IN LOCOMOTIVES.

277. *Q.*—What is the amount of draught produced in locomotive boilers in comparison with that existing in other boilers?

A.—A good chimney of a land engine will produce a degree of exhaustion equal to from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches of water. In locomotive boilers the exhaustion is in some cases equal to 12 or 13 inches of water, but from 3 to 6 inches is a more common proportion.

278. *Q.*—And what force of blast is necessary to produce this exhaustion?

A.—The amount varies in different engines, depending on the sectional area of the tubes and other circumstances. But on the average, it may be asserted that such a pressure of blast as will support an inch of mercury, will maintain sufficient exhaustion in the smoke box to support an inch of water; and this ratio holds whether the exhaustion is little or great. To produce an exhaustion in the smoke box, therefore, of 6 inches of water, the waste steam would require to be of sufficient pressure to support a column of 6 inches of mercury, which is equivalent to a pressure of 3 lbs. on the square inch.

279. *Q.*—How is the force of the blast determined?

A.—By the amount of contraction given to the mouth of the blast pipe, which is a pipe which conducts the waste steam from the cylinders and debouches at the foot of the chimney. If a strong blast be required, the mouth of this pipe requires to be correspondingly contracted, but such contraction throws a back pressure on the piston, and it is desirable to obtain the necessary draught with as little contraction of the blast pipe as possible. The blast pipe is generally a breeches pipe of which the legs join just before reaching the chimney; but it is better to join the two cylinders below, and to let a single pipe ascend to within 12 or 18 inches of the foot of the chimney. If made with too short a piece of pipe above the joining, the steam will be projected against each side of the chimney alternately, and the draught will be damaged and the chimney worn. The blast pipe should not be regularly tapered, but should be large in the body and gathered in at the mouth.

280. *Q.*—Is a large and high chimney conducive to strength of draught in locomotives?

A.—It has not been found to be so. A chimney of three or four times its own diameter in height appears to answer fully as well as a longer one; and it was found that when in an engine with 17 inch cylinders a chimney of 15¼ inches was substituted for a chimney of 17½ inches, a superior performance was the result. The chimney of a locomotive should have half the area of the tubes at the ferules, which is the most contracted part, and the blast orifice should have $\frac{1}{10}$th of the area of the chimney. The sectional area of the tubes through the ferules should be as large as possible. Tubes without ferules it is found pass one fourth more air, and tubes with ferules only at the smoke box end pass one tenth more air than when there are ferules at both ends.

281. *Q.*—Is the exhaustion produced by the blast as great in the fire box as in the smoke box?

A.—Experiments have been made to determine this, and in few cases has it been found to be more than about half as great as ordinary speeds; but much depends on the amount of contraction in the tubes. In an experiment made with an engine having 147 tubes of 1¾ inches external diameter, and 13 feet 10 inches long, and with a fire grate having an area of 9½ square feet, the exhaustion at all speeds was found to be three times greater in the smoke box than in the fire box. The exhaustion in the smoke box was generally equivalent to 12 inches of water, while in the fire box it was equivalent to only 4 inches of water; showing that 4 inches were required to draw the air through the grate and 8 inches through the tubes.

282. *Q.*—What will be the increase of evaporation in a locomotive from a given increase of exhaustion?

A.—The rate of evaporation in a locomotive or any other boiler will vary as the quantity of air passing through the fire, and the quantity of air passing through the fire will vary nearly as the square root of the exhaustion. With four times the exhaustion, therefore, there will be about twice the evaporation, and experiment shows that this theoretical law holds with tolerable accuracy in practice.

283. *Q.*—But the same exhaustion will not be produced by a given strength of blast in all engines?

A.—No; engines with contracted fire grates and an inadequate sectional area of tubes, will require a stronger blast than engines of better proportions; but in any given engine the relations between the blast exhaustion and evaporation hold which have been already defined.

284. *Q.*—Is the intensity of the draught under easy regulation?

A.—The intensity of the draught may easily be diminished by partially closing the damper in the chimney, and it may be increased by contracting the orifice of the blast. A variable blast pipe, the orifice of which may be enlarged or contracted at pleasure, has been much used. There are various devices for this purpose, but the best appears to be that adopted in Stephenson's engine, where a conical nozzle is moved up or down within the blast pipe, which is made somewhat larger in diameter than the base of the cone, but with a ring projecting internally, against which the base of the cone abuts when the nozzle is pushed up. When the nozzle stands at the top of the pipe the whole of the steam has to pass through it, and the intensity of the blast is increased by the increased velocity thus given to the steam; whereas when the nozzle is moved downward the steam escapes through the annular opening left between the nozzle and the pipe, as well as through the nozzle itself, and the intensity of the blast is diminished by the enlargement of the opening for the escape of the steam thus made available.

285. *Q.*—What is the best diameter for the tubes of locomotive boilers?

A.—Bury's locomotive with 14 inch cylinders contains 92 tubes of $2\frac{1}{8}$th inches external diameter, and 10 feet 6 inches long; whereas Stephenson's locomotive with 15 inch cylinders contains 150 tubes of $1\frac{5}{8}$ths external diameter, 13 feet 6 inches long. In Stephenson's boiler, in order that the part of the tubes next the chimney may be of any avail for the generation of steam, the draught has to be very intense, which in its turn involves a considerable expenditure of power; and it is questionable whether the increased expenditure of power upon the blast, in Stephenson's long tubed locomotives, is compensated by the increased generation of steam consequent upon the extension of the heating surface. When the tubes are small in diameter they are apt to become partially choked with pieces of coke; but an internal diameter of $1\frac{5}{8}$ths may be employed without inconvenience if the draught be of medium intensity.

286. *Q.*—Will you illustrate the relation between the length and diameter of locomotive tubes by a comparison with the proportion of flues in flue boilers?

A.—In most locomotives the velocity of the draught is such that it would require very long tubes to extract the heat from the products of combustion, if the heat were transmitted through the metal of the tubes with only the same facility as through the iron of ordinary flue boilers. The Nile steamer, with engines of 110 nominal horses power each, and with two boilers having two independent flues in each, of such dimensions as to make each flue equivalent to 55 nominal horses power, works at 62 per cent. above the nominal power, so that the actual evaporative efficacy of each flue would be equivalent to 89 actual horses power, supposing the engines to operate without expansion; but as the mean pressure in the cylinder is somewhat less than the initial pressure, the evaporative efficacy of each flue may be reckoned equivalent to 80 actual horses power. With this evaporative power there is a calorimeter of 990 square inches, or 12·3 square inches per actual horse power; whereas in Stephenson's locomotive with 150 tubes, if the evaporative power be taken at 200 cubic feet of water in the hour, which is a large supposition, the engine will be equal to 200 actual horses power. If the internal diameter of the tubes be taken at thirteen eighths of an inch, the calorimeter per actual horse power will only be 1·1136 square inches, or in other words the calorimeter in the locomotive boiler will be 11·11 times less than in the flue boiler for the same power, so that the draught in the locomotive must be 11·11 times stronger, and the ratio of the length of the tube to its diameter 11·11 times greater than in the flue boiler, supposing the heat to be transmitted with only the same facility. The flue of the Nile would require to be $35\frac{1}{2}$ inches in diameter if made of the cylindrical form, and $47\frac{3}{4}$ feet long; the tubes of a locomotive if $1\frac{7}{8}$ths inch diameter would only require to be 22·19 inches long with the same velocity of draught; but as the draught is 11·11 times faster than in a flue boiler, the tubes ought to be 246·558 inches, or about $20\frac{1}{2}$ feet long according to this proportion. In practice, however, they are one third less than this, which reduces the heating surface from 9 to 6 square feet per actual horse power, and this length even is found to be inconvenient. It is greatly preferable therefore to increase the calorimeter, and diminish the intensity of the draught.

BOILER CHIMNEYS.

287. *Q.*—By what process do you ascertain the dimensions of the chimney of a land boiler?

A.—By a reference to the volume of air it is necessary in a given time to supply to the burning fuel, and to the velocity of motion produced by the rarefaction in the chimney; for the area of the chimney requires to be such, that with the velocity due to that rarefaction, the quantity of air requisite for the combustion of the fuel shall pass through the furnace in the specified time. Thus if 200 cubic feet of air of the atmospheric density are required for the combustion of a pound of coal,—though 250 lbs. is nearer the quantity generally required,—and 10 lbs. of coal per horse power per hour are consumed by an engine, then 2000 cubic feet of air must be supplied to the furnace per horse power per hour, and the area of the chimney must be such as to deliver this quantity at the increased bulk due to the high temperature of the chimney when moving with the velocity the rarefaction within the chimney occasions, and which, in small chimneys, is usually such as to support a column of half an inch of water. The velocity with which a denser fluid flows into a rarer one is equal to the velocity a heavy body acquires in falling through a height equal to the difference of altitude of two columns of the heavier fluid of such heights as will produce the respective pressures; and, therefore, when the difference of pressure or amount of rarefaction in the chimney is known, it is easy to tell the velocity of motion which ought to be produced by it. In practice, however, these theoretical results are not to be trusted, until they have received such modifications as will make them representative of the practice of the most experienced constructors?

288. *Q.*—What then is the rule followed by the most experienced constructors?

A.—Boulton and Watt's rule for the dimensions of the chimney of a land engine is as follows:—multiply the number of pounds of coal consumed under the boiler per hour by 12, and divide the product by the square root of the height of the chimney in feet; the quotient is the area of the chimney in square inches in the smallest part. A factory chimney suitable for a 20 horse boiler is commonly made about 20 in. square inside, and 80 ft. high; and these dimensions are those which answer to a consumption of 15 lbs. of coal per horse power per hour, which is a very common consumption in factory engines. If 15 lbs. of coal be consumed per horse power per hour, the total consumption per hour in a 20 horse boiler will be 300 lbs., and 300 multiplied by 12=3600, and divided by 9 (the square root of the height) =400, which is the area of the chimney in square inches. It will not answer well to increase the height of a chimney of this area to more than 40 or 50 yards, without also increasing the area, nor will it be of utility to increase the area much without also increasing the height. The quantity of coal consumed per hour in pounds, multiplied by 5, and divided by the square root of the height of the chimney, is the proper collective area of the openings between the bars of the grate for the admission of air to the fire.

289. *Q.*—Is this rule applicable to the chimneys of steam vessels?

A.—In steam vessels Boulton and Watt have heretofore been in the habit of allowing 8½ square inches of area of chimney per horse power, but they now allow 6 square inches to 7 square inches. In some steam vessels a steam blast like that of a locomotive, but of a smaller volume, is used in the chimney, and many of the evils of a boiler deficient in draught may be remedied by this expedient, but a steam blast in a low pressure engine occasions an obvious waste of steam; it also makes an unpleasant noise, and in steam vessels it frequently produces the inconvenience of carrying the smaller parts of the coal up the chimney, and scattering it over the deck among the passengers. It is advisable, therefore, to give a sufficient calorimeter in all low pressure boilers, and a sufficient height of chimney to enable the chimney to operate without a steam jet; but it is useful to know that a steam jet is a resource in the case of a defective boiler, or where the boiler has to be urged beyond its power.

STEAM ROOM AND PRIMING.

290. *Q.*—What is the capacity of steam room allowed in boilers per horse power?

A.—The capacity of steam room allowed by Boulton and Watt in their land wagon boilers is 8¾ cubic feet per horse power in the two horse power boiler, and 5¾ cubic feet in the 20 horse power boiler; and in the larger class of boilers, such as those suitable for 30 and 45 horse power engines, the capacity of the steam room does not fall below this amount, and, indeed, is nearer 6 than 5¾ cubic feet per horse power. The content of water is 18½ cubic feet per horse power in the two horse power boiler, and 15 cubic feet per horse power in the 20 horse power boiler.

291. *Q.*—Is this the proportion Boulton and Watt allow in their marine boilers?

A.—Boulton and Watt in their early steam vessels were in the habit of allowing for the capacity of the steam space in marine boilers 16 times the content of the cylinder; but as there were two cylinders, this was equivalent to 8 times the content of both cylinders, which is the proportion commonly followed in land engines, and which agrees very nearly with the proportion of between 5 and 6 cubic feet of steam room per horse power already referred to. Taking for example an engine with 23 inches diameter of cylinder and 4 feet stroke, which will be 18·4 horse power—the area of the cylinder will be 415·476 square inches, which, multiplied by 48, the number of inches in the stroke, will give 19942·848 for the capacity of the cylinder in cubic inches; 8 times this is 159542·784 cubic inches, or 92·3 cubic feet; 92·3 divided by 18·4 is rather more than 5 cubic feet per horse power.

292. *Q.*—Is the production of the steam in the boiler uniform throughout the stroke of the engine?

A.—It varies with the slight variations in the pressure within the boiler throughout the stroke. Usually the larger part of the steam is produced during the first part of the stroke of the engine, for there is then the largest demand for steam, as the steam being commonly cut off somewhat before the end of the stroke, the pressure rises somewhat in the boiler during that period, and little steam is then produced. There is less necessity that the steam space should be large when the flow of steam from the boiler is very uniform, as it will be where there are two engines attached to the boiler at right angles with one another, or where the engines work at a great speed, as in the case of locomotive engines. A high steam chest too, by rendering boiling over into the steam pipes, or priming as it is called, more difficult, obviates the necessity for so large a steam space; as does also a perforated steam pipe stretching through the length of the boiler, so as not to take the steam from one place. The use of steam of a high pressure, worked expansively, has the same operation; so that in modern marine boilers, of the tubular construction, where the whole or most of these modifying circumstances exist, there is no necessity for so large a proportion of steam room as 5 or 6 cubic feet per nominal horse power, and about one, $1\frac{1}{2}$, or 2 cubic feet of steam room per cubic foot of water evaporated, more nearly represents the general practice.

293. *Q.*—Is this the proportion of steam room adopted in locomotive boilers?

A.—No; in locomotive boilers the proportion of steam room per cubic foot of water evaporated is considerably less even than this. It does not usually exceed $\frac{1}{5}$ of a cubic foot per cubic foot of water evaporated; and with clean water, with a steam dome a few feet high set on the barrel of the boiler, or with a perforated pipe stretching from end to end of the barrel, and with the steam room divided about equally between the barrel and the fire box, very little priming is found to occur even with this small proportion of total steam room. About $\frac{3}{4}$ the depth of the barrel is usually filled with water, and $\frac{1}{4}$ with steam.

294. *Q.*—What is priming?

A.—Priming is a violent agitation of the water within the boiler, in consequence of which a large quantity of water passes off with the steam in the shape of froth or spray. Such a result is injurious, both as regards the efficacy of the engine, and the safety of the engine and boiler; for the large volume of hot water carried by the steam into the condenser impairs the vacuum, and throws a great load upon the air pump, which diminishes the speed and available power of the engine; and the existence of water within the cylinder, unless there be safety valves upon the cylinder to permit its escape, will very probably cause some part of the machinery to break, by suddenly arresting the motion of the piston when it meets the surface of the water,—the slide valve being closed to the condenser before the termination of the stroke, in all engines with lap upon the valves, so that the water within the cylinder is prevented from escaping in that direction. At the same time the boiler is emptied of its water too rapidly for the feed pump to be able to maintain the supply, and the flues are in danger of being burnt from a deficiency of water above them.

295. *Q.*—What are the causes of priming?

A.—The causes of priming are an insufficient amount of steam room, an inadequate area of water level, an insufficient width between the flues or tubes for the ascent of the steam and the descent of water to supply the vacuity the steam occasions, and the use of dirty water in the boiler. New boilers prime more than old boilers, and steamers entering rivers from the sea are more addicted to priming than if sea or river water had alone been used in the boilers—probably from the boiling point of salt water being higher than that of fresh, whereby the salt water acts like so much molten metal in raising the fresh water into steam. Opening the safety valve suddenly may make a boiler prime, and if the safety valve be situated near the mouth of the steam pipe, the spray or foam thus created may be mingled with the steam pas ing into the engine, and materially diminish its effective power; but if the safety valve be situated at a distance from the mouth of the steam pipe, the quantity of foam or spray passing into the engine may be diminished by opening the safety valve; and in locomotives, therefore, it is found beneficial to have a safety valve on the barrel of the boiler at a point remote from the steam chest, by partially opening which, any priming in that part of the boiler adjacent to the steam chest is checked, and a purer steam than before passes to the engine.

296. *Q.*—What is the proper remedy for priming?

A.—When a boiler primes, the engineer generally closes the throttle valve partially, turns off the injection water, and opens the furnace doors, whereby the generation of steam is checked, and a less violent ebullition in the boiler suffices. Where the priming arises from an insufficient amount of steam room, it may be mitigated by putting a higher pressure upon the boiler and working more expansively, or by the interposition of a perforated plate between the boiler and the steam chest, which breaks the ascending water and liberates the steam. In some cases, however, it may be necessary to set a second steam chest on the top of the existing one, and it will be preferable to establish a communication with this new chamber by means of a number of small holes, bored through the iron plate of the boiler, rather than by a single large orifice. Where priming arises from the existence of dirty water in the boiler, the evil may be remedied by the use of collecting vessels, or by blowing off largely from the surface; and where it arises from an insufficient area of water level, or an insufficient width between the flues for the free ascent of the steam and the descent of the superincumbent water, the evil may be abated by the addition of circulating pipes in some part of the boiler, which will allow the water to descend freely to the place from whence the steam rises, the width of the water spaces being virtually increased by restricting their function to the transmission of a current of steam and water to the surface. It is desirable to arrange the heating surface in such a way that the feed water entering the boiler at its lowest point is heated gradually as it ascends, until toward the superior part of the flues it is raised gradually into steam; but in all cases there will be currents in the boiler for which it is proper to provide. The steam pipe proceeding to the engine should obviously be attached to the highest point of the steam chest, in boilers of every construction.

297. *Q.*—Having now stated the proportions proper to be adopted for evaporating any given quantity of water in steam boilers, will you proceed to show how you would proportion a boiler to do a given amount of work? say a locomotive boiler which will propel a train of 100 tons weight at a speed of 50 miles an hour.

A.—According to experiments on the resistance of railway trains at various rates of speed, made by Mr. Gooch, of the Great Western Railway, it appears that a train weighing, with locomotive, tender, and carriages, about 100 tons, experiences, at a speed of 50 miles an hour, a resistance of about 3,000 lbs., or about 30 lbs. per ton; which resistance includes the resistance of the engine as well as that of the train. This, therefore, is the force which must be imparted at the circumference of the driving wheels, except that small part intercepted by the engine itself, and the force exerted by the pistons must be greater than that at the circumference of the driving wheel, in the proportion of their slower motion, or in the proportion of the circumference of the driving wheel to the length of a double stroke of the engine. If the diameter of the driving wheel be $5\frac{1}{2}$ feet, its circumference will be 17·278 feet, and if the length of the stroke be 18 inches, the length of a double stroke will be

3 feet. The pressure on the pistons must therefore be greater than the traction at the circumference of the driving wheel, in the proportion of 17·278 to 3, or, in other words, the mean pressure on the pistons must be 17,278 lbs.; and the area of cylinders, and pressure of steam, must be such as to produce conjointly this total pressure. It thus becomes easy to tell the volume and pressure of steam required, which steam in its turn represents its equivalent of water which is to be evaporated from the boiler, and the boiler must be so proportioned, by the rules already given, as to evaporate this water freely. In the case of a steam vessel, the mode of procedure is the same, and when the resistance and speed are known, it is easy to tell the equivalent value of steam.

STRENGTH OF BOILERS.

298. *Q.*—What strain should the iron of boilers be subjected to in working?

A.—The iron of boilers, like the iron of machines or structures, is capable of withstanding a tensile strain of from 50,000 to 60,000 lbs. upon every square inch of section; but it will only bear a third of this strain without permanent derangement of structure, and it does not appear expedient in any boiler to let the strain exceed 4,000 lbs. upon the square inch of sectional area of metal, especially if it is liable to be weakened by corrosion.

299. *Q.*—Have any experiments been made to determine the strength of boilers?

A.—The question of the strength of boilers was investigated very elaborately a few years ago by a committee of the Franklin Institute, in America, and it was found that the tenacity of boiler plate increased with the temperature up to 550°, at which point the tenacity began to diminish. At 32°, the cohesive force of a square inch of section was 56,000 lbs.; at 570°, it was 66,500 lbs.; at 720°, 55,000 lbs.; at 1,050°, 32,000 lbs.; at 1,240°, 22,000 lbs.; and at 1,317°, 9,000 lbs. Copper follows a different law, and appears to be diminished in strength by every addition to the temperature. At 32° the cohesion of copper was found to be 32,800 lbs. per square inch of section, which exceeds the cohesive force at any higher temperature, and the square of the diminution of strength seems to keep pace with the cube of the increased temperature. Strips of iron cut in the direction of the fibre were found to be about 6 per cent. stronger than when cut across the grain. Repeated piling and welding was found to increase the tenacity of the iron, but the result of welding together different kinds of iron was not found to be favorable. The accidental overheating of a boiler was found to reduce the ultimate or maximum strength of the plates from 65,000 to 45,000 lbs. per square inch of section, and riveting the plates was found to occasion a diminution in their strength to the extent of one third. These results, however, are not precisely the same as those obtained by Mr. Fairbairn.

300. *Q.*—What were the results obtained by him?

A.—He found that boiler plate bore a tensile strain of 23 tons per square inch before rupture, which was reduced to 16 tons per square inch when joined together by a double row of rivets, and 13 tons, or about 30,000, when joined together by a single row of rivets. A circular boiler, therefore, with the ends of its plates double riveted, will bear at the utmost about 36,000 lbs. per square inch of section, or about 12,000 lbs. per square inch of section without permanent derangement of structure.

301. *Q.*—What pressure do cylindrical boilers sustain in practice?

A.—In some locomotive boilers, which are worked with a pressure of 80 lbs. upon the square inch, the thickness of the plates is only $\frac{5}{16}$ths of an inch, while the barrel of the boiler is 39 inches in diameter. It will require a length of 3·2 inches of the boiler when the plates are $\frac{5}{16}$ths thick to make up a sectional area of one square inch, and the separating force will be 39 times 3·2 multiplied by 80, which makes the separating force 9,984 lbs., sustained by two square inches of sectional area—one on each side; or the strain is 4,992 lbs. per square inch of sectional area, which is quite as great strain as is advisable. The accession of strength derived from the boiler ends is not here taken into account, but neither is the weakening effect counted that is caused by the rivet holes. Some locomotives of 4 feet diameter of barrel and of $\frac{3}{8}$ths iron have been worked to as high a pressure as 200 lbs. on the inch; but such feats of daring are neither to be imitated nor commended.

302. *Q.*—Can you give a rule for the proper thickness of cylindrical boilers?

A.—The thickness proper for cylindrical boilers of wrought iron, exposed to an internal pressure, may be found by the following rule:—multiply 2·54 times the internal diameter of the cylinder in inches by the greatest pressure within the cylinder per circular inch, and divide by 17,800; the result is the thickness in inches. If we apply this rule to the example of the locomotive boiler just given, we have $39 \times 2{\cdot}54 \times 62{\cdot}832$ (the pressure per circular inch corresponding to 80 lbs. per square inch)$=6224{\cdot}1379$, and this, divided by 17,800, gives 0·349 as the thickness in inches, instead of 0·3125, or $\frac{5}{16}$ths, the actual thickness. If we take the pressure per square inch instead of per circular inch, we obtain the following rule, which is somewhat simpler:—multiply the internal diameter of the cylinder in inches by the pressure in pounds per square inch, and divide the product by 8,900; the result is the thickness in inches. Both these rules give the strain about one fourth of the elastic force, or 4,450 lbs. per square inch of sectional area of the iron; but 3,000 lbs. is enough when the flame impinges directly on the iron, as in some of the ordinary cylindrical boilers, and the rule may be adapted for that strain by taking 6,000 as a divisor instead of 8,900.

303. *Q.*—In marine and wagon boilers, which are not of a cylindrical form, how do you procure the requisite strength?

A.—Where the sides of the boiler are flat, instead of being cylindrical, a sufficient number of stays must be introduced to withstand the pressure; and it is expedient not to let the strain upon these stays be more than 3,000 lbs. per square inch of section, as the strength of internal stays in boilers is generally soon diminished by corrosion. Indeed, a strain at all approaching that upon locomotive boilers would be very unsafe in the case of marine boilers, on account of the corrosion, both internal and external, to which marine boilers are subject. The stays should be small and numerous rather than large and few in number, as, when large stays are employed, it is difficult to keep them tight at the ends, and oxidation of the shell follows from leakage at the ends of the stays. All boilers should be proved, when new, to twice or three times the pressure they are intended to bear, and they should be proved occasionally by the hand pump when in use, to detect any weakness which corrosion may have occasioned.

304. *Q.*—Will you describe the disposition of the stays in a marine boiler?

A.—If the pressure of steam be 20 lbs. on the square inch, which is a very common pressure in tubular boilers, there will be a pressure of 2,880 lbs. on every square foot of flat surface; so that if the strain upon the stays is not to exceed 3,000 lbs. on the square inch of section, there must be nearly a square inch of sectional area of stay for every square foot of flat surface on the top and bottom, sides, and ends of the boiler. This very much exceeds the proportion usually adopted; and in scarcely any instance are boilers stayed sufficiently to be safe when the shell is composed of flat surfaces. The furnaces should be stayed together with bolts of the best scrap iron, $1\frac{1}{4}$ inch in diameter, tapped through both plates of the water space with thin nuts in each furnace; and it is expedient to make the row of stays, running horizontally near the level of the bars, sufficiently low to come beneath the top of the bars, so as to be shielded from the action of the fire, with which view they should follow the inclination of the bars. The row of stays between the level of the bars and the top of the furnace should be as near the top of the furnace as will consist with the functions they have to perform, so as to be removed as far as possible from the action of the heat; and to support the furnace top, cross bars may either be adopted, to which the top is secured with bolts, as in the case of locomotives, or stays tapped into the furnace top, with a thin nut beneath, may be carried to the top of the boiler; but very little dependence can be put in such stays as stays for keeping down the top of the boiler; and the top of the boiler must, therefore, be stayed nearly as much as if the stays connecting it with the furnace crowns did not exist. The large rivets passing through thimbles, sometimes used as stays for water spaces or boiler shells, are objectionable; as, from the great amount of hammering such rivets have to receive to form the heads, the iron becomes crystalline, so that the heads are liable to come off, and, indeed, sometimes fly off in the act of being formed. If such a fracture occurs between the boilers after they are seated in their place, or in any position not accessible from the outside, it will in general be necessary to empty the faulty boiler, and repair the defect from the inside.

305. *Q.*—What should be the pitch or numerical distribution of the stays?

A.—The stays, where the sides of the boiler are flat, and the pressure of the steam is from 20 to 30 lbs., should be pitched about a foot or 18 inches asunder; and in the wake of the tubes, where stays cannot be carried across to connect the boiler sides, angle iron ribs, like the ribs of a ship, should be riveted to the interior of the boiler, and stays of greater strength than the rest should pass across, above, and below the tubes, to which the angle irons would communicate the strain. The whole of the long stays within a boiler should be firmly riveted to the shell, as if built with and forming a part of it; as, by the common method of fixing them in by means of cutters, the decay or accidental detachment of a pin or cutter may endanger the safety of the boiler. Wherever a large perforation in the shell of any circular boiler occurs, a sufficient number of stays should be put across it to maintain the original strength; and where stays are intercepted by the root of the funnel, short stays in continuation of them should be placed inside.

BOILER EXPLOSIONS.

306. *Q.*—What is the chief cause of boiler explosions?

A.—The chief cause of boiler explosions is, undoubtedly, too great a pressure of steam, or an insufficient strength of boiler; but many explosions have also arisen from the flues having been suffered to become red hot. If the safety valve of a boiler be accidentally jammed, or if the plates or stays be much worn by corrosion, while a high pressure of steam is nevertheless maintained, the boiler necessarily bursts; and if, from an insufficiency of water in the boiler, or from any other cause, the flues become highly heated, they may be forced down by the pressure of the steam, and a partial explosion may be the result. The worst explosion is where the shell of the boiler bursts; but the collapse of a furnace or flue is also very disastrous generally to the persons in the engine room; and sometimes the shell bursts and the flues collapse at the same time; for if the flues get red hot, and water be thrown upon them either by the feed pump or otherwise, the generation of steam may be too rapid for the safety valve to permit its escape with sufficient facility, and the shell of the boiler may, in consequence, be rent asunder. Sometimes the iron of the flues becomes highly heated in consequence of the improper configuration of the parts, which, by retaining the steam in contact with the metal, prevents the access of the water: the bottoms of large flues, upon which the flame beats down, are very liable to injury from this cause; and the iron of flues thus acted upon may be so softened that the flues will collapse upward with the pressure of the steam. The flues of boilers may also become red hot in some parts from the attachment of scale, which, from its imperfect conducting power, will cause the iron to be unduly heated; and if the scale be accidentally detached, a partial explosion may occur in consequence.

307. *Q.*—Does the contact of water with heated metal occasion an instantaneous generation of steam?

A.—It is found that a sudden disengagement of steam does not immediately follow the contact of water with the hot metal, for water thrown upon red hot iron is not immediately converted into steam, but assumes the spheroidal form and rolls about in globules over the surface. These globules, however high the temperature of the metal may be on which they are placed, never rise above the temperature of 205°, and give off but very little steam; but if the temperature of the metal be lowered, the water ceases to retain the spheroidal form, and comes into intimate contact with the metal, whereby a rapid disengagement of steam takes place. If water be poured into a very hot copper flask, the flask may be corked up, as there will be scarce any steam produced so long as the high temperature is maintained; but so soon as the temperature is suffered to fall below 350° or 400°, the spheroidal condition being no longer maintainable, steam is generated with rapidity, and the cork will be projected from the mouth of the flask with great force.

308. *Q.*—What precautions can be taken to prevent boiler explosions?

A.—One useful precaution against the explosion of boilers from too great an internal pressure, consists in the application of a steam gauge to each boiler, which will make the existence of any undue pressure in any of the boilers immediately visible; and every boiler should have a safety valve of its own, the passage leading to which should have no connection with the passage leading to any of the stop valves used to cut off the connection between the boilers; so that the action of the safety valve may be made independent of the action of the stop valve. In some cases stop valves have jammed, or have been carried from their seats into the mouth of the pipe communicating between them, and the action of the safety valves should be rendered independent of all such accidents. Safety valves, themselves, sometimes stick fast from corrosion, from the spindles becoming bent, from a distortion of the boiler top with a high pressure, in consequence of which the spindles become jammed in the guides, and from various other causes which it would be tedious to enumerate; but the inaction of the safety valves is at once indicated by the steam gauge, and when discovered, the blow through valves of the engine and blow off cocks of the boiler should at once be opened, and the fires raked out. A cone in the ball of the waste steam pipe to send back the water carried upward by the steam, should never be inserted; as in some cases this cone has become loose, and closed up the mouth of the waste steam pipe, whereby the safety valves being rendered inoperative, the boiler was in danger of bursting.

309. *Q.*—May not danger arise from excessive priming?

A.—If the water be carried out of the boiler so rapidly by priming that the level of the water cannot be maintained, and the flues or furnaces are in danger of becoming red hot, the best plan is to open every furnace door and throw in a few buckets full of water upon the fire, taking care to stand sufficiently to the one side to avoid being scalded by the rush of steam from the furnace. There is no time to begin drawing the fires in such an emergency, and by this treatment the fires, though not altogether extinguished, will be rendered incapable of doing harm. If the flues be already red hot, on no account must cold water be suffered to enter the boiler, but the heat should be maintained in the furnaces, and the blow off cocks be opened, or the mud hole doors loosened, so as to let all the water escape; but at the same time the pressure must be kept quite low in the boiler, so that there will be no danger of the hot flues collapsing with the pressure of the steam.

310. *Q.*—Are plugs of fusible metal useful in preventing explosions?

A.—Plugs of fusible metal were at one time in much repute as a precaution against explosion, the metal being so compounded that it melted with the heat of high pressure steam; but the device, though ingenious, has not been found of any utility in practice. The basis of fusible metal is mercury, and it is found that the compound is not homogeneous, and that the mercury is forced by the pressure of the steam out of the interstices of the metal combined with it, leaving a porous metal which is not easily fusible, and which is, therefore, unable to perform its intended function. In locomotives, however, and also in some other boilers, a lead rivet is inserted with advantage in the crown of the fire box, which is melted out if the water becomes too low, and thus gives notice of the danger.

311. *Q.*—May not explosion occur in marine boilers from the accumulation of salt on the flues?

A.—Yes, in marine boilers this is a constant source of danger, which is only to be met by attention on the part of the engineer. If the water in the boiler be suffered to become too salt, an incrustation of salt will take place on the furnaces, which may cause them to become red hot, and they may then be collapsed even by their own weight aided by a moderate pressure of steam. The expedients which should be adopted for preventing such an accumulation of salt from taking place within the boiler as will be injurious to it, properly fall under the head of the management of steam boilers, and will be explained in a subsequent chapter.