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CHAPTER XXIX.

THE SUPPLY OF POWER.

(1) Producing the Steam.

Introductory.—The production of power for driving the mills forms no inconsiderable part of the cost of steel. The amount of fuel burnt under the boilers is generally more than is used for melting, and much more than is used for reheating.

In an iron works the steam required for driving the engines can usually be raised from the waste heat escaping from the puddling and mill furnaces, so that there is little inducement to use steam economically. But, in a steel works, as neither the Bessemer nor Siemens processes give out any waste heat which can be profitably employed for steam raising, the boilers must be heated by coal, except in those cases where boilers are attached to reheating furnaces, and can use their waste heat; but as these, in any case, can supply only a small proportion of the requisite steam, economy in its use becomes a matter of importance. Yet even now little attention is paid, in many works, to the preventable waste due to the continued use of low pressures of steam, and the omission to superheat it, to condense it after use, or to treat and heat the feed-water, &c.

In an electric lighting station, where the bill for boiler fuel is about half the amount of the sales, such neglect would be fatal. And though this proportion is far less in a steel works, nevertheless the manager should have a sound knowledge of what conduces to economy in the production of power. Therefore, although space forbids a full treatment, it seems desirable to give at least an outline of the subject in a work dealing with the manufacture of steel.

Sources of Heat.—Generally the power required for driving the mills is obtained from steam engines. A limited portion of the steam used by them is sometimes supplied by boilers heated by the waste gases from reheating furnaces, and usually spoken of as "furnace-fired boilers"; but much the larger portion, often the whole, has to be raised in a battery of boilers, directly heated by coal. These boilers are called by the workmen "coal-fired" or "hand-fired boilers" (even though some form of mechanical stoker be employed), in contradistinction to those heated by the waste gases.

Spare gas, which will burn under the boilers, can sometimes be obtained from the blast furnaces, when these are near the steel works; but where such gas is available it is now more often burnt directly in the cylinders of gas engines, to generate electric current, which is used for lighting, for driving the auxiliary machinery, or even, in some cases, for driving the mills themselves. This method of obtaining and using power will be treated in Chapter xxxi.

The generation of power by steam falls naturally under three heads—(1) the fuel which provides the heat; (2) the boilers, with their accessories, which furnish the steam; and (3) the engines, with their accessories, which utilise the steam when formed. The efficiency of any of these may differ widely, and such variations will affect the fuel bill.

Quality of Fuel.—As a rule, the quality of fuel is not within the control of the mill manager, who has to use what local circumstances dictate. The best large coal got in the mines fetches high prices for household use, or for the manufacture of illuminating gas, and the mills have to put up with the residue, consisting of slack of varying degrees of fineness, which makes much more ash than the large coal. Coal in pieces of uniform size is required at the gas producers, if good gas is to be made, but boilers are much less dependant on the size and uniformity of the fuel.

Where there is an opportunity for choice, it is best to select for boiler purposes, other things being equal, those coals which contain the smallest proportion of volatile and tarry matters. A coal rich in these matters is most suitable for use in a gas producer, as it affords that rich "fat" gas, burning with a long flame of high radiating power, which is fairly consumed when surrounded by walls of incandescent firebrick. But when such a gas is burnt in contact with, or in close proximity to, the comparatively cold surface of a boiler, combustion is checked and becomes very imperfect; consequently a great excess of cold air must usually be admitted, or a considerable proportion of the Hydrocarbons will escape unconsumed, and much of the CO will pass away without being burnt to CO_2. Usually the problem is, in a heating furnace, to lengthen out sufficiently the space within which combustion remains active, and in a boiler furnace to shorten it so that combustion is completed close to the grate, and burning gases may not meet the cool boiler surface.

The power of a cold surface to retard combustion in a mixture of gas and air is shown when a piece of wire gauze is lowered on to the flame of a Bunsen burner. So much of the mixture as is below the gauze will continue to burn freely. But what passes through it, although it has actually traversed the flame, is so cooled by its subsequent passage through the gauze that it will not burn until a light is applied on the upper side, when that part also will ignite and continue burning. The miners' safety lamp, invented by Sir Humphrey Davy, makes use of the fact that combustion in a gas flame may be entirely extinguished by cooling it; even when the inflammable mixture is burning within the gauze chimney of the lamp, the flame will not pass through it to fire the explosive mixture outside.

The percentage of fixed Carbon in the coal of a district may vary considerably, but the British coals may be roughly classed according to their content of fixed Carbon as follows:—

South Staffordshire coals, .	40 to 50	per cent. of fixed Carbon.
Durham and Lancashire, . .	50 to 60	,, ,,
Newcastle, ...	60 to 70	,, ,,
South Wales steam coals, .	70 to 80	,, ,,
Anthracite, ...	75 to 90	,, ,,

Their respective values as boiler fuels are in this order, and bear a close relation to the quantity of fixed Carbon they contain.

The percentage of ash and earthy matters is always highest in the finest slacks, which contain much of the dirt from the floor of the mine. The ash is light and powdery, unless the coal contains sufficient alkaline matters to fuse the ash into a hard clinker, the removal of which adds greatly to the labour of the firemen, and the wear and tear of the firebars. Its presence produces irregular and incomplete combustion, and, therefore, necessitates frequent cleaning of the fires. The opening of the fire-doors to enable this to be accomplished means the admission of much cold air, which greatly increases the wear and tear of the boilers.

Firegrates.—The object of the grate is to support the fuel in such a way that the air required for combustion can find its way through the mass of coal with tolerable regularity. The bars must be sufficiently close together to prevent small coal falling through before it is consumed, and yet provide a sufficient proportion of openings, compared with the solid bar, to allow enough air to enter. They must be of such form as to be readily cleaned, particularly if the coal forms much clinker, and must not be easily broken during cleaning, nor distorted by heating.

Given these conditions, minor details are of no consequence, though enthusiasts would appear to doubt this, seeing how new patterns are being continually patented for which remarkable economy of fuel is expected or claimed.

On the contrary, the manner in which the coal is charged on to the grate is a matter of great importance. The best thickness of fire varies with the class of coal used and its size, and one fireman will get a good deal more work out of his coal than another by watching this point, and by firing at regular intervals.

When raw coal is thrown on to a hot fire, consisting of partially coked incandescent coal, from which the volatile matters have mostly been driven off, large volumes of smoky gas are formed immediately, which require much more air for combustion than does the partially coked coal on which it is laid. The problem is to supply above the fuel, just at this instant, a sufficient supply of air, which ought to be highly heated, to secure the combustion of these gases, without admitting such an excess as unduly to cool the products of combustion later on when the gas has been driven off. Adjustable openings through the furnace door, or near the bridge, are often provided, but the firemen can rarely be got to use them—in many cases they really have not the time to spare for such refinements—and the use of the Prideaux fire door, fitted with louvres, which were opened wide by the act of opening the door, and automatically closed slowly against a cataract cylinder, has been abandoned as too complicated for ordinary use. Moreover, the air admitted was unheated.

In 1868 Frisbie devised a means of charging the fuel from below, so that any gases distilled off had to pass through the incandescent coke above, but the wear and tear were excessive. This principle is now being applied in other forms, which provide a continuous instead of an intermittent supply of fuel, a necessary condition for complete combustion where the air supply is constant.

Mechanical Stokers.—The simplest way of securing exactly the requisite amount of air for complete combustion is to retain the air supply constant, and to supply the coal continuously. Many mechanical stokers have been provided which do this, and there is no doubt that appreciable economy of fuel is obtainable by their use. They avoid the necessity for opening periodically a large fire door, through which to throw the fuel by hand, admitting at the same time large volumes of cold air, which cool down the furnace and damage the boiler. The drawback to many of them is that the cost of maintaining the machinery goes far to offset the reduction they effect in the coal bill.

Different kinds of stokers suit different kinds of coal, perhaps the simplest form of mechanical stoker, and the most effectual for most coals, is the Chain grate, which is shown as fitted to the Stirling boiler (fig. 421). The firebars form a slowly travelling band moving continually forward. A continuous stream of coal from the hopper falls on to the outer end of the grate, and the gas driven off from the raw coal at this end passes below the incandescent fire-brick arch of the furnace, over the incandescent coke at the inner end, where, the fire being thinner, an excess of air, raised to a very high temperature in its passage through the coke, meets the gas and effects very complete combustion of all volatile matters. The ash remaining after the combustion of the coke falls off the inner end of the travelling grate into the ashpit, whence it can be withdrawn when necessary.

Gas-fired Boilers.—Where there is enough gas at the blast furnaces to spare any for use at the steel works boilers, they are often fired with it.

Experiments made by Mr. Joseph H. Harrison, M.Inst. C.E., of Middlesbrough, on a Babcock & Wilcox boiler, under ordinary every-day working conditions, showed that 1,000 cubic feet of such gas, of fair average quality (the volume being reckoned at the standard temperature of 32° F.), will evaporate 1 cubic foot (62·4 lbs.) of water supplied at 178° F. The gas was taken direct from the furnace, uncleaned, and containing its initial sensible heat, which represented 6 per cent. of the total available heating power of the gas above 32° F., 60 per cent. of the heating power of the gas being transferred to the water in the boiler.

This figure will be taken later, when comparing the performance of gas engines and steam engines, each driven by gas from the blast furnace, although, owing to defective design, many boilers now working consume 10 to 30 per cent. more gas than these experiments show to be necessary if reasonable care is used.

Analysis of Flue Gases.—The test of the perfection of the combustion is the proportion of CO_2 found in the waste gases. If it were possible to limit the supply of air to that theoretically required for perfect combustion, the CO_2 would generally be about 21 per cent. of the whole, but owing to the admission of an undue supply at the grate, or to leakage through the brickwork, it is often only one-third or one-fourth of this amount. Instruments of a practicable form are now obtainable which will give, automatically, a continuous record of the percentage of CO_2 present, which, with care, can be maintained at an average of 13 per cent., and sometimes higher, with considerable saving in the quantity of fuel consumed.

Chemical Treatment of Feed Water.—If the mill manager has little chance of selecting his coal, he usually has none at all of choosing his water. Near the sea it is often salt, or at least brackish, and most of the canal water in the English Midlands is loaded with salts or acids, and so are the waters pumped from most mines. All these directly corrode the boiler.

Where water is drawn from limestone or chalk formations it is excessively hard, and unless softened, forms a heavy scale, which is a bad conductor of heat. This not only increases the consumption of coal, but, by causing overheating, adds seriously to the wear and tear of the boilers. On the other hand, waters are occasionally met with which are so soft that lime must be added to them, or rapid pitting of plates and tubes will ensue. There are also some alkaline waters which are most objectionable.

Waters vary so much from each other that a long treatise would fail to say how everyone should be dealt with so as to render them really suitable for boiler purposes. But one thing that can be said is, that no one of the much-vaunted nostrums, sold under various fancy names as boiler compositions, can possibly be applicable to every case, while some of them are absolutely harmful, as they dissolve not only the scale but the boiler as well.

The only suitable course to pursue is to have careful analyses made of the water from time to time, to obtain the advice of a chemist skilled in the subject, and to be careful to adhere to the quantities of the reagents he advises should be added. While limewater, added in the correct quantity, may be most effectual, an excess will often produce results much worse than when none at all is added; an excess of caustic soda will attack the brass fittings on the boilers, while this and other soda salts, if present in excess, cause frothing and priming.

Water Softeners.—These are appliances for softening hard or neutralising acid waters, and for precipitating the various matters held in solution before allowing the feed-water to enter the boiler. Such matters are bad conductors of heat, and, if deposited on the heating surface, reduce its efficiency, and lead to overheating of the plates or tubes, whose life is thereby shortened.

It is not possible to give exact figures as to the increase in consumption of fuel entailed by a given thickness of scale—it is certainly appreciable—but a very short experience with boilers is sufficient to contradict the exaggerations on this point sometimes indulged in by advocates of questionable remedies intended to prevent its formation. In any case, the prevention of scale should be regarded rather as a means of preserving the boiler than of saving the fuel, and it is better to treat water outside than inside a boiler.

The most objectionable form of scale is a light flocculent one, which does far more harm than a thin hard one, which occasionally does not seem to be a very bad conductor of heat, and has so little detrimental effect in this direction that occasionally it is deliberately produced, when a new boiler is first started, in order to prevent pitting, which is liable to occur when some very soft waters are employed.

The essential parts of a water softener are (1) an appliance for adding definite quantities of the requisite chemical solutions to the water to be purified, generally consisting of tumbling tanks or small water wheels. The amount added is directly proportional to the speed of their movement, and this speed depends upon the rapidity with which the water flows in. (2) A settling tank, or tanks, of sufficient capacity to allow the bulk of the precipitates to be deposited before the water leaves them. (3) Filters filled with sawdust, wood shavings, vegetable fibre, or other suitable material, to hold back the remainder, so that nothing but clear water shall pass to the boilers. Sometimes the water has to be heated; in other cases the reactions will take place in the cold.

Feed-heating.—Whatever number of units of heat can be imparted to the feed water outside the boiler, just so many less have to be supplied from the fuel to the water when inside the boiler. The following table shows what percentage of heat may be saved by heating the feed to various points, with steam of different pressures in the boiler :—

TABLE CXI.—Percentage of Saving obtained for each Fahr. Degree Increase in Temperature of Feed Water.

Initial Temperature of Feed.	Lbs. Pressure in the Boiler per Square Inch above the Atmosphere.										
	0	20	40	60	80	100	120	140	160	180	200
32°	·0872	·0861	·0855	·0851	·0847	·0844	·0841	·0839	·0837	·0835	·0833
40°	·0878	·0867	·0861	·0856	·0853	·0850	·0847	·0845	·0843	·0841	·0839
50°	.0886	·0875	·0868	·0864	·0860	·0857	·0854	·0852	·0850	·0848	·0846
60°	·0894	·0883	·0876	·0872	·0867	·0864	·0862	·0859	·0856	·0855	·0853
70°	·0902	·0890	·0884	·0879	·0875	·0872	·0869	·0867	·0864	·0862	·0860
80°	·0910	·0898	·0891	·0887	·0883	·0879	·0877	·0874	·0772	·0870	·0868
90°	·0919	·0907	·0900	·0895	·0888	·0887	·0884	·0883	·0879	·0877	·0875
100°	·0927	·0915	·0908	·0903	·0899	·0895	·0892	·0890	·0887	·0885	·0883
110°	·0936	·0923	·0916	·0911	·0907	·0903	·0900	·0898	·0895	·0893	·0891
120°	·0945	·0932	·0925	·0919	·0915	·0911	·0908	·0906	·0903	·0901	·0899
130°	·0954	·0941	·0934	·0928	·0924	·0920	·0917	·0914	·0912	·0909	·0907
140°	·0963	·0950	·0943	·0937	·0932	·0929	·0925	·0923	·0920	·0918	·0916
150°	·0973	·0959	·0951	·0946	·0941	·0937	·0934	·0931	·0929	·0926	·0924
160°	·0982	·0968	·0961	·0955	·0950	·0946	·0943	·0940	·0937	·0935	·0933
170°	·0992	·0978	·0970	·0964	·0959	·0955	·0952	·0949	·0946	·0944	·0941
180°	·1002	·0988	·0981	·0973	·0969	·0965	·0961	·0958	·0955	·0953	·0951
190°	·1012	·0998	·0989	·0983	·0978	·0974	·0971	·0968	·0964	·0962	·0960
200°	·1022	·1008	·0999	·0993	·0988	·0984	·0980	·0977	·0974	·0972	·0969
210°	·1033	·1018	·1009	·1003	·0998	·0994	·0990	·0987	·0984	·0981	·0979
220°		·1029	·1019	·1013	·1008	·1004	·1000	·0997	·0994	·0991	·0989
230°		·1039	·1031	·1024	·1018	·1012	·1010	·1007	·1003	·1001	·0999
240°		·1050	·1041	·1034	·1029	·1024	·1020	·1017	·1014	·1011	·1009
250°		·1062	·1052	·1045	·1040	·1035	·1031	·1027	·1025	·1022	·1019

As circulation is much less interfered with when the feed water is of approximately the same temperature as the water in the boilers, they steam much more freely when supplied with hot feed, and are relieved from the strains which would be induced by injecting cold water. The saving in fuel effected is as great, and often greater than can be accounted for by calculation, a condition of affairs unapproachable in the case of any other form of heat saving appliance.

Economisers.—The economy due to a hot feed is only obtained when the heat imparted to the water is such as would otherwise be lost. In the case of non-condensing engines, exhausting to the atmosphere through a feed-heater, the exhaust steam can never be appreciably hotter than 212° F., consequently the feed cannot reach the boiler at over 200° F., and it is usually nearer 150° F. With condensers or exhaust turbines, this exhaust steam can be used to much greater advantage, and the better method of heating the feed is by means of the waste gases on their way to the chimney after passing the boiler.

The temperature of the water in the boiler is from 300° to 400° F., and the waste gases must always be appreciably hotter, generally 600° or 700° F., so that by arranging for the gases and the water to flow in opposite directions, the feed can be raised to 200° or even 250° F. without interfering with the working of the boilers, provided the chimney is large enough and high enough to secure the requisite draught, with a temperature of 300° or 400° F. Practically the only appliance used for the purpose is the familiar Green's economiser (fig. 419), which consists of a series of vertical cast-iron pipes, 4 inches

internal diameter, up and down which scrapers are kept continually moving to remove the soot, which, being a non-conductor, would soon seriously reduce the transfer of heat. The economiser is not suitable for untreated waters high in lime, as the lime is rapidly deposited in the tubes in the form of a hard scale, and the pipes have to be frequently drilled to get rid of it.

Boilers.—New forms of boilers are constantly being devised, for which their inventors claim exceptional economy of fuel, but the exhaustive experiments of Bryan Donkin and others have made it clear that there is practically no difference in this respect between one form of boiler and another, when all are worked under similar conditions. Safety, simplicity, durability, and accessibility for cleaning, examination, and repairs are the points to which attention should be directed, and, provided the heating surface is sufficient and the circulation not impeded, the economy will look after itself.

The Lancashire boiler, which consists of a horizontal rivetted shell, 7 to 9 feet in diameter by 28 to 30 feet long, through which pass two, or rarely three, horizontal flues, in which the fire-grates are situated, is too well known

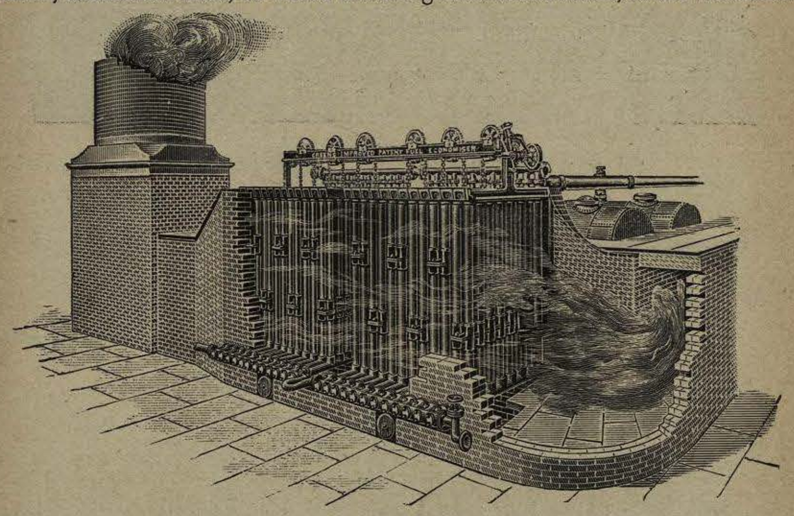

Fig. 419.—Green's Modern Economiser.

to need description. It has one advantage; it contains a large volume of water, which forms an excellent reservoir of heat, and so equalises the pressure that steam is not blown to waste through the safety valves, directly the engines are stopped; and similarly it will continue to supply steam during periods of heavy demand, without the pressure falling as much as in boilers which contain a smaller volume of water.

The disadvantages are the restricted space above the fire-grate, which necessitates the burning gases coming in contact with the boiler surface before combustion is completed; and the wear and tear with the high pressure now becoming common.

On these accounts boilers formed mainly of tubes filled with water, and placed either approximately horizontally, as in the well-known Babcock & Wilcox boiler (fig. 420), or nearly vertically, as in the Stirling boiler (fig. 421), are now being installed in increasing numbers. The failure of a tube, which is easily replaced, in a boiler of these newer types, is a small matter compared with the bursting of a shell or the collapse of a flue in a Lancashire boiler.

It is also possible to provide in these newer boilers much more ample space for combustion above the grate, and so ensure that the gases are more completely burnt before they strike the boiler surface.

Incidentally, also, the heating surface in boilers of this type is commonly from 30 to 45, often 50, times as much as the area of the grate, whereas in

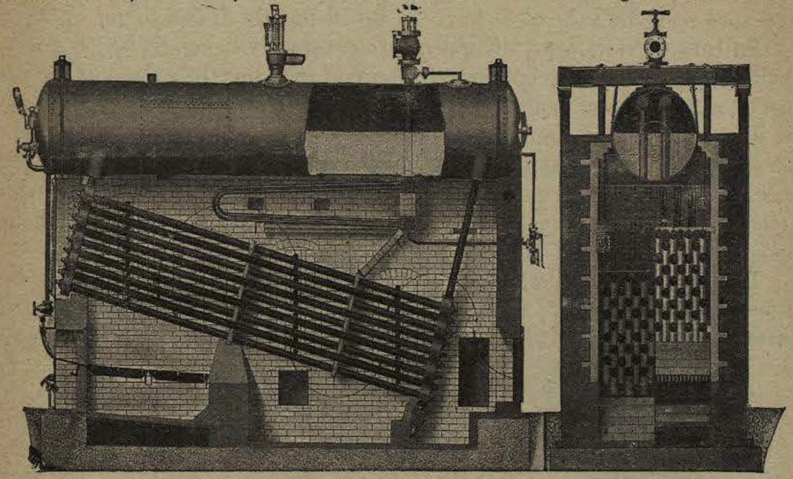

Fig. 420.—Babcock & Wilcox Boiler, with Superheater.

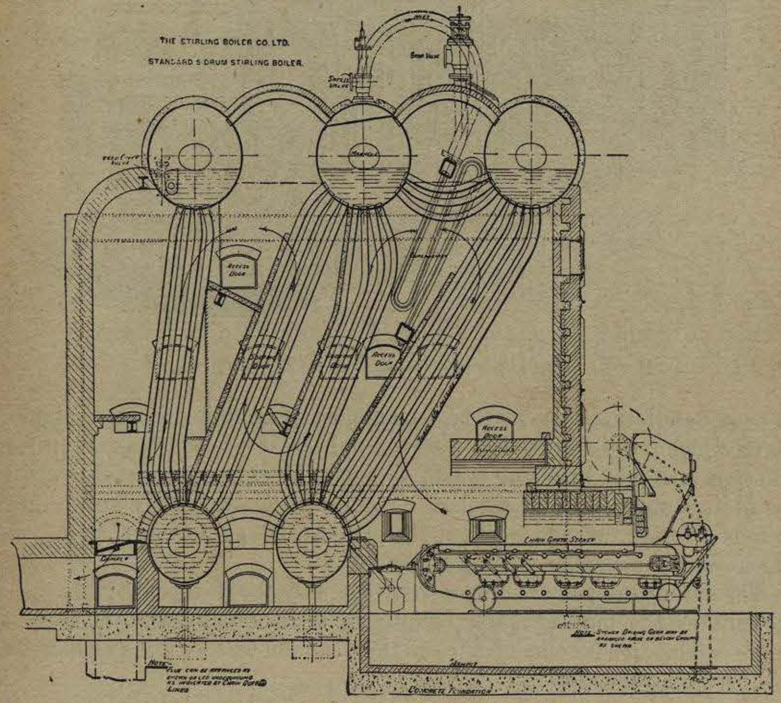

Fig. 421.—Stirling Boiler, with Superheater and Chain Grate.

a Lancashire boiler the proportion allowed is only half as much. Consequently, it is easier to obtain an efficiency of 70 per cent. with the tube boilers than 60 per cent. with boilers of the Lancashire type, as usually constructed. With Welsh steam coals the latter can be made to give much the same results, provided the fire-grate area is restricted, but this involves employing more

boilers to do the same work, with the additional first cost and expenses involved by the extra plant.

Superheating.—The space above the water level in a steam boiler is filled with steam given off by the heated water, the pressure of the steam increasing with the rise in temperature of the water. But, if this steam be removed from contact with the water, and heated in a separate vessel, outside of, but in free communication with, the steam space of the boiler, the temperature of the steam may be raised indefinitely, although its pressure may remain the same as it was when formed originally in the boiler. A given weight of the steam will then contain a greater quantity of heat, and is, therefore, capable of doing a greater quantity of work. Of the heat utilised in the boiler, the larger portion (from about $\frac{3}{4}$ to $\frac{2}{3}$, according to the pressure of the steam) was used in changing the water from the liquid to the gaseous state, but when the steam is once formed, any additional heat gives it so much additional power to perform work. This explains, broadly, why superheating the steam conduces to economy. Moreover, it sometimes is more convenient to increase the heat than the pressure of the steam.

Superheaters consist of bundles of solid-drawn steel tubes, through which the steam passes on its way between the boiler and the engine, the products of combustion flowing around them. The gases and the dry steam are such poor conductors of heat, that the tubes should be near enough to the grate for the temperature of the gases to be between 900° to 1,200° F., or the amount of surface will be excessive. The group of small tubes shown in the upper part of the boilers (figs. 420 and 421) are the superheaters.

The specific heat of dry steam is generally taken to be 0·48, so that every degree of heat imparted to it should be, theoretically, rather less than half as effective, as the same increase of temperature imparted to the feed water. This result is not obtained in practice, nor can the temperature be raised by what would otherwise be lost heat, as is possible with the feed water, and therefore some fuel must be expended for the purpose. Experience shows that condensing non-compound reciprocating engines, which lose heavily by the initial condensation caused by the alternate heating and cooling each time the direction of travel of the piston is reversed, benefit most by the superheating of the steam, and that the first 40° or 50° F. of superheat are considerably more effectual in reducing consumption than any equal increment of heat afterwards. Steam turbines, in which the direction of flow is always in one direction, are less benefited.

The following list showing the saving effected by superheating is taken from an article by Mr. R. M. Neilson* :—

TABLE CXII.—Saving due to Superheating.

Turbines.

Degrees of Superheat, Fahr., ...	13	50	70	100	150	200	260
Percentage reduction in consumption of steam,	6·1	8·0	9·5	14	19	23	24·5

Piston Engines.

Degrees of Superheat, Fahr., ...	30	40	50	100	150	225
Percentage reduction in consumption of steam, .	7·8	8·65	12	20·5	23	33

* *The Engineering Magazine*, vol. xxxix., p. 81, April, 1905.

The exact saving depends also upon the size and type of engine, and the pressure of the steam. The following figures are given by various makers of engines and superheaters :—

Degrees of Superheat, Fahr.	Percentage Reduction in Consumption of Steam.			
	A.	B.	C.	D.
50	6–8	8	8	...
100	12–16	14	14·5	...
150	16–18	22	21·5	21–25
200	22 25	26	26·5	33
250	...	30	31·5	...
300	...	34	34·5	...

The above are the savings in weight of steam used by the engines under test conditions, and take no account of the additional fuel used to superheat the steam; they are not, therefore, realised in practice. The loss by radiation from the steam pipes also increases with the rise in temperature, but the practical advantages of supplying engines with thoroughly dried steam more than offset any loss on this account, if the pipes are reasonably protected by non-conducting composition. It is doubtful if the increased wear and tear of the engine ever justifies the use of high superheat in a steel works. Where ordinary valves are employed, probably 50° F. superheat, by the time the steam reaches the engine, is as much as can be profitably employed, and with specially designed engines 150° F., corresponding to a maximum temperature of about 500° F., is as much as can be recommended. Beyond this point troubles increase very fast.

Economy due to Increased Boiler Pressures.—The quantity of fuel needed to convert a given quantity of water into steam at a high pressure is very little more than that required to do so when the steam is formed at a low pressure, owing to the very small amount of additional heat required to raise the pressure of steam when once it is formed. If the amount of heat needed to convert a certain weight of water into steam of 30 lbs. pressure per square inch above the atmosphere is taken as unity, the amount necessary to raise it to the higher pressures commonly used can be found by reference to the annexed Table.

TABLE CXIII.—Relative Heat consumed in raising Steam at Various Pressures.

1 Boiler Pressure in Lbs. per Square Inch above Atmosphere.	2 Comparative Number of Units of Heat Absorbed in Raising Steam at this Pressure.
30	1·0000
60	1·0087
90	1·0148
120	1·0198
150	1·0244
175	1·0272
200	1·0295
250	1·0337

The pressure employed has been steadily rising year by year until to-day it is rarely under 100 lbs., while 150 lbs. is the pressure most often adopted in this country for new plants, and on the Continent, where fuel is dearer, 180 is frequently used. Some plants in this country are now working at 200 lbs., and it is quite probable that even higher pressures will soon be employed.

Given efficient boilers wherewith to generate steam, an increase in the steam pressure is the easiest means available if economy of fuel is the object in view. It must be remembered, however, that every increase in pressure carries with it an increase in the first cost and upkeep of the boilers and their accessories, a source of expenditure which may easily surpass any saving effected in fuel. Considerable judgment is needed to decide what is on the whole the pressure most economical in any particular district. The pressure attained, may, however, be expended, economically or extravagantly, according as the engines employed are or are not of suitable size and construction for the work they have to perform, the consumption of steam at any pressure, by different engines, varying within very wide limits. Important as is the influence of the engine on the economy obtainable, it is only possible in the space available in this work to give the barest outline of this question.

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