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"FEED-WATER HEATERS."

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READ AT

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When James Watt condensed the steam coming from the cylinder of his engine and pumped the condensed steam and water into the boiler he heated the feed-water. In the ordinary surface condenser the condensed steam which is pumped back into the boiler is of much higher temperature than the ordinary temperature of water, and here also the feed-water is heated. In these cases the ostensible object is to save the heat in the steam which would otherwise be thrown away. When Mr. Weir takes steam from the intermediate receiver, or when others heat the feed-water by exhausting through the heater, they are really trying to save the heat in the steam which would otherwise be lost, or partially lost, in a more efficient way than by further expansion. Later the boiler came to be considered too. It was seen that in the case of the boiler the facts of the case were, gases formed at high temperature in the furnace, delivering up their heat on the way to the chimney which they reached at low temperature. It was seen that one way to increase economy was to lower the chimney temperature still further, and Mr. Green did this by placing between the boiler and the chimney a series of pipes through which the water circulated on its way to the boiler, and so the temperature of the feed-water was increased. This was a method of heating which applied to the boiler alone, and could go on though there were no engine. Next the feed-water was heated by steam taken directly from the boiler. Formerly the economy of heaters was thought to depend on the saving of heat which was going to waste; now it is seen to be due to more than that. Under the old assumption it was thought that one could calculate exactly how much heat had been saved. It was thought the heat saved was equal to the heat gained by the water in the boiler. Now it is known that assumption does not contain the whole matter. If heat which is rejected by the engine or boiler is used for heating the feed it is not exact to say that the heat saved is gained by the feed-water. There is more heat gained than that. The water in the boiler is put in better form for receiving heat from the hot gases circulating through it, and it does absorb more heat than it would were the feed-water not heated. This quantity of heat gained by the water is quite independent of that which the feed-water has taken in.

The most primitive form of feed-heater is that which is placed in the flue between the boiler and the chimney. The principle applied in it is simply to extract more heat out of the gases before they are finally discharged into the chimney. The heater is in the form of a series of tubes through which the water circulates before it reaches the boiler; the rate at which the water moves through the tubes is the rate at which it is supplied to the boiler. The heaters of this kind are Sir Edward Green's economiser, Mr. Mumford's, John Penn and Son's, and Mr. Yarrow's new arrangement of boiler. Sir Edward Green's economiser on the average reduces the temperature of the hot gases from about 650° on the boiler side of the economiser to about 350° Fah. on the chimney side. The water goes into the boiler at a temperature of about 200°. The Druitt Halpin system is to heat the water during the day and store it in a tank, drawing as feed-water from the tank in the evening when the lighting engines are in work. Mr. Yarrow's is much the same in principle. Three of the back rows of tubes of his boiler are used as feed-heaters, but the temperature of the gases is lowered after they have come past them, as in the case of the Green feed-heater. There is not anything extraordinary in it, since the feed-heating is done by the hot gases before they escape. Of the same class as this is the Belleville boiler. Here, instead of having as in the old pattern ten tubes to each element, there are now two boilers of seven tubes to each element in each boiler. The feed-water first circulates through the top boiler which is heated with the waste gases coming from the first boiler. This is the feed-heater. The second is heated directly by the furnace gases and in the evaporator. Air is allowed to enter into the space between the water-heater and the evaporator, and it is possible that this space between the water-heater and the evaporator, acting as a combustion chamber, gives more perfect combustion and an increase of economy. Anyway, there is an increased economy with this later arrangement than in the first with lower temperature of the furnace gases.

Some three years ago the Mumford boilers with the tubes fitted in groups had a somewhat similar arrangement for the feed. The old Mumford boiler was made up of four or five sections or bundles of tubes on each side with tubes parallel to the length of the boiler. There was a diaphragm fitted along the length of the boiler dividing the tubes into two parts lengthways for the guidance of the hot gases. The grate was between the two lower drums, and the hot gases went along circulating amongst the tubes on the inside of the diaphragm, and when they got to the back they turned and came to the front again. The coldest place of the gases was at the front, outside the diaphragm. Now just at the front, where the gases were coldest, a feed-water pipe was led into each of the two front vessels into which the two front bundles of tubes were expanded. This vessel was divided into two parts by a plate with a valve in it. The water was pumped into the space above the plate and valve and flowed up the outside tubes which had the colder gases circulating outside them. The feed-water thus got heated before it was allowed to partake of the general circulation of the water of the boiler. It was not observed that this arrangement produced any better effect, but the better effect may have existed without it being noticed, for careful experiments were not made with this boiler, as were made with Mr. Yarrow's. All these typical cases have to do with the feed-water being heated by means of the hot gases before they reach the chimney. But there is another way by which the water may be heated, and the aim was simply to save the heat in the rejected steam. That is heating by exhaust. Now in the jet condenser the steam is condensed by coming directly in contact with the water, and as the pressure is wanted there as low as possible, the temperature of the condensed water and steam cannot be high. It is not so high as is accounted desirable now, and in boilers of the best design this method is now discarded. To obtain high temperature of the feed-water Mr. Weir heats it by means of steam taken directly from the intermediate or low-pressure receiver. This feed-water heater is under control of the engineer more than are the economisers, which are fitted between the boiler and the chimney. In this heater the water is sprayed into a chamber and gets mixed with the steam and so becomes heated. It is then heated by direct contact with the steam, and as that steam is at considerable pressure the temperature of the feed may be very high. The Lundkvist is of the same kind as the Weir, but the steam and the water are kept separate, as in the live steam-heater. The fourth kind of heater is that which is made up of a number of tubes through which the feed-water is made to flow, while steam directly from the boiler quite independently from the engine circulates round them. Here it is a case of boiler only, and if there is economy it will be an economy of evaporation whether the engine be there or not. It is clear that there will be some loss of heat at the feed-water heater, and whatever economy is gained due to greater efficiency in the boiler itself will have to make up for the loss of the feed-water heater. Another feed-heater of this kind is the Babcock and Wilcox, but steam direct from the boiler is introduced into the heater, and the resulting temperature may be nearly equal to the temperature of the water in the boiler. We have then four systems of feed-heating: (1.) Feed-heating by exhaust; and it is possible that the heat saved from the exhaust does not measure the whole gain. (2.) Feed-heating by waste gases; and in this case the heat lost by the gases shows the entire gain because there is no place else that the heat can come from. (3.) Feed-heating by steam taken from the low pressure or intermediate receivers; and in this case, as in the first, the heat given to the water by the steam may not show the entire gain, because the temperatures of the waste gases have not been observed, and they may be lower with the feed-heater in action than without. (4.) Feed-heating with steam taken direct from the boiler; in this case the heat taken from the steam and sent back will show a loss. But the greater quantity of heat taken from the gases may compensate for this, and may be more than the loss. The gain, if any, will be the difference between the gain from the gases and the loss from the heater. With a heater which uses the waste gases for raising the temperature of the feed a considerable economy is effected. This is best shown by making a simple calculation with ordinary data. The data which I propose to take is that taken in an important article which appeared in the *Engineer* of April 16, 1886.

Take first the case of the feed coming from the hot well. This feed-water is usually delivered at a temperature of 120°. If the pressure of the steam in the boiler is 120 lb., each pound of steam carries in with it 1,220 thermal units, measuring from zero, of which 120 units come in with the feed-water, leaving 1,100 to be given by the furnace. So the relation which the feed brings in to the whole heat is $\frac{1220}{120} = 10$, or about 10 per cent. If the feed had been pumped in at the temperature of the sea, say about 50°, then the feed would have brought in $\frac{1220}{50} = 24$, or $\frac{1}{24}$th part, or about 4 per cent. of all the heat comes in with the feed. Were the feed raised to 212° then the fraction of the whole heat would be $\frac{1220}{212} = 5{\cdot}75$, or about 17 per cent. We see then that with feed-water at the temperature of the sea the percentage of heat brought in is about 4 per cent.; with hot well at a temperature of 120° it is about 10 per cent. With feed raised to 212° the gain is about 17 per cent., which gives a gain above the temperature of the sea of 13 per cent., and a gain above the temperature of the hot well of 7 per cent. Steam at a temperature of 120° has a pressure equal to the exhaust, and the feed-water cannot be raised in temperature to 212° in this way. The feed-water can be raised in temperature to 212°, and above that by passing through tubes round which the flue gases circulate. This method is that adopted in the cases given at the beginning of the paper. It can also be heated by steam from the intermediate receiver by Mr. Weir's system. In this instance the temperature of the feed-water can be raised above 212° in correspondence with the temperature of the steam from the intermediate receiver. The *Engineer* takes a case. It says: "Suppose the feed-water should be raised to 250°, it appears there will be an advantage of 8 per cent. over the ordinary heating of the hot well. But there will be a loss of steam when it is taken from the intermediate receiver, and the loss will be nearly 4 per cent., so that there will be a net gain of 4 per cent. Mr. Weir, however, has a graphical method of explaining the action of his feed-heater. He takes the case of a triple-expansion engine, and shows the diagram ABCDEF as representing the compounded expansion diagram for the three cylinders. He takes the boiler pressure at 160 lb. absolute, relief in high-pressure cylinder 76 lb., pressure in intermediate receiver 60 lb., relief in intermediate cylinder 22 lb., pressure in low-pressure receiver 16·7 lb., exhaust temperature 140° Fah. and hot well temperature 100° Fah. With this he assumes that the water is taken from the hot well at a temperature of 100° Fah., it goes into the heater, and heated up to a temperature of 218° Fah. by direct contact with the steam from the low-pressure receiver. He then makes the same calculation as did the *Engineer*, and he takes the temperature of the water in the hot well as a base, namely 100°. The water is raised from 100° to 218°, that is 118°. The steam in the low-pressure receiver is at a temperature of 1,180°, that is 1,080° above the temperature of the hot well. And consequently 10·9 per cent. of the heat in the steam is required to raise the feed-water to 218° Fah. The total thermal units in the steam leaving the boiler is 1,124 (measuring from 100°), so that $\frac{118}{1124} \times 100 = 10{\cdot}49$ per cent. of the total heat in the steam goes back to the boiler. The advantage is shown in the diagram as follows. Draw NR, making AN = 10·49 per cent. of AM, make NR = AB, draw the adiabatic curve RR to the point of relief in the intermediate cylinder, the sectioned area ANRBE shows the extra work obtained from the high and intermediate engines with the same consumption of coal.

This Mr. Weir says is 10·49 per cent. gain of the total work done by the steam in the two cylinders, or about 7 per cent. in the three cylinders. He takes also the case where the steam for heating might be taken from the intermediate receiver where the temperature is 292·7°. The temperature of the water would then require to be raised 74·7° Fah. With this 6·6 per cent. of the total heat entering the high-pressure cylinder is returned after passing through the first cylinder, so that the efficiency of the high pressure would be increased ·088 per cent. for each degree the feed is heated by steam from the intermediate receiver. Make NV = 6·6 per cent. of AM, draw QS, the adiabatic curve, to the point of cut-off in the high-pressure engine, the black area represents the extra work obtained from the high-pressure cylinder with the same consumption of fuel. Of course the work in the steam taken from these receivers is lost to the cylinders which come after, and that must be deducted from the gain. Here there is a gain by sending the heat back to the boiler, a loss due to the steam not expanding to its full extent, and a loss in the heating machinery. Mr. Weir says the economy is from 5 to 8 per cent., and that the gain depends on whether the engine is compound, triple or quadruple expansion.

On a trial made on the *Oriole*, a small paddle steamer plying between London, Margate, Ramsgate, Deal and Dover, to find out if any advantage was gained by the use of the live steam feed-water heater it was shown that without the heater 85 lb. pressure was maintained with difficulty by the stokers. At the end of three-quarters of an hour the feed-water was sent through the feed-heater. In about a quarter of an hour the feed rose from 140° to 320° and the boiler pressure to

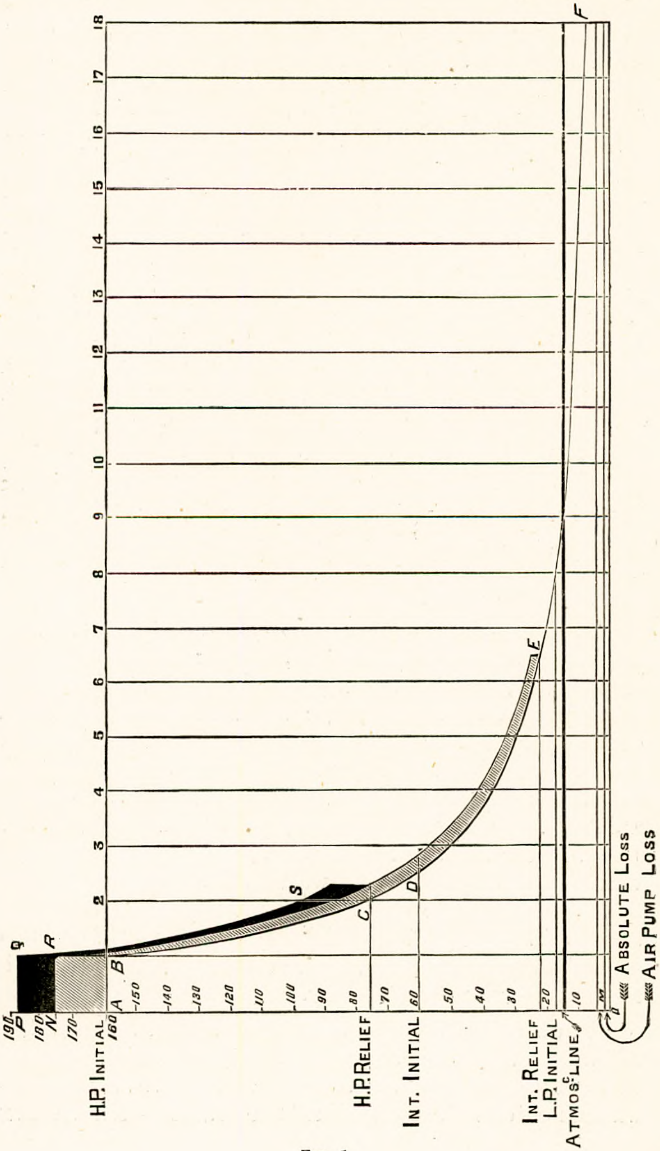

H.P. Initial
H.P. Relief
Int. Initial
Int. Relief
L.P. Initial
Atmos. Line
Absolute Loss
Air Pump Loss

FIG. 1.

97 lb., and remained there. The revolutions rose from 34 to 35½. Mr. Kirkaldy has a letter from his Grace the Duke of Sutherland stating that with the feed-heater the consumption of coal has fallen from 6 tons to 5·1 tons on board his yacht *Sans Peur.* And Mr. A. Bird, chief engineer of the ss. *Lisnacrieve*, reports the increase of pressure when the feed-heater was on was from 77 lb. to 80 lb. The feed rose in temperature from 126° to 200°, and the distance run per 24 hours from 240 to 245 miles, and the saving in coal was 9·6 per cent. The results of the use of the Lundkvist feed-heater on the ss. *Gunther*, of Hamburg, 600 indicated horse-power, are as follows: Trial without feed-heater, lasting eight hours, 517 indicated horse-power, 76 revolutions; vacuum 24·9 in.; 11·4 tons of coal per 24 hours. Trial with feed-heater, lasting eight hours, 542 indicated horse-power, 77 revolutions; 28·2 in. vacuum; 10·6 tons of coal for 24 hours. The engineer of the steamer, who conducted the experiments, writes: "At every watch grease-scum can be taken away."

The results on ss. *Italia* are as follows. The engineer writes August 2nd, 1897: Trial without feed-heater, lasting twenty-four hours, 733 indicated horse-power, 72 revolutions; 25½ in. vacuum, 1·6 kilos. of coal per indicated horse-power per hour. Trial with feed-water heater, lasting twenty-four hours, 759 indicated horse-power, 73 revolutions; 27½ in. vacuum, 1·342 lb. of coal per indicated horse-power per hour. In ss. *Kronborg* the result was: In the course of the whole year without feed-water heater an average of 3·78 barrels of coal was consumed per hour with a speed of 7·838 knots. With feed-heater 3·12 barrels of coal from March 2nd, 1897, to June 6th, 1897, with a mean speed of 8·003 knots.

I now come to the observations which, through the kindness of the superintendent of the Palace Steamers Company, I was allowed to make on the live steam feed-water heater in use on board the Palace Steamer *La*

Marguerite. The range of temperature was fortunately not great. The feed from the hot well was about 120° Fah., and the temperature of the feed-water when the feed-water heater was in use stood about 170° Fah. In the observations made, the feed-water heater was first in use, and afterwards the steam was turned off from it, allowing the water to flow through it without being raised in temperature. It was sought to keep the pressure of steam constant without varying the amount of opening of the stop valve. Should it be found that the pressure of steam fell, the draught was to be increased by raising the damper door.

At first the feed-water heater was in use and the steam which stood at 105 lb. kept rising. This continued for some time, the handle of the stop valve not being interfered with throughout. After about half an hour the steam was shut off from the feed-water heater, and the water allowed to simply run through it. The steam pressure continued constant for about twenty minutes, then the temperature of the feed-water began to fall, and the pressure of the steam soon began to follow it. The damper door was then raised a little to allow greater draught. Afterwards the pressure began to sink again, and the damper doors were raised still higher. After the pressure had gone back some pounds, and the damper doors had been considerably raised, the pressure remained steady. While this was going on in the engine room, a thermometer registered to measure temperatures up to 400° centigrade, lent me by Messrs. Townson and Mercer, inserted amongst the waste gases in the aft funnel was being observed. It varied considerably from minute to minute, but this was mainly due to the firing of the furnaces. It could not be said that the advantage or disadvantage of the heater was shown by the thermometer. The object was to keep the pressure of steam in the engine room constant, by varying the firing of the furnaces. Had a fiercer fire been required through the want of the heater, then it was expected that the temperature of the chimney would have shown an increase. This was not shown. That the heater had an influence was shown by the rising of the pressure while the heater was on, and the falling when off; also by the necessity of a raised damper door to increase the draught, and maintain even a lower pressure of steam constant.

The following valuable table gives the boiler pressure, the temperature of hot well, the mean temperature and the highest temperature of the feed, also the temperature of the steam used.

TRIALS OF CAIRD AND RAYNER'S LIVE STEAM FEED-HEATERS.

NAME OF SHIP	MEAN OF TRIALS				
	Boiler pressure	Temp. of steam used	Temp. of hot well	Mean temp. of feed	Highest temp. attained
Dunvegan Castle	163 lb.	374°	67°	230°	254°
Tintagel Castle	162 „	370°	62°	218°	239°
Avondale Castle	160 „	370°	62°	219°	237°
Dunolly Castle	161 „	370°	68°	224°	236°
Raglan Castle	170 „	376°	68°	225°	236°
Braemar Castle	193 „	384°	65°	230°	260°
Carisbrooke Castle	196 „	388°	67°	252°	261°

Experiments have also been made on board the ss. *Gunther*, to prove that the feed-water heater extracts the air from the feed-water. This was done by taking indications of the feed-pumps first without the feed-heater and second with it. Indicator diagrams were taken of the feed-pump when the feed-water heater was not in use. During the length of stroke the air drawn in with the feed-water is compressed, and during the suction period the air remaining is expanded. A diagram was taken with the feed-heater in use. Here it is seen that there is no compression period during the downstroke, and a fast rising line in the middle of the stroke. There is no trace of air on the suction side.

In his *Traité de Physique Industrielle*, Professor Ser tells us that in an experiment made by MM. Thomas and Laurens, with a spiral tube 34 millimetres in diameter, and 42 metres in length, and with a heating surface of 4·48 square metres, and with steam at a pressure of 3 atmospheres, they brought to the boiling point in 4 minutes 400 kilogrammes of water from a temperature of 8°. Here the co-efficient of transmission was 1,521 thermal units per square metre per degree of difference of temperature. M. Peclet also reports that he brought to the boiling point 900 kilogrammes of the juice of betterave from 4° with steam at 135° in 16 minutes in a double-bottomed vessel with a heating surface of 2·4 square metres. Here the co-efficient of transmission was 1,626 calories per square metre per hour per degree of difference of temperature.

Another experiment was made by MM. Thomas and Laurens, this time with the water at the boiling point to start with, and with steam passing through the coil they used in the first instance, and they turned into vapour 250 kilogrammes in eleven minutes. Here the co-efficient was 4,672. In still another experiment, and with only a difference of temperature of 21° between the steam and boiling water, the co-efficient of transmission was 5,010. Here it is seen that there is a vast difference in receptivity of heat of water at the boiling point and water lower in temperature than the boiling. Professor Ser adds this: "Arrivé à l'ebullition les mouvements sont ordinairement tumultueux et la transmission est notablement accrue." When the water has come to the boiling point the movements are more than ordinarily tumultuous, and the transmission is notably increased. The water moves much more rapidly over the heating surfaces, and as a consequence the co-efficient of transmission is increased.

The next point to be determined is whether it is the condition of water or its motion over the heating surface which is the likely factor in this matter. In order to determine this it will be observed that in each of the above experiments there were like conditions. It was simply a quicker movement of the water over all the surfaces which might legitimately be credited with the change in the co-efficient of transmission. If then we can prove that a more rapid transit of the water over the surfaces does produce such a change we have an explanation of the economy produced by the live steam feed-water heater.

In this I cannot do better than quote the part on this subject in my paper on water-tube boilers: "The apparatus he used consisted of a thin copper tube, a foot in length and four inches internal diameter. The water was made to enter at the pipe C, pass through the tube AB, and flow out again at D (Fig. 2). The temperature of the water to be heated

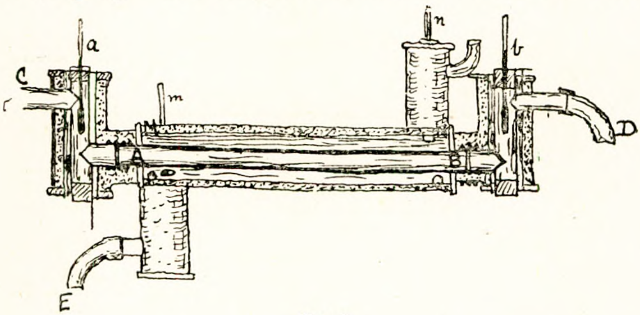


FIG. 2.

was shown by a thermometer at a, and, after heating, at b; a casing or muff, MNPQ, made of copper, surrounded the tube AB. Steam was passed through this muff by the connection shown at E, and its temperature was shown by the thermometers n and m. All the surfaces of the casing or muff were covered with wadding to prevent radiation. The principal object which the Professor had in view was to find the transmission co-efficient at different given velocities of water in the tube AB, the temperature of the heating medium being constant, and the results of his experiments are given in the following table :

Speed of water through the tube	Co-efficient	Speed of water through the tube	Co-efficient
·1	1,400	·7	3,180
·2	2,230	·8	3,330
·3	2,550	·9	3,480
·4	2,710	1·0	3,640
·5	2,860	1·1	3,800
·6	3,020		

From the above tables it will be seen what a great gain of transmission efficiency can be obtained by increasing the velocity of the water to be heated over the

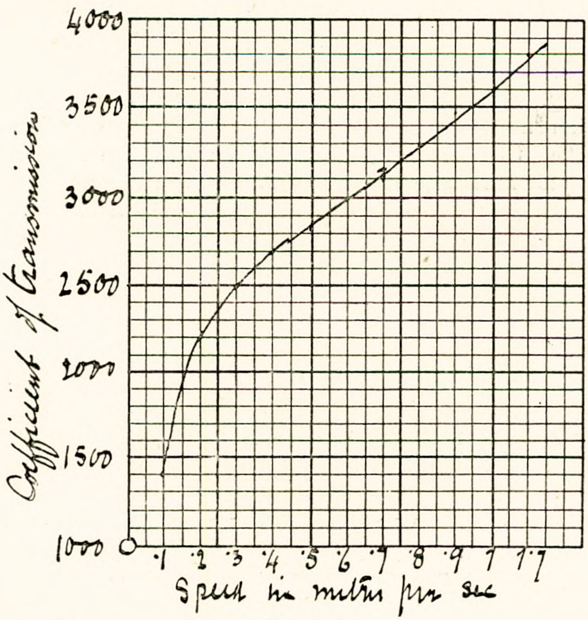


FIG. 3.

heating surfaces, and the increase is clearly shown by the accompanying curves (Fig. 3) ; when we examine these carefully we see that the rate of increase of transmission rises very rapidly between the velocities ·1 and ·3 metres per second; from ·3 to 1·1 the transmission of efficiency does not rise so rapidly, still there is a rise proportional to the speed. From this part of the curve the co-efficient of transmission Q works out to be,

$$Q = 2{,}080 + 156 \times \text{velocity of water.}"^{*}$$

The results of dividing up the boilers into two parts as Mr. Yarrow did, so that one part will evaporate while another part heats the feed, are as follows. The utmost care was taken to get correct results. Pyrometers were inserted at the furnace side of the boiler and the temperatures taken. Simultaneously temperatures were taken on the flue side of the tubes and the difference of the temperatures recorded. A very great number of experiments were made and then records kept. The average difference of temperature was taken. It was found that the difference was greater when the feed-water was led into and through confined to the three back rows of tubes; and the advantage is shown in the second column given below :

Rate of consumption in lb. of coal per sq. ft. of grate	Advantage of difference of temperature	Funnel temperature
52	89°	662°
19	45°	433°
31·4	67°	608°

Here it is seen that when the consumption was rapid the average excess of difference of temperature between the furnace side of the tubes and the flue side was 89°; when the consumption was slow 45°, and when medium 67°. The advantage, of course, is due partly to the separation of the two parts of the work of the boiler; first raising the feed water to

* Paper No. 77, Vol. X, pp. 11, 12, 13.

the temperature of the water, and second the evaporation. By keeping these separate there is a lower temperature obtained for the flue gases. The water more readily takes away the heat from the gases in the evaporative part of the boiler. The results of the two advantages are seen in the following table:

Water evaporated per sq. ft. of heating surface	Without feed-heater	With feed-heater
3	10·25	12
4	10·1	11·75
5	10	11·6
6	9·75	11·4
7	9·6	11·2
8	9·5	10·85
9	9·25	10·5
10	8·8	10

It will be seen from this table that when the evaporation is at the rate of 3 lb. per square foot of heating surface the advantage is 1·75 lb. evaporated per pound of coal and when evaporating at 10 lb. per square foot of heating surface it is 1·2 lb.

Here then we have at last arrived at an explanation, based on experiment, of the economy produced by the boiler steam feed-water heater. It also explains that there will be gain produced by all other types of feed-heater not shown in the heat of the steam at all.

But there is another question to answer. That question is, Where does the heat come from? It does not come out of the boiler steam. On the whole there must be a slight loss by the use of that. Where then does it come from? It comes from the hot gases. Turn again to Mr. Yarrow's experiment and notice the effect of having the feed heating of the water, separate from the evaporative part. The water left in the inner part of the boiler is in undisturbed possession and does nothing but circulate and evaporate steam. It is undisturbed and so moves quickly over the hot surfaces, absorbing heat from them as rapidly as possible, and so lowers the temperature of the chimney gases. So it is with an ordinary Scotch boiler; the water kept all at a high temperature is in undisturbed possession, and so keeps all of it always boiling and moving quicker over the surfaces it touches. When it does this it reduces the temperature of the chimney gases more rapidly. This is a simple explanation and it is based on experiment. There is not any need to think of the fight between two sinks as explained by one nor the motivity of the water as explained by another. It is not due to increased efficiency of the heating surface; the heating surface is quite willing to transmit much or transmit little. It depends for its state on the speed of the water over the heating surface. It is the higher in efficiency the quicker the water moves over it. This explanation of the advantage of the live steam feed-heater was first given by *The Engineer*, April 16, 1886, but the statement was based on engineering instinct and not on experiment.*

Finally, the whole of the heat in the boiler steam taken out of the boiler to heat the feed-water is not given back to the boiler with the feed. There is a loss, but this is compensated by the greater rate of absorption by the rapidly moving water in the boiler. We have then seen the methods of calculation applied in the case of the feed-heater by the hot well, by an economiser in the flues, by a separate boiler, by Mr. Weir's system, and by a system which has been adopted in the Yarrow, the Blechynden and Mumford types of boilers; and we find all the calculations are based on the assumption that all the heat which goes into the boiler goes in with the steam. None of the

* Since the above was read Mr. Macfarlane Gray has shown in an article written by him and published December 9th, 1897, where the same view is given, namely, that the economy arises from the greater rapidity of motion of the water over the heating surface. This also was based on instinct.

calculations take into consideration the effect on the hot gases of the furnace. None of them are based on the assumption that the motion of the water over the surface of the fire plates increases the quantity of heat absorbed. Even we have had Professor Cotterell laying it down that no advantage could be obtained from a boiler steam feed-water heater, and only because his assumption was that any heat which went into the boiler came in with the steam. We see now this is a wrong assumption. In every case where the feed is heated, heat goes into the boiler in two ways. It follows a compound interest law ; or—shall I rather say ?—a skin-friction law. The higher the temperature of the feed the greater is the quantity of heat going back into the boiler, and the greater is the economy. The higher the temperature of the feed the greater is the speed of the water in the boiler over the heating surface, and the quicker does the water carry away with it the heat from the surface of the plate. The higher the temperature of the feed the less is the disturbing influence of the circulation of the water in the boiler, the better is its motion in its proper circuit, and the quicker does it carry away heat from the surface. Whenever the feed is heated it influences not one thing but two things—the heat taken from the steam and the heat taken from the hot gases. No calculations can give correct results which are not based on the two assumptions. It has been customary to lay down rules for the calculation of the increased efficiency as if all boilers were affected alike by a feed-water heater. This will not be the case. An express boiler lends itself to the rapid motion of the water over its surfaces more than does the Belleville or the Babcock and Wilcox, or the Scotch type, and the influence of the feed-water will be sooner felt, and its influence will be greater. One Scotch boiler will lend itself to the motion of the water much more readily than will another, and therefore its economy under the influence of a heater will be greater. There cannot very well be any general rule, or if there is some empirical formula it will have constants between limits. Feed-water heaters will, of course, affect ordinary draught. Where a feed-water heater is used longer chimneys will be required, or else artificial draught to obtain high rate of combustion.

I come now to a description of the typical feed-water heaters. First in point of time is that of Captain Savery in 1698. Just two hundred years ago, a patent was granted to him for a boiler made in two pieces, in one of which the water was raised to the boiling point and in the other for evaporating that water. Next comes a similar one by Mr. Druitt Halpin. He calls it a thermal storage plant. In this system water is heated during the day and stored heated, to be used at night in an electric-light installation: the water is heated while there is no other use for the boilers. He obtained with it 16 per cent. gain; Professor Unwin found 19 per cent. Like this also is the Belleville boiler with Belleville economiser. It is simply two similar boilers. In the boilers of the *Diadem* there are seven rows of $4\frac{1}{2}$-in. tubes and above these a combustion chamber; above this again is another boiler with nests of tubes $2\frac{3}{4}$-in. seven rows in height. The furnace air blowing engines supply jets of air to the combustion chamber as well as to the furnace. The feed is pumped into the lower part of the economiser, travels to the top, and then goes to the steam collector for feeding the generator tubes.

The following table shows it compared with the boilers of the *Powerful:*

ONE BOILER.

	Number of elements		Heating surface						
	Generator	Economiser	Generator	Economiser	Total	Fire-grate	Weight	Water	Total weight
Powerful	8	nil	1,420	—	1,420	49	17·4	1·1	18·5
Diadem	8	6	995	355	1,420	49	16·7	1·3	18

Mr. Yarrow's boiler had a grate surface of 33 square feet, and a heating surface of 1,840 square feet, having tubes varying from $1\frac{1}{4}$ in. to 1 in. diameter. The experiments have already been described. In Mr. Blechynden's boiler the three back rows of tubes were divided off from the others by means of a diaphragm of refractory material, and the gases circulated up amongst the front row and then down amongst the three back rows. The gases were colder before they reached the back rows, and the probability is that the three back rows were down comers, while the front ones were up comers. The distance from back to front was divided into two parts in the ratio of 2 to 1. Two-thirds of the tubes were on the fire side by the diaphragm, and one-third at the back.

Green's economiser is shown in figure 4, the perspective view of which shows it clearly. It consists of a set of cast iron tubes about 4 in. in diameter by 9 ft. in length, made in sections of various widths to suit the convenience of the boiler plant, and set vertically in parallel rows to afford facility for inspection. The feed-water heater is situated in a by-pass in the main flue; it may be cut off by a damper to allow of inspection without interfering with the working of the boilers. The water inlet is at the bottom, and the water flows up the pipes and out of the feed-water heater at the end next the boiler. The water then comes into the tubes where the gases leave the heater, and leaves where the gases come in. There is a blow-off valve in the lower branch pipe opposite the feed inlet, and a safety valve on the upper branch pipe at the end opposite the outlet. Each tube is provided with a scraper, which is made to travel slowly and continuously up and down, to keep the surface of the tube clear of soot. These scrapers are grouped together, so that those adjoining sections of tubes form a single set which is balanced by the set on the next two sections

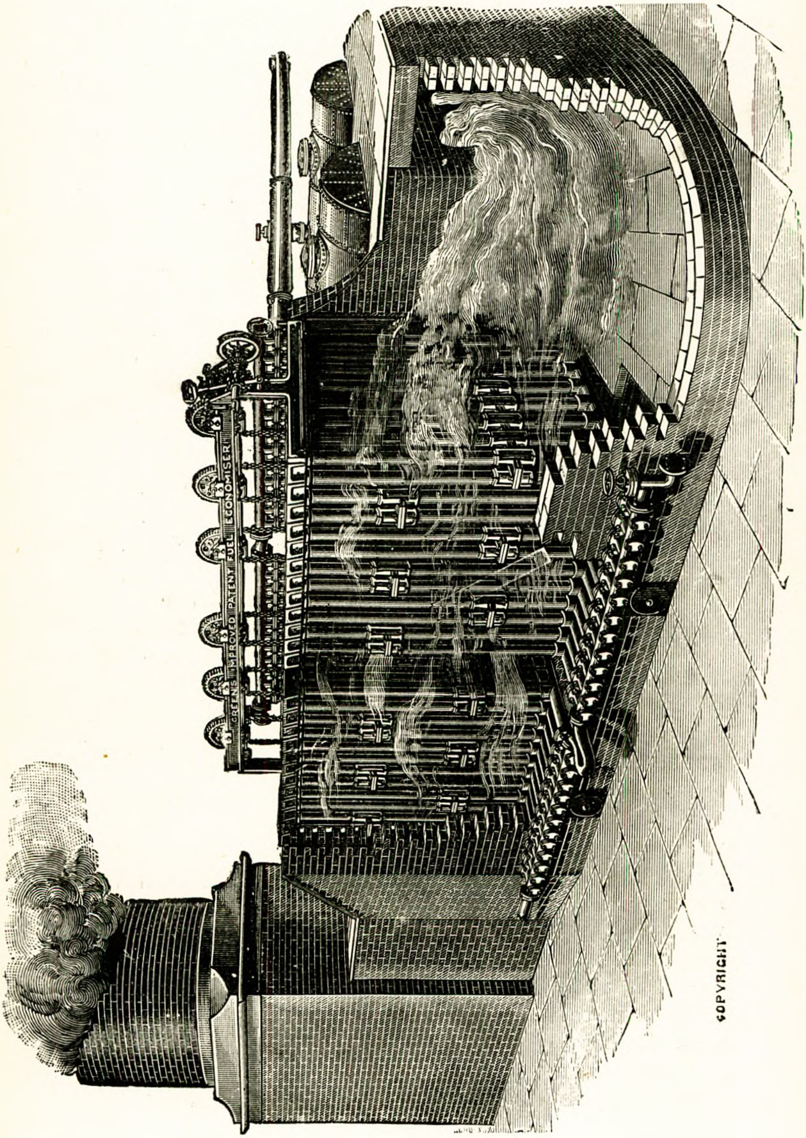


FIG. 4.

of tubes. The tubes are made from a special combination of best Scotch pig and Hematite. Each tube is tested to 640 lb. per square inch. The joints of the tubes and boxes are made conical, turned and bored and forced together by powerful hydraulic machinery.

The Mumford Feed-Heater.—Mr. Yarrow read a paper at the last spring meeting of the Naval Architects, on the advantages of pumping the feed-water into the tubes remote from the fire, and the results of his experiments proved this to be an efficacious method. A pocket was made in the outside part of the lower drum. This was partitioned off from the rest of the heater at a place so as to include the openings to three rows of tubes remote from the fire. The feed-water was pumped into this pocket, and rose through the tubes, and as it rose it was heated by the gases spent to some extent before they reached them. The water was thus heated before it began to circulate with that which was being heated for evaporation. As it got heated it left impurities behind it, and from the improved circulation of the evaporative part of the boiler a lower temperature of the funnel gases was obtained. The original water-tube boiler made by Mr. Mumford was made of sections. These sections consisted of bundles of tubes, expanded into a plate with a branch at the end. The branch fitted into branches on the lower and upper drums. There were usually five sections on each side, and it was an easy matter to take out any section when anything went wrong. A diaphragm went midway along the tubes from end to end, so that the hot gases went along amongst the tubes on the inside of the diaphragm until they reached the end; then they turned and came back amongst the tubes on the outside of the diaphragm and then passed up the uptake and funnel at the front. Mr. Mumford arranged to pump the feed-water into the two front sections only, and the bottoms of the branches were so arranged that the feed went up the tubes situated on the outside of

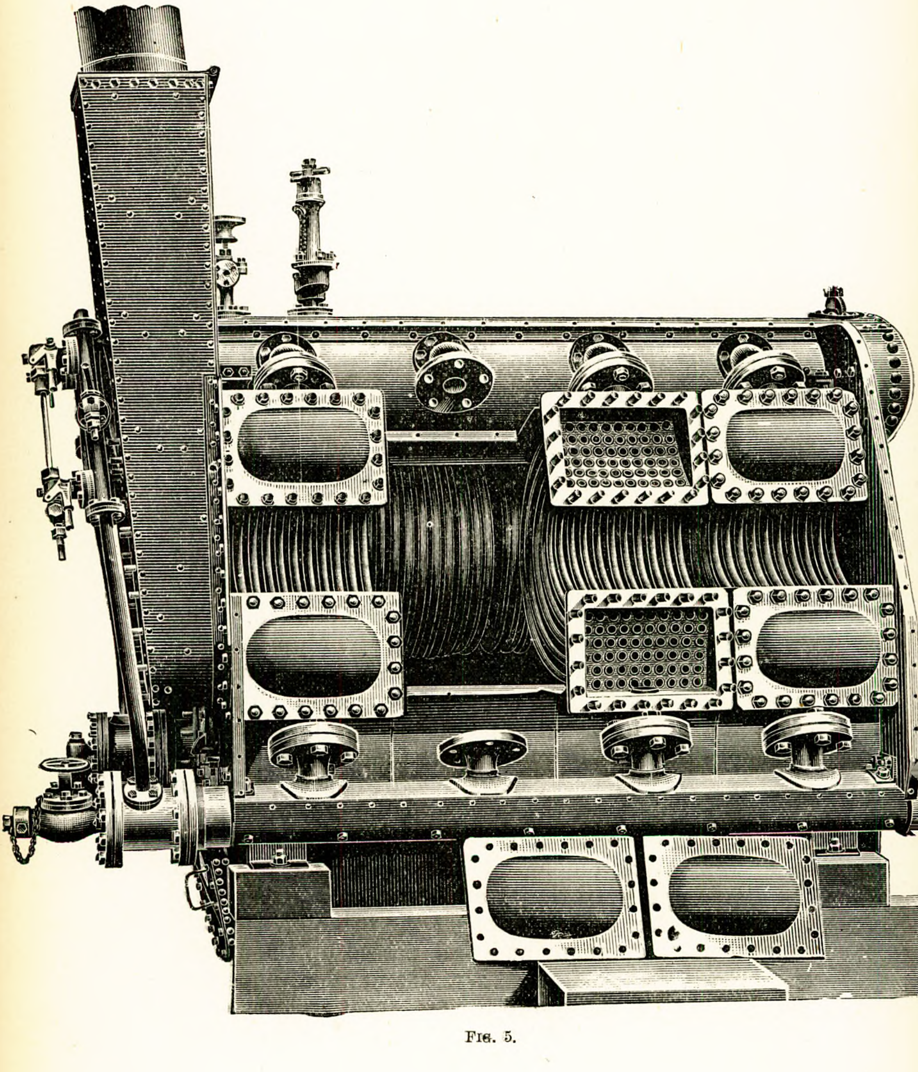


Fig. 5.

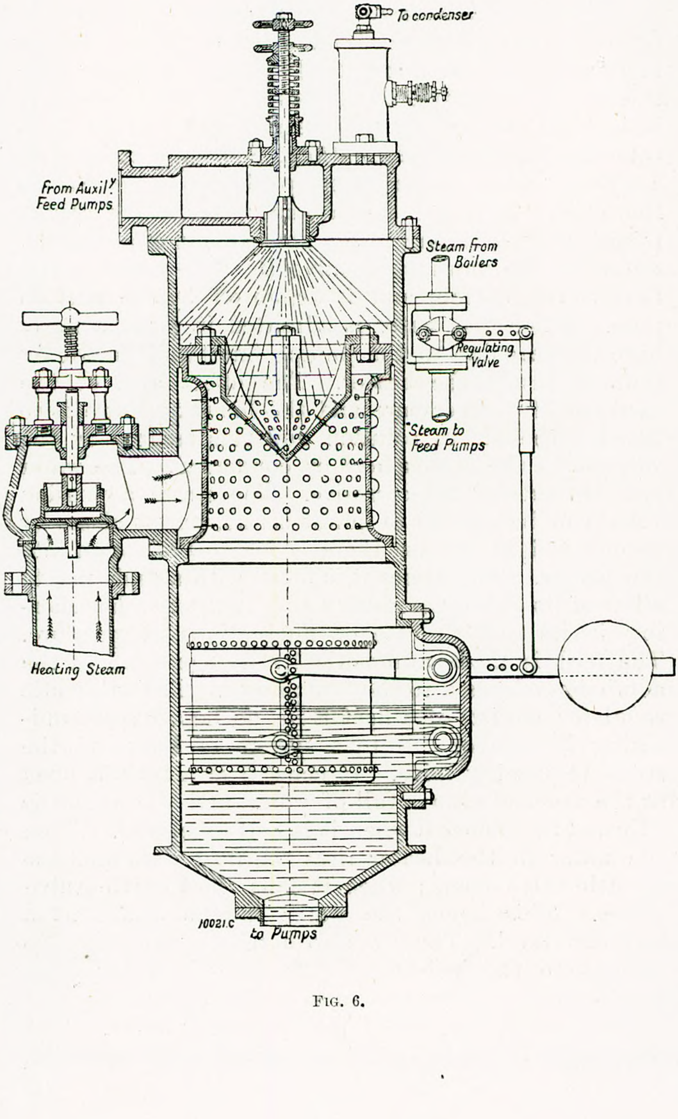

To condenser
From Auxil^y Feed Pumps
Steam from Boilers
Regulating Valve
Steam to Feed Pumps
Heating Steam
10021.C
to Pumps

FIG. 6.

the diaphragm only. Mr. Mumford has discarded this plan in the new continuous drums.

Weir's Feed-Heater.—The apparatus is shown in figure 6. The feed-water is admitted at the branch pipe marked, from auxiliary feed pumps through the spring-loaded valve D on the cover in a thin sheet and is instantly heated by the steam. Below there is a conical piece with perforations, and supporting that a cylindrical chamber with perforations, so as to thoroughly mix the steam and water. The steam from the low-pressure casing and exhaust of auxiliaries enters by the non-return valve B. The heated water falls to the bottom and is drawn off by the suction pipe. When the water is admitted it is at a fairly high pressure due to the pumps, but this is suddenly relieved inside the heater. The effect also of the increase of temperature and the lower pressure is to liberate the air in solution, and this escapes by the valve K to the atmosphere or condenser. The water is thus rendered non-corrosive. The steam admission valve can be opened to admit steam, but it closes by its own weight in case there is no flow of steam into the heater. Sometimes it is fitted with a dash pot to allow of its closing gradually and prevent it hammering in its seat in case of fluctuations of pressure. The feed is made automatic by a regulation of the admission of steam to the feed pumps. The automatic regulator consists of a float E in the heater communicating its rise or fall by a system of levers to the steam regulating valve. It consists of a tank E open at the top and always full of water, and the weight is adjusted to balance it when it is half immersed. When the water in the heater rises the float rises and the throttle valve opens; when it falls the throttle valve closes. This keeps the water in the heater at a constant level. There is also a relief valve fitted to the cover of the feed-heater. There is also a compound gauge which shows the pressure in the heater and another the pressure of the in-going water. The pressure of the water ought to be from 15 lb. to 25 lb.,

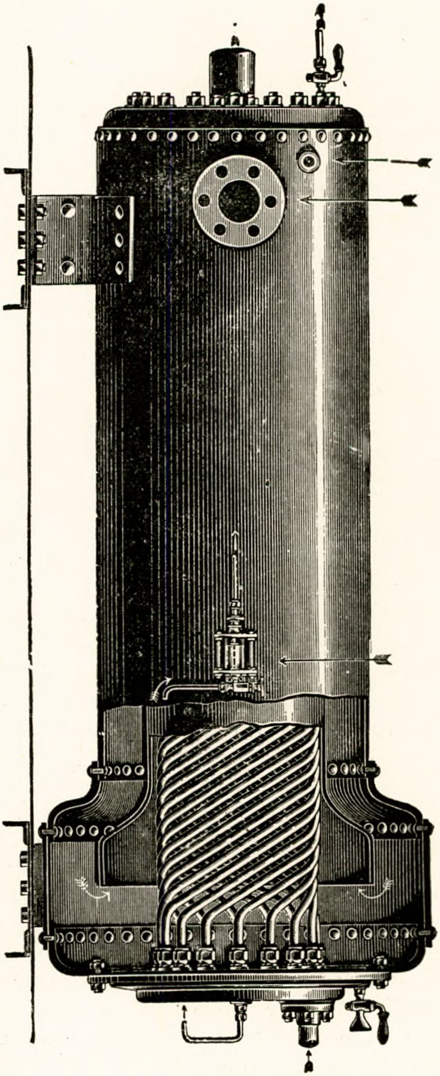


FIG. 7.

which should be adjusted by the spring loaded relief valve. It will be seen that this feed-heater partakes of the nature of a condenser and steam feed-heater.

Maudslay, Sons and Field, Ltd.—It is built of wrought iron and riveted as shown in fig. 7, where it will be seen there are two shells leaving an annular space between them. The inner shell envelopes a number of spiral copper tubes through which the steam passes. These tubes are jointed at the top and bottom to stand pipes, and the steam goes in at the top marked "steam inlet," flows down through them, and is drawn off at the condensed water outlet. The feed water is pumped in at the bottom branch marked "feed-water inlet" into the annular space and rises in that, being heated as it rises until it reaches the top, when it flows over into the inside amongst the tubes. As it sinks amongst the steam tubes and rises in temperature the oil and other impurities separate out and rise to the top. There is a pipe at the top by which these impurities are drawn off marked "oil and air outlet." At the top there is also a soda cup, at the bottom the feed water is taken away, and there is also a sludge cock at the side.

The Lundkvist Feed-Water Heater.—This consists of a cast-iron base with the inlet pipe and door, to allow of the tubes being inspected, also drain cock; further, of the middle piece, which is closed at the ends with rolled brass tube-plates, and fitted with No. 16 S.W.G. red metal tubes packed with packing cord and ferrules with guards for preventing the tubes getting out. There is an outlet branch, an overflow and air opening, and water-gauge. The condensed feed-water in the condenser of the main engine is lifted by the air-pump so high up in the discharge pipe that it, through its own weight, flows downward through the hot well out through a connecting pipe into the feed-water heater. It flows up through the conical piece in the cast-iron base, goes through the heating tubes into the top piece, then down under the division, and flows finally over into the suction pipe to the feed-pumps. The steam for heating the water comes in, and is carried away condensed. The grease separates out from the water at 194°, and as the steam forms in bubbles in the water the grease attaches itself to it and rises with it to the surface, where it is skimmed off by a skimming spoon let in through the cover. Like Mr. Weir's feed-water heater, exhaust steam from the auxiliaries is sometimes used for heating purposes. Sometimes it is taken from the low-pressure receiver separately, or conjointly from the low-pressure receiver. The makers—the Elsinore Shipbuilding and Engineering Co., Elsinore, Denmark—make a statement to the effect that this feed-heater raises the temperature of the feed-water from 62° Fah. to 180° Fah., and it purifies the water from air and grease.

Babcock and Wilcox.—Perhaps the feed-water heater fixed at the top of the Babcock and Wilcox boiler is the most original part of it, and its excellence is possibly due to its simplicity. It is a live steam feed-heater and purifier all in one. Other live steam feed-water heaters transmit the heat from the steam to the water through the tube walls. This one heats the water directly by contact. It consists of a separate horizontal cylinder at the top of the boiler. The feed-water is admitted at the top in the middle of the cylinder, the live steam a little to the side of this, and the purified hot feed-water is led off at each side to the header of the boiler, while the impurities and insoluble salts are blown out from below. The feed-water enters the cylinder in a fine spray, and coming in contact with steam gets heated. It falls into a tray and spills over the side in a fine spray and again gets heated. A third time it sprays over the edge and again gets heated. The cylinder is kept half full of water.

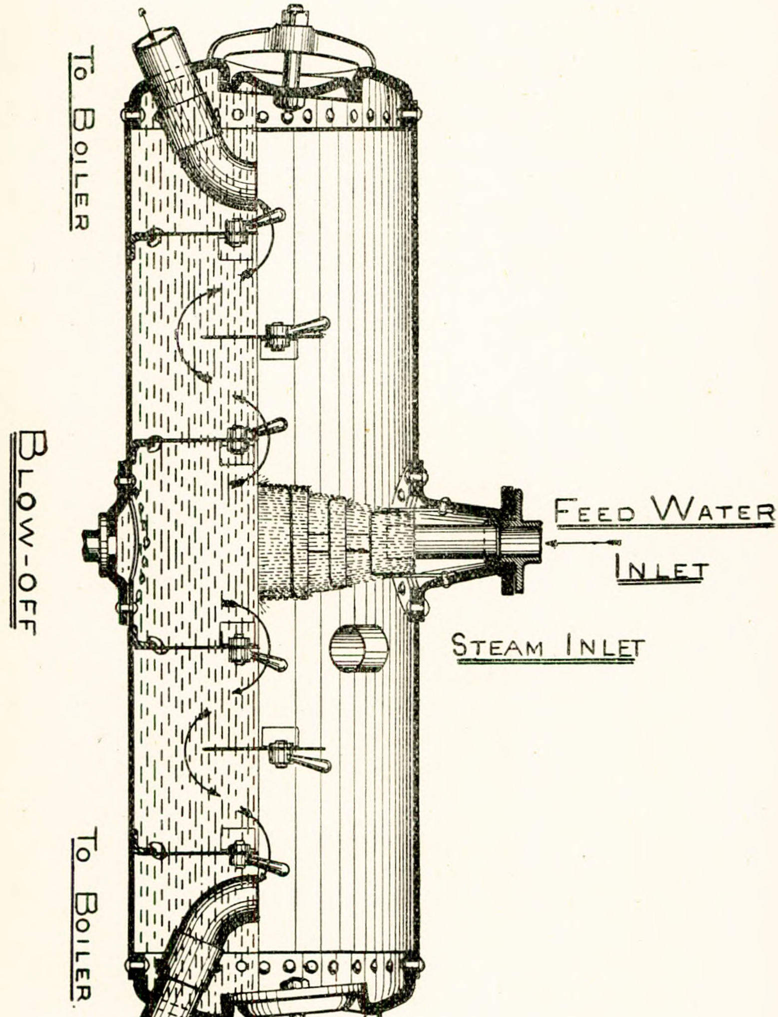


FIG. 8.

There are adjustable vertical plates in the water space placed in a vertical direction to cause the water to move in a sinuous path to the exit pipe. By this means it is all brought to the surface again in contact with the steam and again gets heated. The impurities and insoluble salts separate out from the water as it rises in temperature, and this separation is going on throughout the path of the water from the inlet branch to the outlet. The impurities and insoluble salts settle at the bottom of the cylinder and are blown off at intervals.

W. H. Bailey and Co.'s Heater.—This is of a novel

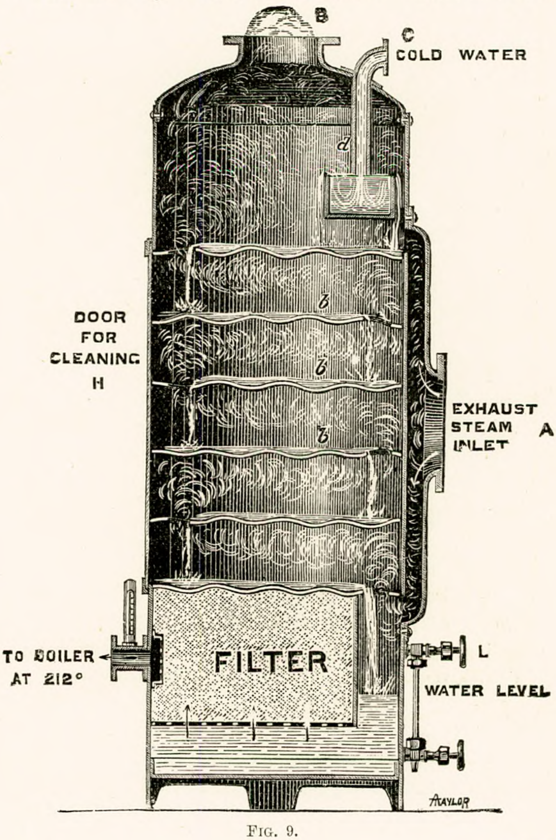


FIG. 9.

design, and it is claimed that it extracts lime from the water, and so relieves from scale the boiler into which the water is fed. A sectional view of it is shown in figure. It consists of a cylindrical wrought-iron shell fitted internally with corrugated shelves, and the water first falling into a box sprays over the edges on to the first shelf, spreads in a thin sheet over that and sprays over the edge of it. This continues until the water reaches the bottom, when it rises through a filter and passes out at a branch in the side to the boiler. The exhaust steam which heats the water as it spreads along the shelves, and sprays over the edges, enters the side of the heaters by the branch A. The cold water enters the heater by the pipe marked C. The filter is composed of hay or straw pressed in wet.

Caird and Rayner's Live Steam Feed-Water Heater.—This is shown in the figure which has been kindly prepared by the firm at the request of the author for this paper. It will be observed by those who know this type that the design has been entirely changed. Formerly the tubes went round spirally the whole circumference; now each tube has a separate coil of its own. The effect of confining the live steam a long time in the coils will be seen in the table of latest results already given. The feed-heater consists of a cylindrical vessel of cast or wrought iron, inside of which is placed a series of coils of seamless copper tubes. The heater is so placed that the feed-water is forced through it on its way to the boiler from the feed pump. The feed-water enters by a branch pipe at the bottom, and leaves it by a similar branch at the top, whilst boiler steam at full pressure is admitted to the coils at the top, and when it has reached the bottom its temperature is very little different from that of the water coming in, and the condensed water from the coils is led to the hot well and pumped back into the boiler. The length of the coils is arranged to give time for the steam to give up its heat and be

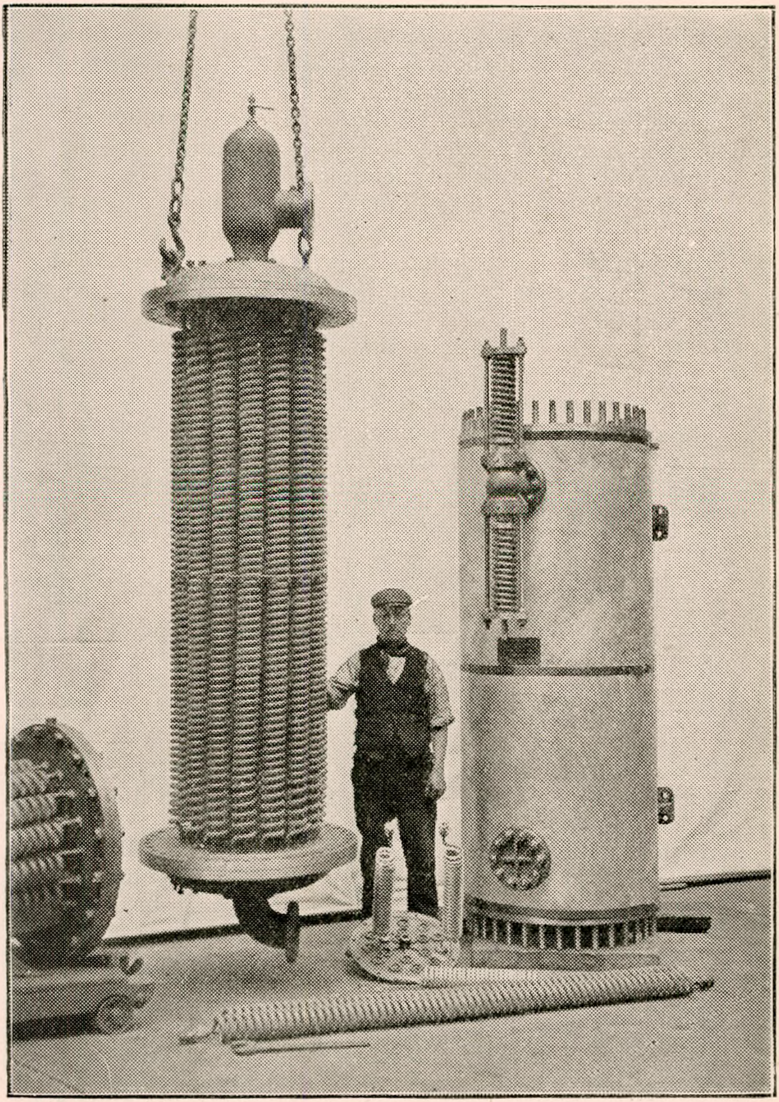


Fig. 10.

reduced in temperature equal to that of the entering water. There is provision made at the inlet and outlet branches of the feed for taking the temperatures by means of a thermometer. There is also a spring loaded relief valve fitted inside the shell as required by the Board of Trade. The tubes are secured to the tube plates by a patent metallic joint, which keeps it quite steam tight. The hexagon on the union prevents any straining action on the tube in screwing up the joint, and the joint itself is a valuable one, and has been tested and found perfectly tight at very high pressures. An arrangement of cocks and valves can be provided so that the feed-water may be passed through the heater or not, as may be desired. This firm also make a feed-heater which utilises the exhaust steam coming from non-condensing engines to heat the feed-water. The temperature of such steam varies from 200° to 220°, and this feed-heater partakes of the nature of a condenser as well as a heater of feed-water. It consists of a cylindrical vessel, usually of cast iron, having a cover bolted on either end. An opening the size of the exhaust pipe from the engine is made in each cover; the pipe from the exhaust is connected usually to the upper end, the lower end is connected to the atmosphere. There are seamless copper tubes arranged inside, and through these coils the feed-water is pumped on its way to the boiler. There is also a different design for larger sizes. The tubes in this case are expanded into flat tube plates, and they are straight. There is a box at the bottom with a vertical division in the middle. The exhaust goes in at one side, goes up the inside of half the number of tubes, and comes down the other half into the other half of the bottom box, and goes out through a branch pipe. At the bottom of the box there is a condensed steam outlet. The feed-water is admitted by a branch at the bottom and is taken away at the top. There is a dome fixed over the top tube plate. (Fig. 10.)

Kirkaldy's Feed-Water Heater consists of a cast-iron case inclosing coiled copper tubes, fixed to a stand-pipe at top and bottom with metallic joint. Steam from the boiler enters the tubes by a branch pipe, and is gradually condensed until it is finally delivered from a cock to the hot well. The heat of the steam is given up to the feed-water surrounding the tubes, the entering, or hottest, steam being surrounded by the water just about to leave the apparatus, the inlet for feed being at one of the bottom branch pipes, and its exit at the top branch pipe connected to the air vessel. The steam and the water thus flow in opposite directions. Above the branch pipe is a vessel in which air is trapped, and from which it is drawn off by a cock, and a pipe ending in the hot well. On the opposite side to the feed inlet is an escape valve. The coils and stand pipes are tested to 400 lb. pressure per square inch.

Wheeler's Feed-Heater is shown in Fig. 11. The

FIG. 11.

feed-water comes in at the right bottom branch pipe, flows up through the tubes on the right to the upper chamber, and flows down the tubes on the left to the bottom outlet. The exhaust steam enters at the bottom, exhaust outlet at the top.

The "Row" Feed-Heater.—In this feed-heater exhaust steam is used. The feed-water enters at A, the outlet B. Exhaust inlet is at the top side, exhaust outlet at bottom branch. Condensed steam is drawn off at C, and impurities are blown off at D. The tubes are indented as shown in figure. It is formed by taking a tube of annular section and indenting it in a regular manner, the indentations preferably intersecting each other at right-angles, so that a liquid passing through the tube is broken up and diverted into contact with a large amount of impinging surface. It is, due to its shape, perfectly elastic between the tube plates. Here is a table given by the makers, showing the evaporative efficiency of one square foot "Row" tube compared with plain tube.

	Plain tube	"Row" Tube
Steam pressure in tube	62 lb.	62 lb.
Initial temperature of water......	43° F.	43° F.
Time to raise 11 gallons to 212°	14 min.	6 min. 20 sec.
Time to evaporate	34 min.	16 min. 30 sec.

AVERAGE OF FOUR TESTS WITH STEAM AT 212° F.

TUBE	Temp. of inlet water	Temp. of outlet water	Temp. of steam	Quantity of water heated	Time
200 sq. in. of plain copper tube $1\frac{1}{2}$ in. bore, $\frac{1}{16}$-in. thick	58° F.	180° F.	212°	1 Gallon	2 min 58 sec.
200 sq. in. of "Row" tube formed from $1\frac{1}{2}$ in. copper tube $1\frac{1}{2}$ in. bore, $\frac{1}{16}$-in. thick	58° F.	180° F.	212°	1 Gallon	1 min. 30 sec.

The North-Eastern Feed-Cleaner and Heater.—This heater is of the live steam type and is particularly designed and arranged for the removal of grease, fatty

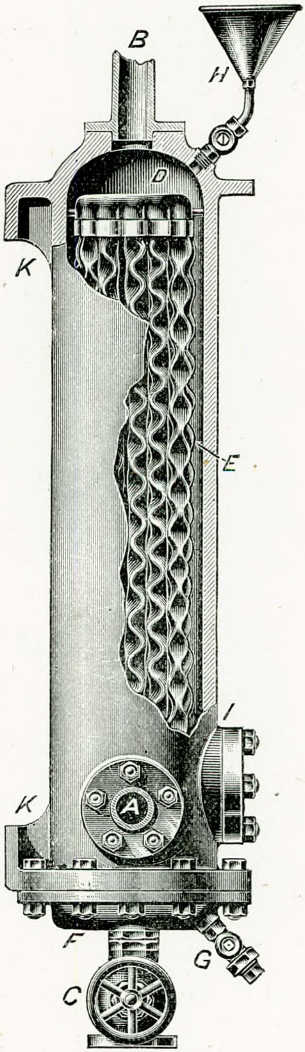


FIG. 12.

acids and air from feed-water by centrifugal action. The figure shows the apparatus. The water enters from the feed pumps and moves up the central pipe to the small turbine and by the rotational action of this the impurities are separated out. The scum rises to the surface and is blown off by the scum

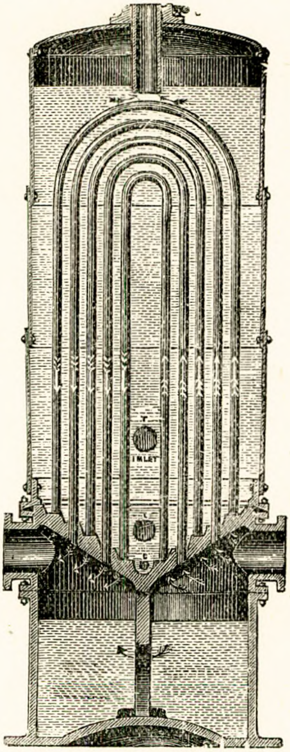


FIG. 13.

cock into the settling tank. The overflow goes down through a pipe. As the feed-water descends it becomes heated by the heating coils and leaves for the boiler by a branch pipe. A gauge glass is there. When the grease and other impurities are thrown to the surface by the centrifugal action

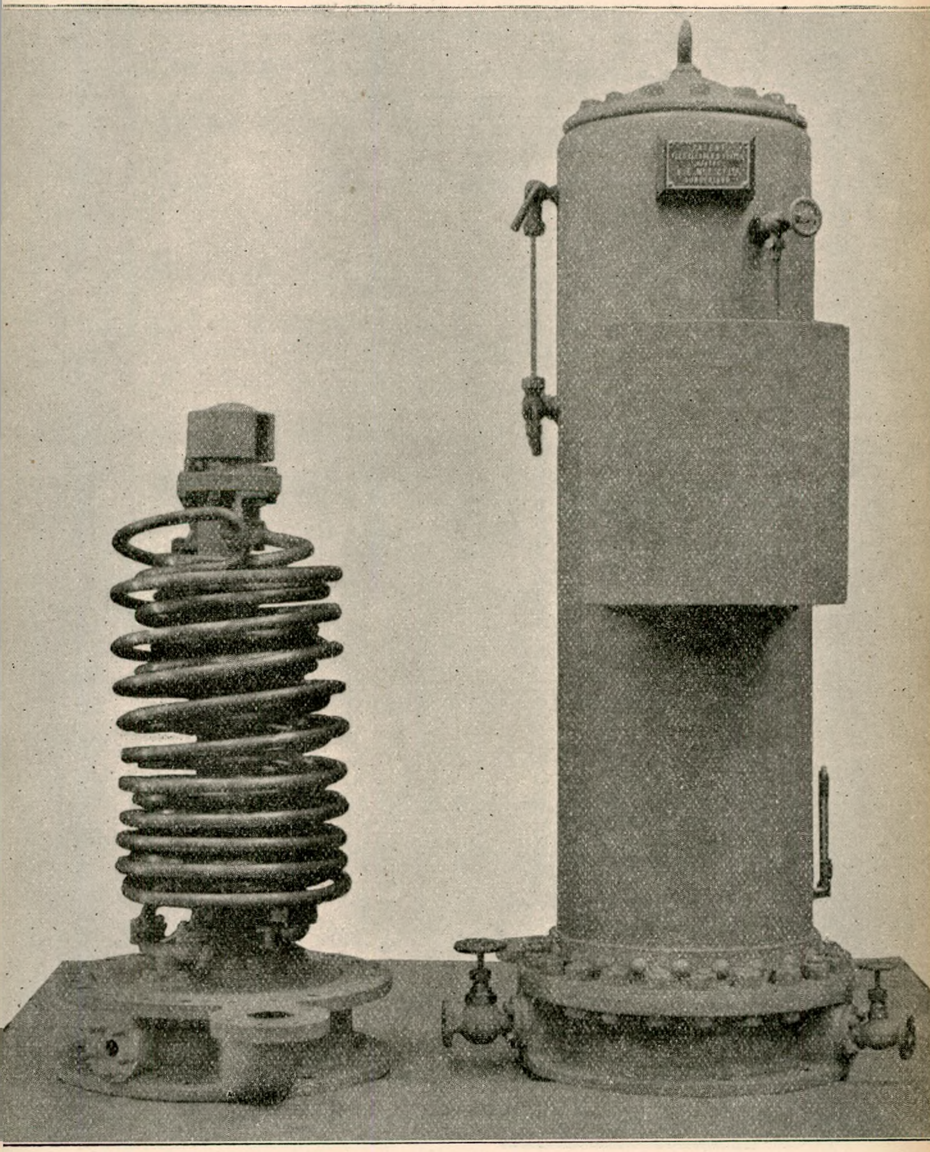


FIG. 14.

of the turbine it is removed by the scum pipe into a separating tank; but it requires some attention when the engines are first set away, that being to see that the regulating valve on the scum pipe is set so as to allow the air that has been in mechanical suspension in the feed-water, gathering at the top of the chamber, to escape by means of the scum pipe. The water is skimmed once or twice in the watch.

Morison's Feed-Water Heater.—This consists of a

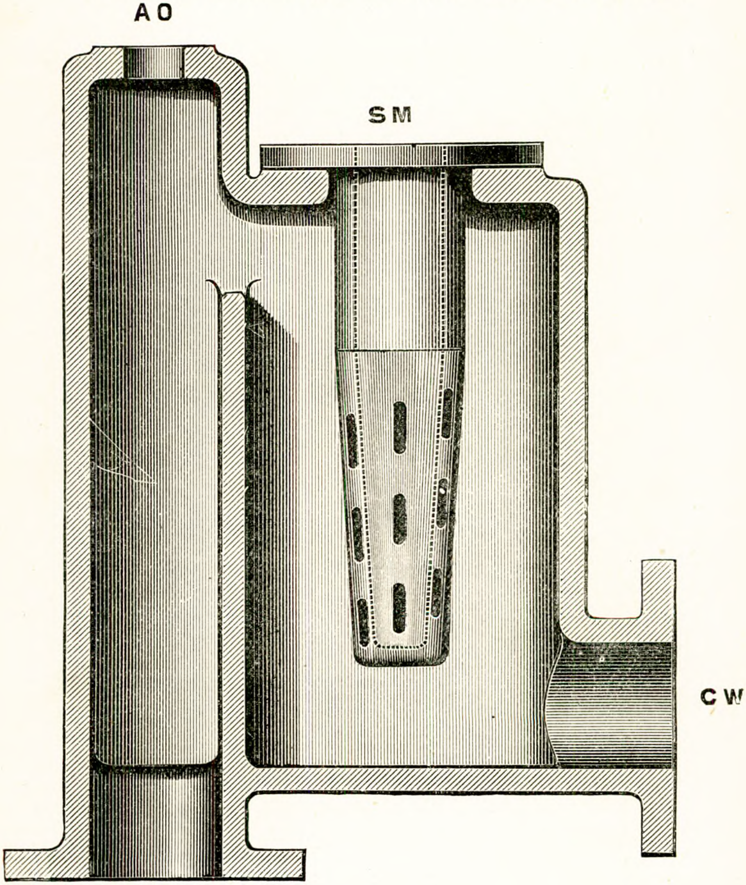
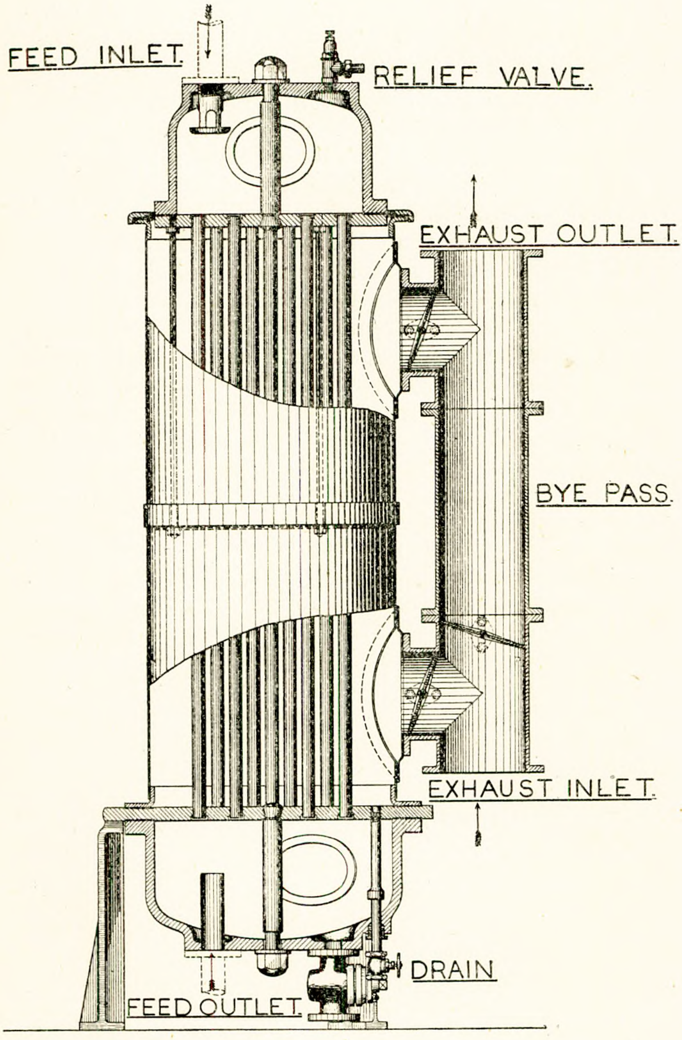


FIG. 15.

cast-iron vessel into which steam from the evaporator is admitted and condenses amongst the feed-water. The water from the hot well enters the heater by CW (Fig. 15) and the steam from the evaporator by SM, which contains slots set at an angle so that the escaping steam causes a centrifugal motion of the water in which it is condensed. The heated feed-water flows out at HW to the feed-pump suction. Any steam or vapour or air freed from the water escapes at AO to the hot well. The makers only claim that this feed-heater condenses the steam generated by an evaporator, and so as not to interfere with the action of the pumps. It also promotes the escape of air from the feed-water by the centrifugal action from the steam nozzle. It raises the temperature of the feed-water to about 160°.

Babcock and Wilcox Exhaust Steam Feed-Water Heater.—It consists of an upper and lower water chamber connected by a number of brass tubes with their ends expanded into tube plates of the chambers. The exhaust steam circulates round the outside of the tubes, and by means of the by-pass valve can be sent direct to the atmosphere if desired, and the heater can be put out of work and cleaned. The makers say that each 10° of rise in temperature of the feed-water is equivalent to a saving of one per cent. in fuel (Fig. 16).

Joseph Wright and Co.'s Feed-Heater.—The cold water in this heater is admitted by a branch at the bottom and drawn off heated at the top. The outlet pipe descends through the surface of the water beneath the scum on its surface. The steam goes through a number of bent tubes of special length to allow time for the heat to get through. These tubes are made of solid-drawn brass with both ends expanded into the bored holes of the same tube plate. There is a syphon bottom and an automatic water joint which prevents back pressure.



SECTION.

FIG. 16.