CHAPTER II.

HEAT, COMBUSTION, AND STEAM.

HEAT.

134. *Q.*—What is meant by latent heat?

A.—By latent heat is meant the heat existing in bodies which is not discoverable by the touch or by the thermometer, but which manifests its existence by producing a change of state. Heat is absorbed in the liquefaction of ice, and in the vaporization of water, yet the temperature does not rise during either process, and the heat absorbed is therefore said to become latent. The term is somewhat objectionable, as the effect proper to the absorption of heat has in each case been made visible; and it would be as reasonable to call hot water latent steam. Latent heat, in the present acceptation of the term, means sensible liquefaction or vaporization; but to produce these changes heat is as necessary as to produce the expansion of mercury in a thermometer tube, which is taken as the measure of temperature; and it is hard to see on what ground heat can be said to be latent when its presence is made manifest by changes which only heat can effect. It is the *temperature* only that is latent, and latent temperature means sensible vaporization or liquefaction.

135. *Q.*—But when you talk of the latent heat of steam, what do you mean to express?

A.—I mean to express the heat consumed in accomplishing the vaporization compared with that necessary for producing the temperature. The latent heat of steam is usually reckoned at about 1000 degrees, by which it is meant that there is as much heat in any given weight of steam as would raise its constituent water 1000 degrees if the expansion of the water could be prevented, or as would raise 1000 times that quantity of water one degree. The boiling point of water, being 212 degrees, is 180 degrees above the freezing point of water—the freezing point being 32 degrees; so that it requires 1180 times as much heat to raise 1 lb. of water into steam, as to raise 1180 lbs. of water one degree; or it requires about as much heat to raise a pound of boiling water into steam, as would raise 5½ lbs. of water from the freezing to the boiling point; 5½ multiplied by 180 being 990 or 1000 nearly.

136. *Q.*—When it is stated that the latent heat of steam is 1000 degrees, it is only meant that this is a rough approximation to the truth?

A.—Precisely so. The latent heat, in point of fact, is not uniform at all temperatures, neither is the total amount of heat the same at all temperatures. M. Regnault has shown, by a very elaborate series of experiments on steam, which he has lately concluded, that the total heat in steam increases somewhat with the pressure, and that the latent heat diminishes somewhat with the pressure. This will be made obvious by the following numbers:

Pressure.	Temperature.	Total Heat.	Latent Heat.
15 lbs.	213·1°	1178·9°	965·8°
50	281·0	1199·6	918·6
100	327·8	1213·9	886·1

If, then, steam of 100 lbs. be expanded down to steam of 15 lbs., it will have 35 degrees of heat over that which is required for the maintenance of the vaporous state, or, in other words, it will be surcharged with heat.

137. *Q.*—What do you understand by specific heat?

A.—By specific heat, I understand the relative quantities of heat in bodies at the same temperature, just as by specific gravity I understand the relative quantities of matter in bodies of the same bulk. Equal weights of quicksilver and water at the same temperature do not contain the same quantities of heat, any more than equal bulks of those liquids contain the same quantity of matter. The absolute quantity of heat in any body is not known; but the relative heat of bodies at the same temperature, or in other words their specific heats, have been ascertained and arranged in tables,—the specific heat of water being taken as unity.

138. *Q.*—In what way does the specific heat of a body enable the quantity of heat in it to be determined?

A.—If any body has only half the specific heat of water, then a pound of that body will, at any given temperature, have only half the heat in it that is in a pound of water at the same temperature. The specific heat of air is ·2669, that of water being 1; or it is 3·75 times less than that of water. An amount of heat, therefore, which would raise a pound of water 1 degree would raise a pound of air 3·75 degrees.

COMBUSTION.

139. *Q.*—What is the nature of combustion?

A.—Combustion is nothing more than an energetic chemical combination, or, in other words, it is the mutual neutralization of opposing electricities. When coal is brought to a high temperature it acquires a strong affinity for oxygen, and combination with oxygen will produce more than sufficient heat to maintain the original temperature; so that part of the heat is rendered applicable to other purposes.

140. *Q.*—Does air consist of oxygen?

A.—Air consists of oxygen and nitrogen mixed together in the proportion of 3·29 lbs. of nitrogen to 1 lb. of oxygen. Every pound of coal requires about 2·66 lbs. of oxygen for its saturation, and therefore for every pound of coal burned, 8·75 pounds of nitrogen must pass through the fire, supposing all the oxygen to enter into combination. In practice, however, this perfection of combination does not exist; from one-third to one-half of the oxygen will pass through the fire without entering into combination at all; so that from 16 to 18 lbs. of air are required for every pound of coal burned. 18 lbs. of air are about 240 cubic feet, which may be taken as the quantity of air required for the combustion of a pound of coal in practice.

141. *Q.*—What are the constituents of coal?

A.—The chief constituent of coal is carbon or pure charcoal, which is associated in various proportions with volatile and earthy matters. English coal contains 80 to 90 per cent. of carbon, and from 8 to 18 per cent. of volatile and earthy matters, but sometimes more than this. The volatile matters are hydrogen, nitrogen, oxygen, and sulphur.

142. *Q.*—What is the difference between anthracite and bituminous coal?

A.—Anthracite consists almost entirely of carbon, having 91 per cent. of carbon, with about 7 per cent. of volatile matter and 2 per cent. of ashes. Newcastle coal contains about 83 per cent. of carbon, 14 per cent. of volatile matter, and 3 per cent. of ashes.

143. *Q.*—Will you recapitulate the steps by which you determine the quantity of air required for the combustion of coal?

A.—Looking to the quantity of oxygen required to unite chemically with the various constituents of the coal, we find for example that in 100 lbs. of anthracite coal, consisting of 91·44 lbs. of carbon, and 3·46 lbs. of hydrogen, we shall for the 91·44 lbs. of carbon require 243·84 lbs. of oxygen—since to saturate a pound of carbon by the formation of carbonic acid, requires $2\frac{2}{3}$ lbs. of oxygen. To saturate a pound of hydrogen in the formation of water, requires 8 lbs. of oxygen; hence 3·46 lbs. of hydrogen will take 27·68 lbs. of oxygen for its saturation. If then we add 243·84 lbs. to 27·68 lbs. we have 271·52 lbs. of oxygen required for the combustion of 100 lbs. of coal. A given weight of air contains nearly 23·32 per cent of oxygen; hence to obtain 271·52 lbs. of oxygen, we must have about four times that quantity of atmospheric air, or more accurately, 1164 lbs.

of air for the combustion of 100 lbs. of coal. A cubic foot of air at ordinary temperature weighs about ·075 lbs.; so that 100 lbs. of coal require 15,524 cubic feet of air, or 1 lb. of coal requires about 155 cubic feet of air, supposing every atom of the oxygen to enter into combination. If, then, from one-third to one-half of the air passes unconsumed through the fire, an allowance of 240 cubic feet of air for each pound of coal will be a small enough allowance to answer the requirements of practice, and in some cases as much as 300 cubic feet will be required,—the difference depending mainly on the peculiar configuration of the furnace.

144. *Q.*—Can you state the evaporative efficacy of a pound of coal?

A.—The evaporative efficacy of a pound of carbon has been found experimentally to be equivalent to that necessary to raise 14,000 lbs. of water through 1 degree, or 14 lbs. of water through 1000 degrees, supposing the whole heat generated to be absorbed by the water. Now, if the water be raised into steam from a temperature of 60°, then 1118·9° of heat will have to be imparted to it to convert it into steam of 15 lbs. pressure per square inch. $14{,}000 \div 1118{\cdot}9 = 12{\cdot}512$ lbs. will be the number of pounds of water, therefore, which a pound of carbon can raise into steam of 15 lbs. pressure from a temperature of 60°. This, however, is a considerably larger result than can be expected in practice.

145. *Q.*—Then what is the result that may be expected in practice?

A.—The evaporative powers of different coals appear to be nearly proportional to the quantity of carbon in them; and bituminous coal is, therefore, less efficacious than coal consisting chiefly of pure carbon. A pound of the best Welsh or anthracite coal is capable of raising from 9½ to 10 lbs. of water from 212° into steam, whereas a pound of the best Newcastle is not capable of raising more than about 8½ lbs. of water from 212° into steam; and inferior coals will not raise more than 6½ lbs. of water into steam. In America it has been found that 1 lb. of the best coal is equal to 2½ lbs. of pine wood, or, in some cases to 3 lbs.; and a pound of pine wood will not usually evaporate more than about 2½ lbs. of water, though, by careful management, it may be made to evaporate 4½ lbs. Turf will generate rather more steam than wood. Coke is equal or somewhat superior to the best coal in evaporative effect.

146. *Q.*—How much water will a pound of coal raise into steam in ordinary boilers?

A.—From 6 to 8 lbs. of water in the generality of land boilers of medium quality, the difference depending on the kind of boiler, the kind of coal, and other circumstances. Mr. Watt reckoned his boilers as capable of evaporating 10·08 cubic feet of water with a bushel or 84 lbs. of Newcastle coal, which is equivalent to 7½ lbs. of water evaporated by 1 lb. of coal, and this may be taken as the performance of common land boilers at the present time. In some of the Cornish boilers, however, a pound of coal raises 11·8 lbs. of boiling water into steam, or a cwt. of coal evaporates about 21 cubic feet of water from 212°.

147. *Q.*—What method of firing ordinary furnaces is the best?

A.—The coals should be broken up into small pieces, and sprinkled thinly and evenly over the fire a little at a time. The thickness of the stratum of coal upon the grate should depend upon the intensity of the draught: in ordinary land or marine boilers it should be thin, whereas in locomotive boilers it requires to be much thicker. If the stratum of coal be thick while the draught is sluggish, the carbonic acid resulting from combustion combines with an additional atom of carbon in passing through the fire, and is converted into carbonic oxide, which may be defined to be invisible smoke, as it carries off a portion of the fuel: if, on the contrary, the stratum of coal be thin while the draught is very rapid, an injurious refrigeration is occasioned by the excess of air passing through the furnace. The fire should always be spread of uniform thickness over the bars of the grate, and should be without any holes or uncovered places, which greatly diminish the effect of the fuel by the refrigeratory action of the stream of cold air which enters thereby. A wood fire requires to be about 6 inches thicker than a coal one, and a turf fire requires to be 3 or 4 inches thicker than a wood one, so that the furnace bars must be placed lower where wood or turf is burned, to enable the surface of the fire to be at the same distance from the bottom of the boiler.

148. *Q.*—Is a slow or a rapid combustion the most beneficial?

A.—A slow combustion is found by experiment to give the best results as regards economy of fuel, and theory tells us that the largest advantage will necessarily be obtained where adequate time has been afforded for a complete combination of the constituent atoms of the combustible, and the supporter of combustion. In many of the cases, however, which occur in practice, a slow combustion is not attainable; but the tendencies of slow combustion are both to save the fuel, and to burn the smoke.

149. *Q.*—Is not the combustion in the furnaces of the Cornish boilers very slow?

A.—Yes, very slow; and there is in consequence very little smoke evolved. The coal used in Cornwall is Welsh coal, which evolves but little smoke, and is therefore more favorable for the success of a smokeless furnace; but in the manufacturing districts, where the coal is more bituminous, it is found that smoke may be almost wholly prevented by careful firing and by the use of a large capacity of furnace.

150. *Q.*—Do you consider slow combustion to be an advisable thing to practise in steam vessels?

A.—No, I do not. When the combustion is slow, the heat in the furnaces and flues is less intense, and a larger amount of heating surface consequently becomes necessary to absorb the heat. In locomotives, where the heat of the furnace is very intense, there will be the same economy of fuel with an allowance of 5 or 6 square feet of surface to evaporate a cubic foot of water as in common marine boilers with 10 or 12.

151. *Q.*—What is the method of consuming smoke pursued in the manufacturing districts?

A.—In Manchester, where some stringent regulations for the prevention of smoke have for some time been in force, it is found that the readiest way of burning the smoke is to have a very large proportion of furnace room, whereby slow combustion may be carried on. In some cases, too, a favourable result is arrived at by raising a ridge of coal across the furnace lying against the bridge, and of the same height: this ridge speedily becomes a mass of incandescent coke, which promotes the combustion of the smoke passing over it.

152. *Q.*—Is the method of admitting a stream of air into the flues to burn the smoke regarded favorably?

A.—No; it is found to be productive of injury to the boiler by the violent alternations of temperature it occasions, as at some times cold air impinges on the iron of the boiler, and at other times flame,—just as there happens to be smoke or no smoke emitted by the furnace. Boilers, therefore, operating upon this principle, speedily become leaky, and are much worn by oxidation, so that, if the pressure is considerable, they are liable to explode. It is very difficult to apportion the quantity of air admitted, to the varying wants of the fire; and as air may at some times be rushing in when there is no smoke to consume, a loss of heat, and an increased consumption of fuel may be the result of the arrangement; and, indeed, such is the result in practice, though a carefully performed experiment usually demonstrates a saving in fuel of 10 or 12 per cent.

153. *Q.*—What other plans have been contrived for obviating the nuisance of smoke?

A.—They are too various for enumeration, but most of them either operate upon the principle of admitting air into the flues to accomplish the combustion of the uninflammable parts of the smoke, or seek to attain the same object by passing the smoke over or through the fire or other incandescent material. Some of the plans, indeed, profess to burn the inflammable gases as they are evolved from the coal, without permitting the admixture of any of the uninflammable products of combustion which enter into the composition of smoke; but this object has been very imperfectly fulfilled in any of the contrivances yet brought under the notice of the public, and in some cases these contrivances have been found to create weightier evils than they professed to relieve.

154. *Q.*—You refer, I suppose, to Mr. Charles Wye Williams' Argand furnace?

A.—I chiefly refer to it, though I also comprehend all other schemes in which there is a continuous admission of air into the flues, with an intermittent generation of smoke.

155. *Q.*—This is not so in Prideaux's furnace?

A.—No; in that furnace the air is admitted only during a certain interval, or for so long, in fact, as there is smoke to be consumed.

156. *Q.*—Will you explain the chief peculiarities of that furnace?

A.—The whole peculiarity is in the furnace door. The front of the door consists of metal venetians, which are opened when the top lever is lifted up, and shut when that lever descends to its lowest position. When the furnace door is opened to replenish the fire with coals, the top lever is raised up, and with it the piston of the small cylinder attached to the side of the furnace. The venetians are thereby opened, and a stream of air enters the furnace, which, being heated in its passage among the numerous heated plates attached to the back of the furnace door, is in a favorable condition for effecting the combustion of the inflammable parts of the smoke. The piston in the small cylinder gradually subsides and closes the venetians; and the rate of the subsidence of the piston may obviously be regulated by a cock, or, as in this case, a small screw valve, so that the venetians shall just close when there is no more smoke to be consumed;—the air or other fluid within the cylinder being forced out by the piston in its descent.

157. *Q.*—Had Mr. Watt any method of consuming smoke?

A.—He tried various methods, but eventually fixed upon the method of coking the coal on a dead plate at the furnace door, before pushing it into the fire. That method is perfectly effectual where the combustion is so slow that the requisite time for coking is allowed, and it is much preferable to any of the methods of admitting air at the bridge or elsewhere, to accomplish the combustion of the inflammable parts of the smoke.

158. *Q.*—What are the details of Mr. Watt's arrangement as now employed?

A.—The fire bars and the dead plate are both set at a considerable inclination, to facilitate the advance of the fuel into the furnace. In Boulton and Watt's 30 horse power land boiler, the dead plate and the furnace bars are both about 4 feet long, and they are set at the angle of 30 degrees with the horizon.

159. *Q.*—Is the use of the dead plate universally adopted in Boulton and Watt's land boilers?

A.—It is generally adopted, but in some cases Boulton and Watt have substituted the plan of a revolving grate for consuming the smoke, and the dead plate then becomes both superfluous and inapplicable. In this contrivance the fire is replenished with coals by a self-acting mechanism.

160. *Q.*—Will you explain the arrangement of the revolving grate?

A.—The fire grate is made like a round table capable of turning horizontally upon a centre; a shower of coal is precipitated upon the grate through a slit in the boiler near the furnace mouth, and the smoke evolved from the coal dropped at the front part of the fire is consumed by passing over the incandescent fuel at the back part, from which all the smoke must have been expelled in the revolution of the grate before it can have reached that position.

161. *Q.*—Is a furnace with a revolving grate applicable to a steam vessel?

A.—I see nothing to prevent its application. But the arrangement of the boiler would perhaps require to be changed, and it might be preferable to combine its use with the employment of vertical tubes, for the transmission of the smoke. The introduction of any effectual automatic contrivance for feeding the fire in steam vessels, would bring about an important economy, at the same time that it would give the assurance of the work being better done. It is very difficult to fire furnaces by hand effectually at sea, especially in rough weather and in tropical climates; whereas machinery would be unaffected by any such disturbing causes, and would perform with little expense the work of many men.

162. *Q.*—The introduction of some mechanical method of feeding the fire with coals would enable a double tier of furnaces to be adopted in steam vessels without inconvenience?

A.—Yes, it would have at least that tendency; and as the space available for area of grate is limited in a steam vessel by the width of the vessel, it would be a great convenience if a double tier of furnaces could be employed without a diminished effect. It appears to me, however, that the objection would still remain of the steam raised by the lower furnace being cooled and deadened by the air entering the ash-pit of the upper fire, for it would strike upon the metal of the ash-pit bottom.

163. *Q.*—Have any other plans been devised for feeding the fire by self-acting means besides that of a revolving grate?

A.—Yes, many plans, but none of them, perhaps, are free from an objectionable complication. In some arrangements the bars are made like screws, which being turned round slowly, gradually carry forward the coal; while in other arrangements the same object is sought to be attained by alternately lifting and depressing every second bar at the end nearest the mouth of the furnace. In Juckes' furnace, the fire bars are arranged in the manner of rows of endless chains working over a roller at the mouth of the furnace, and another roller at the farther end of the furnace. These rollers are put into slow revolution, and the coal which is deposited at the mouth of the furnace is gradually carried forward by the motion of the chains, which act like an endless web. The clinkers and ashes left after the combustion of the coal, are precipitated into the ash-pit, where the chain turns down over the roller at the extremity of the furnace. In Messrs. Maudslays' plan of a self-feeding furnace the fire bars are formed of round tubes, and are placed transversely across the furnace. The ends of the bars gear into endless screws running the whole length of the furnace, whereby motion is given to the bars, and the coal is thus carried gradually forward. It is very doubtful whether any of these contrivances satisfy all the conditions required in a plan for feeding furnaces of the ordinary form by self-acting means, but the problem of providing a suitable contrivance, does not seem difficult of accomplishment, and will no doubt be effected under adequate temptation.

164. *Q.*—Have not many plans been already contrived which consume the smoke of furnaces very effectually?

A.—Yes, many plans; and besides those already mentioned there are Hall's, Coupland's, Godson's, Robinson's, Stevens's, Hazeldine's, Inche's, Bristow and Attwood's, and a great number of others. One plan, which promises well, consists in making the flame descend through the fire bars, and the fire bars are formed of tubes set on an incline and filled with water, which water will circulate with a rapidity proportionate to the intensity of the heat. After all, however, the best remedy for smoke appears to consist in removing from it those portions which form the smoke before the coal is brought into use. Many valuable products may be got from the coal by subjecting it to this treatment; and the residuum will be more valuable than before for the production of steam.

STEAM.

165. *Q.*—Have experiments been made to determine the elasticity of steam at different temperatures?

A.—Yes; very careful experiments. The following rule expresses the results obtained by Mr. Southern:—To the given temperature in degrees of Fahrenheit add 51·3 degrees; from the logarithm of the sum, subtract the logarithm of 135·767, which is 2·1327940; multiply the remainder by 5·13, and to the natural number answering to the sum, add the constant fraction ·1, which will give the elastic force in inches of mercury. If the elastic force be known, and it is wanted to determine the corresponding temperature, the rule must be modified thus:—From the elastic force, in inches of mercury, subtract the decimal ·1, divide the logarithm of the remainder by 5·13, and to the quotient add the logarithm 2·1327940; find the natural number answering to the sum, and subtract therefrom the constant 51·3; the remainder will be the temperature sought. The

French Academy, and the Franklin Institute, have repeated Mr. Southern's experiments on a larger scale; the results obtained by them are not widely different, and are perhaps nearer the truth, but Mr. Southern's results are generally adopted by engineers, as sufficiently accurate for practical purposes.

166. *Q.*—Have not some superior experiments upon this subject been lately made in France?

A.—Yes, the experiments of M. Regnault upon this subject have been very elaborate and very carefully conducted, and the results are probably more accurate than have been heretofore obtained. Nevertheless, it is questionable how far it is advisable to disturb the rules of Watt and Southern, with which the practice of engineers is very much identified, for the sake of emendations which are not of such magnitude as to influence materially the practical result. M. Regnault has shown that the total amount of heat, existing in a given weight of steam, increases slightly with the pressure, so that the sum of the latent and sensible heats do not form a constant quantity. Thus, in steam of the atmospheric pressure, or with 14·7 lbs. upon the square inch, the sensible heat of the steam is 212 degrees, the latent heat 966·6 degrees, and the sum of the latent and sensible heats 1178·6 degrees; whereas in steam of 90 pounds upon the square inch the sensible heat is 320·2 degrees, the latent heat 891·4 degrees, and the sum of the latent and sensible heats 1211·0 degrees. There is, therefore, 33 degrees less of heat in any given weight of water, raised into steam of the atmospheric pressure, than if raised into steam of 90 lbs.* pressure.

167. *Q.*—What expansion does water undergo in its conversion into steam?

A.—A cubic inch of water makes about a cubic foot of steam of the atmospheric pressure.

168. *Q.*—And how much at a higher pressure?

A.—That depends upon what the pressure is. But the proportion is easily ascertained, for the pressure and the bulk of a

* A table containing the results arrived at by M. Regnault is given in the Key.

given quantity of steam, as of air or any other elastic fluid, are always inversely proportional to one another. Thus if a cubic inch of water makes a cubic foot of steam, with the pressure of one atmosphere, it will make half a cubic foot with the pressure of two atmospheres, a third of a cubic foot with the pressure of three atmospheres, and so on in all other proportions. High pressure steam indeed is just low pressure steam forced into a less space, and the pressure will always be great in the proportion in which the space is contracted.

169. *Q.*—If this be so, the quantity of heat in a given weight of steam must be nearly the same, whether the steam is high or low pressure?

A.—Yes; the heat in steam is nearly a constant quantity, at all pressures, but not so precisely. Steam to which an additional quantity of heat has been imparted after leaving the boiler, or as it is called "surcharged steam," comes under a different law, for the elasticity of such steam may be increased without any addition being made to its weight; but surcharged steam is not at present employed for working engines, and it may therefore be considered in practice that a pound of steam contains very nearly the same quantity of heat at all pressures.

170. *Q.*—Does not the quantity of heat in any body vary with the temperature?

A.—Other circumstances remaining the same the quantity of heat in a body increases with the temperatures.

171. *Q.*—And is not high pressure steam hotter than low pressure steam?

A.—Yes, the temperature of steam rises with the pressure.

172. *Q.*—How then comes it, that there is the same quantity of heat in the same weight of high and low pressure steam, when the high pressure steam has the highest temperature?

A.—Because although the temperature or sensible heat rises with the pressure, the latent heat becomes less in about the same proportion. And as has been already explained, the latent and sensible heats taken together make up nearly the same amount at all temperatures; but the amount is somewhat greater at the higher temperatures. As a damp sponge becomes wet when subjected to pressure, so warm vapor becomes hot when forced into less bulk, but in neither case does the quantity of moisture or the quantity of heat sustain any alteration. Common air becomes so hot by compression that tinder may be inflamed by it, as is seen in the instrument for producing instantaneous light by suddenly forcing air into a syringe.

173. *Q.*—What law is followed by surcharged steam on the application of heat?

A.—The same as that followed by air, in which the increments in volume are very nearly in the same proportion as the increments in temperature; and the increment in volume for each degree of increased temperature is $\frac{1}{490}$th part of the volume at 32°. A volume of air which, at the temperature of 32°, occupies 100 cubic feet, will at 212° fill a space of 136·73 cubic feet. The volume which air or steam—out of contact with water—of a given temperature acquires by being heated to a higher temperature, the pressure remaining the same, may be found by the following rule:—To each of the temperatures before and after expansion, add the constant number 458: divide the greater sum by the less, and multiply the quotient by the volume at the lower temperature; the product will give the expanded volume.

174. *Q.*—If the relative volumes of steam and water are known, is it possible to tell the quantity of water which should be supplied to a boiler, when the quantity of steam expended is specified?

A.—Yes; at the atmospheric pressure, about a cubic inch of water has to be supplied to the boiler for every cubic foot of steam abstracted; at other pressures, the relative bulk of water and steam may be determined as follows:—To the temperature of steam in degrees of Fahrenheit, add the constant number 458, multiply the sum by 37·3, and divide the product by the elastic force of the steam in pounds per square inch; the quotient will give the volume required.

175. *Q.*—Will this rule give the proper dimensions of the pump for feeding the boiler with water?

A.—No; it is necessary in practice that the feed pump should be able to supply the boiler with a much larger quantity of water than what is indicated by these proportions, from the risk of leaks, priming, or other disarrangements, and the feed pump is usually made capable of raising $3\frac{1}{2}$ times the water evaporated by the boiler. About $\frac{1}{240}$th of the capacity of the cylinder answers very well for the capacity of the feed pump in the case of low pressure engines, supposing the cylinder to be double acting, and the pump single acting; but it is better to exceed this size.

176. *Q.*—Is this rule for the size of the feed pump applicable to the case of high pressure engines?

A.—Clearly not; for since a cylinder full of high pressure steam, contains more water than the same cylinder full of low pressure steam, the size of the feed must vary in the same proportion as the density of the steam. In all pumps a good deal of the effect is lost from the imperfect action of the valves; and in engines travelling at a high rate of speed, in particular, a large part of the water is apt to return through the suction valve of the pump, especially if much lift be permitted to that valve. In steam vessels moreover, where the boiler is fed with salt water, and where a certain quantity of supersalted water has to be blown out of the boiler from time to time, to prevent the water from reaching too high a degree of concentration, the feed pump requires to be of additional size to supply the extra quantity of water thus rendered necessary. When the feed water is boiling or very hot, as in some engines is the case, the feed pump will not draw from a depth, and will altogether act less efficiently, so that an extra size of pump has to be provided in consequence. These and other considerations which might be mentioned, show the propriety of making the feed pump very much larger than theory requires. The proper proportions of pumps, however, forms part of a subsequent chapter.