THE COMBUSTION OF FUEL,

WITH SPECIAL REFERENCE TO

SMOKE PREVENTION.

BY

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PREFACE.

Much of the substance of the following pages was given in a lecture to the Association of Sanitary Inspectors, at the Carpenters' Hall, London, on March 4th, 1899. It was reproduced in *The Mechanical Engineer* immediately afterwards, with considerable additional matter. The whole has been collected, and is now presented complete for the first time.

In a lecture it is impossible to attempt to describe all the different appliances for the promotion of combustion, so that there are many machines and other apparatus not mentioned. Those which were originally given are typical examples of existing practice.

W. W. F. Pullen.

THE COMBUSTION OF FUEL.

WITH SPECIAL REFERENCE TO SMOKE PREVENTION.

Coal, of one quality or another, is almost the only fuel used for manufacturing purposes in this country, and it is principally with its application to the raising of steam for motive power and heating purposes in steam boilers that I propose to deal in this lecture.

It may be advantageous to first glance at the different kinds of coal which may be used in a boiler furnace.

Varieties of Coal.—By far the most extensively used are the bituminous coals, so called because they evolve gas on heating, which burns with a smoky, yellow flame, like bitumen. These coals differ considerably in properties, and are very generally used for steam production. They are also the coals which give most trouble in the way of smoke.

Anthracite is a very hard coal, containing but little volatile matter, and consequently burning with little or no flame. It produces next to no smoke.

Smokeless steam coals are those which, if not pure anthracite, approach it very nearly in character, while they burn with short flame and little smoke.

Cannel coal is used almost entirely for gas making on account of the large amount of volatile hydrocarbon it contains. Lignite is a comparatively young coal, and, as a rule, much inferior to those mentioned above.

Slack, dross, and smudge are names given to very inferior fuel, which can only be burnt economically with the aid of a good draught.

Professor Humboldt Sexton has classified coals in the following manner:—*

Kind of Coal.	Carbon per cent.	Hydrogen per cent.	Oxygen per cent.
Non-caking Coal, Long Flame...	75 to 80	5·5 to 4·5	19·5 to 15
Gas Coal	80 to 85	5·8 to 5	14·2 to 10
Furnace Coal	85 to 89	5·5 to 5	11 to 5·3
Coking Coal	88 to 91	5·5 to 4·5	6 to 5·3
Anthracite Coal	90 to 93	4·5 to 4	5·5 to 3

The analyses of a few different kinds of coal are given below:—†

	Wayne's Merthyr Steam Coal.	Tupton Slack.	Anthracite.	Bituminous.
Carbon.........................	87·49	70·04	91·5	87
Hydrogen	3·66	5·16	3·5	5
Oxygen	2·69	9·42	2·6	4
Nitrogen..........	1·17			
Sulphur	·79			
Ash	3·00	11·86	2·4	4
Moisture	1·20	3·52		
Calorific value in B.T.U.	15000	13400	15250	15400

Combustion.—The phenomenon of combustion may be described as the evolution of heat, due to rapid chemical combination, and is only complete when every constituent

* Fowler's "Mechanical Engineer's Pocket Book," p. 251, 1899 edition.

† These are analyses of samples which are fairly typical of different coals used in boiler furnaces.

of the fuel which is capable of combining with oxygen has taken up the maximum amount of that gas; or, in other words, has reached its highest state of oxidation. Thus, in any sample of coal the carbon must be burnt to carbon-dioxide (CO_2), the hydrogen to water (H_2O), and the sulphur to sulphur-dioxide (SO_2).

If the carbon had left the flue as carbon-monoxide (CO), combustion would be said to be incomplete, and a considerable waste of heat would be the result; because the carbon-monoxide may combine with further oxygen, and give out further heat in forming carbon-dioxide (CO_2).

The number of British thermal units (B.T.U.) evolved by the combustion of 1 lb. of each of the different constituents of coal are given below:—

1 lb. hydrogen burnt to H_2O (steam)	53,340	B.T.U.
1 lb. carbon burnt to CO_2	14,540	,,
1 lb. carbon burnt to CO	4,350	,,
1 lb. carbon-monoxide burnt to CO_2	4,370	,,
1 lb. carbon in the form of CO burnt to CO_2	10,190	,,
1 lb. sulphur burnt to SO_2	4,000	,,

When the reverse action takes place, heat is absorbed instead of given out by the constituents of the fuel; for example, if water is broken up into its constituents hydrogen and oxygen, then an amount of water (9 lb.) containing 1 lb. of hydrogen would have to receive 61,260 British thermal units before complete dissociation could take place.

The composition of atmospheric air is approximately:

By weight 23 per cent oxygen and 77 per cent nitrogen;
By volume 21 per cent oxygen and 79 per cent nitrogen;

and consequently, at least, 11·5 lb. of air will be required to supply 2·65 lb. of oxygen to burn 1 lb. carbon; and at least 34·6 lb. of air will be required to supply 7·97 lb. of oxygen to burn 1 lb. of hydrogen. Roughly speaking, each pound of carbon requires at least 142 cubic feet of air, and every pound of hydrogen requires 430 cubic feet of air for combustion.

For this combustion to be perfect each molecule of combustible matter must come into contact with corresponding molecules of oxygen, and consequently the air supplied must be very intimately mixed up with the combustible matter while it is at a temperature at which chemical combination can take place.

In this lies the secret of the economical burning of fuel and the prevention of smoke.

To permit of the intimate contact of the constituents of the fuel with the oxygen of the air much more of the latter must be supplied than the figures above indicate, because it is no easy matter to bring about these suitable conditions for combustion.

It must be evident at the outset that there is much greater probability of a thorough mixture when the air is admitted to the fuel in a large number of small jets than by a few large jets.

It must also be evident that the less excess of air supplied the higher will be the temperature of combustion, and the smaller the quantity of heat carried away up the chimney and wasted.

We now see the kind of problem which the engineer has to solve in the economical combustion of coal. An excess of air is absolutely necessary, but that excess must not be greater than that required to produce complete combustion.

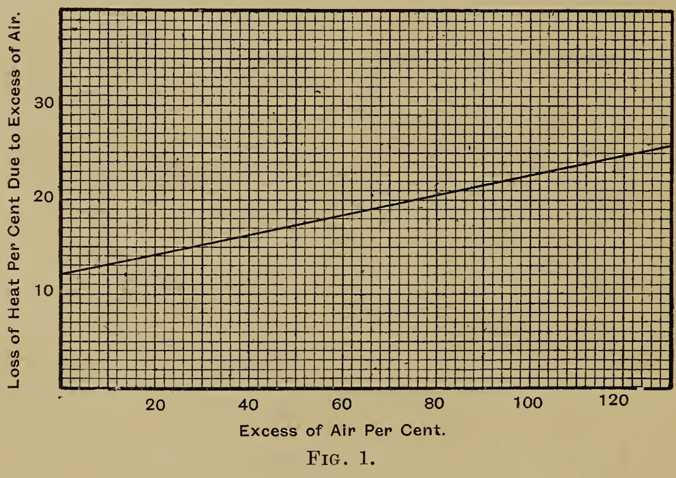


Fig. 1.

Some idea of the loss of heat through excess of air may be gathered from the accompanying diagram (Fig. 1).

The quantities along the base represent the percentage excess of air, and vertically are plotted the corresponding losses of heat per cent. The gases are here assumed to pass into the chimney at about 600 deg. Fah.

An excess of air dilutes the chimney gases and makes the percentage of carbon-dioxide (CO_2) less than would be the case if there were less air. Hence, conversely, an increase of CO_2 indicates a decrease in the excess of air if combustion is complete.

An analysis of the flue gases at once indicates the excess of air by the amount of free oxygen which they contain. Also, a knowledge of the CO_2 will give a tolerably accurate value of the excess of air if combustion has been complete.

The Econometer.—An instrument which indicates continuously the percentage of CO_2 in the chimney gases is supplied in this country by Messrs. Meldrum, of Manchester, and is shown in the next illustration. It is called the "Econometer," because the percentage of CO_2 which it measures also indicates the relative economy of the furnace.

The relative density of some of the constituents of furnace gases may be obtained from any book of tables. They will be found to be:—

Carbon-dioxide (CO_2)	·00198
Carbon-monoxide (CO)	·00126
Oxygen	·00144
Sulphur-dioxide (SO_2)	·00288
Nitrogen	·00126

It will be noticed that of all these sulphur-dioxide is the heaviest, but as there is always only a very small quantity its influence in comparison with the large quantity of carbon-dioxide will be almost inappreciable. If there is in the products of combustion a relatively large quantity of CO_2, we conclude that the combustion has been complete without a great excess of air; but should the quantity of CO_2 be small, then the excess of air has been very much greater than is necessary, and, consequently, much heat has been carried up the chimney thereby. If, on the other hand, there appears in the chimney gases more than a trace of carbon-monoxide, combustion has not been complete, and heat has been wasted through imperfect combustion. In modern boiler furnaces not more than a trace of CO should be produced.

The difference in density of the constituents of the chimney gases is made use of in the econometer. Referring to the illustration, a chemical balance is situated in a

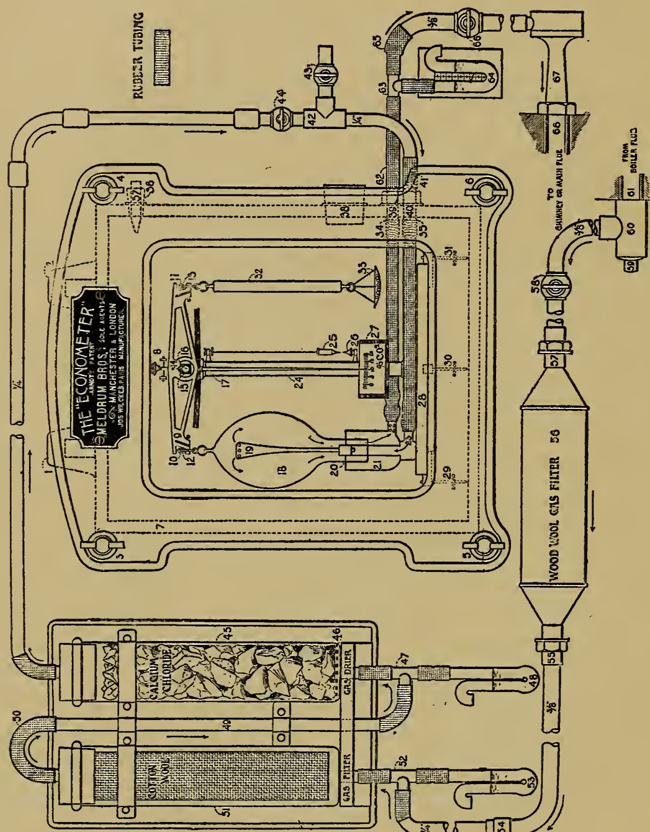


Fig. 2.—The Econometer.

case with a transparent front which is bolted to the wall. To the left arm of the balance is suspended an inverted glass vessel 20, into the interior of which the fixed pipe 19 is placed. This pipe is connected to the flue, and through it are aspirated the chimney gases. If the balance pointer indicates zero when the inverted weighing globe is full of air, then the introduction of a heavier gas, such as CO_2, would cause the left end of the balance arm to move downwards; and if the balance is *very stable*—that is, if its of centre of gravity is, comparatively speaking, far below the suspending knife edge—the amount of depression of the left arm, and consequently the movement of the pointer, will indicate the amount of increase of weight in the weighing globe. This is the principle of action of the econometer.

A connection is made with the flue at 61, through which the gases are taken to the wood wool filter 56, from which it passes to the cotton wool filter 51. They are then passed through the calcium chloride tube, in which all moisture is extracted, after which the gases are taken direct to the weighing globe by the tubes 23 and 19. To produce a continuous circulation of gases through the instrument the lower end of the weighing globe dips into the vessel 21, which is connected by the pipes 22, 62, and 68, to the chimney or main flue, and which acts as an aspirator.

This instrument gives a continuous record of the state of combustion by registering the percentage of CO_2 in the furnace gases, and that the record is accurate enough is shown by the following comparisons, which are taken from a number. The percentage of CO_2 was also determined simultaneously by an Orsatt apparatus. In each case the figures given are the average values of a large number of determinations :—

CO_2 by Econometer	16·84	15·56	16·27
CO_2 by Orsatt apparatus ...	16·83	14·92	16·38

If there were no excess of air and the combustion complete, there would be a little over 20 per cent of CO_2 by volume in the products of combustion. Fifteen per cent of CO^2 is considered very good, but from 14 to 11 per cent is more common, while 6 and 7 per cent is not unknown. Leakage of air through the brickwork of the flues often occurs, and this materially reduces the percentage of CO_2 as well as the efficiency of the boiler. This can be detected with the econometer by connecting the instrument to a point in the flue as near the fire as convenient, and at the same time with the chimney. An observation is taken with one connection, and after switching over to the other connection another observation is taken. The difference in the readings of the econometer is chiefly due to the air leakage. The leakage of air into the flues is the chief cause of error in the econometer when there is any, and the supplementary connection is sometimes awkward to provide in an existing boiler setting.

Although complete combustion is much to be desired in populous districts, it does not necessarily produce maximum economy under all conditions. As an instance of what I mean, let us take the two methods of burning coal gas. With the Bunsen burner we obtain a thorough mixture of air with the gas before combustion takes place, and the result is a non-luminous flame. With the fishtail or batswing burner there is no previous mixture of air with the gas, and some of the carbon becomes separated in the flame and rendered incandescent, producing a luminous flame. The latter is a good radiator, while the Bunsen flame is a bad radiator. As a great quantity of the heat generated in a boiler furnace reaches the furnace plates by radiation, it is evident that flame in a furnace is very desirable, and is absolutely necessary unless the amount of heating surface is very large, and so disposed that the furnace gases can be made to give up their heat by contact.

The analogue of the Bunsen flame is not found in the boiler furnace, as the air for supporting combustion does not mix with the gaseous part of the fuel, prior to its introduction to the furnace, as in the Bunsen burner. What actually happens more nearly approximates to the chain of events in the batswing burner, where a luminous flame is produced.

When green coal is first placed upon the fire, the volatile part of it, consisting of hydrocarbons, is very quickly distilled off, leaving behind the non-volatile portion called coke. These hydrocarbons burn with a good deal of flame, and the major portion of the heat thus produced finds its way to the furnace plates by radiation. The heat of combustion of the residue is given to the water partly by radiation from the incandescent coke and partly from the contact of the hot gases with the heating surfaces.

If the hydrocarbons before igniting are thoroughly mixed with air at a sufficiently high temperature, complete combustion will take place without smoke. But should the supply of air be insufficient, or the air not thoroughly mixed with the hydrocarbons, partial combustion will take place, and some of the carbon will be condensed by the breaking up of the hydrocarbons. The carbon is separated in the form of lamp black, or soot, and in the finely-divided state as found in the chimney varies in appearance from a faint grey to the densest black, depending much on the relative quantity.

Most authorities agree that, when once formed, soot burns with great difficulty even in contact with air at a high temperature; hence it is very necessary to prevent its formation rather than attempt to do away with it after it is formed.

I mentioned just now that complete combustion may not under certain circumstances be the most economical. For instance, a large excess of air may produce complete combustion without smoke, but with the result that an enormous amount of heat was being wasted in heating the excess of air and sending it up the chimney. On the other hand, a very slight amount of smoke indicates that combustion is not quite complete, but at the same time it also indicates that the excess of air is probably small, and consequently the waste on that account is not large. This is why some owners of works prefer a slightly smoky chimney.

Methods of Firing.—It has been shown by experience that very careful hand-firing with most kinds of coal will prevent smoke if the fires are not forced too hard, but where one careful fireman can be found there are many who cannot be placed in the same category.

The best method of firing is believed to be that called the "alternate method," where one side of the fire is fed at a time, so that the volatile gases given off by the green coal are ignited by the incandescent fuel on the other half of the grate. During the time of firing, cold air in too large a volume enters the furnace through the firehole door, and a considerable waste in the chimney gases occurs. The damper should be lowered before firing, so as to reduce the draught, but this is seldom done except by the most careful stokers, when the damper gear is very handy. An uneven fire, or one with holes, tends to produce the same result, and, therefore, it is not surprising that mechanical firing should be resorted to where feasible.

The other methods are the "spreading" system in which the fire is covered uniformly all over with green fuel, and the "coking" method in which the green fuel is fed in front of the fire-door and after coking is pushed down the bars.

The chief features of mechanical stokers are—even fires, absence of uneven air supply, uniform combustion, and with a large number of furnaces a reduction in the cost of labour.

They are unsuitable for large coal, and work best with dry fuel. They work equally well with very inferior fuel.

They are of two kinds: (1) coking stokers, in which the fuel is first coked on entering the furnace, and after the volatile matter has been distilled the residue is pushed down the grate and burnt. (2) Sprinkling stokers, in which the fuel is evenly scattered or sprinkled over the fire without previous coking. The coking stoker gives a smokeless chimney, but the sprinkling stoker produces the most rapid combustion, and in some cases is more economical. It is also possible to adjust the rate of combustion with them through a wide range.

Before describing any mechanical stokers I wish to draw attention to an appliance which reduces smoke, and at the same time enables a cheap fuel to be rapidly and economically burnt on an ordinary boiler grate. I refer to the forced draught produced by a steam jet; a typical example of which is Messrs. Meldrum's appliance in the next illustration.

Meldrum's Forced Draught Furnace.—This furnace is very simple in construction, and very effective for the purpose for which it is designed, namely, the burning of inferior fuel rapidly and economically. It also has the virtue of producing very little smoke. The front casting (Fig. 3) is of the usual type, except that the ashpit is closed in, and a couple of steam jet blowers inserted in it. Steam is supplied to the blowers by a pipe which conveys it from the steam space in the boiler into a cast-iron superheater over the fire hole door on the inside of the furnace, and thence to the blower tubes. The superheating of the steam assists in heating the air, tending to improve combustion; but its chief purpose is to prevent condensation on the boiler plates. To prevent smoke upon the introduction of green fuel, a door is placed in the casting behind the bars to admit a supplementary supply of air from the ashpit to the top of the fuel, to enable the volatile hydrocarbons to be burnt before they leave the furnace. This door is shown at C (Fig. 6). It is operated and adjusted by the handle D.

On account of the noise of the steam jets, which

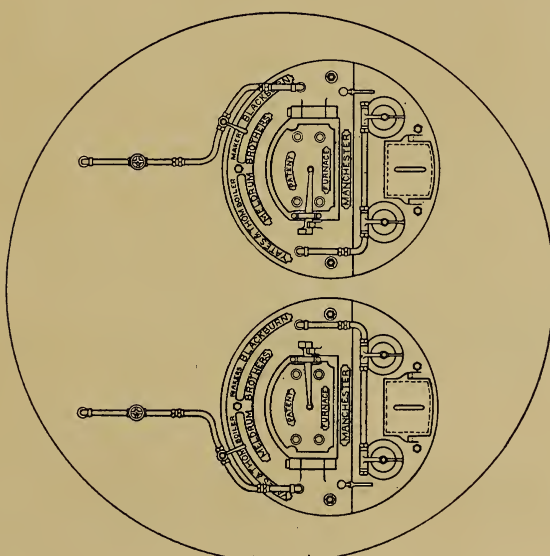


Fig. 3.—Front Elevation, Meldrum's Forced Draught Furnace.

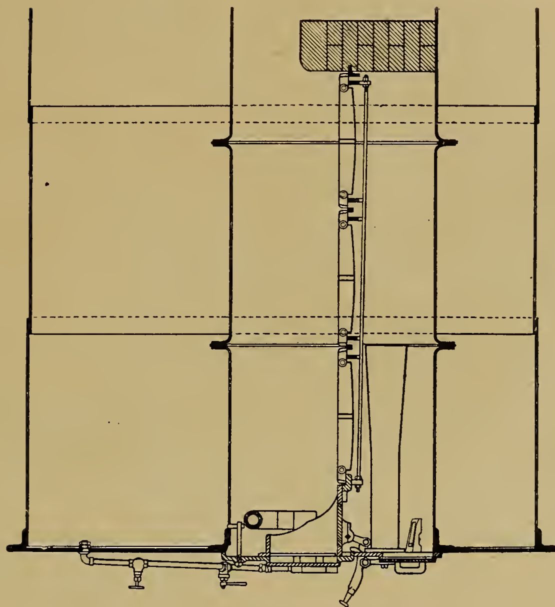
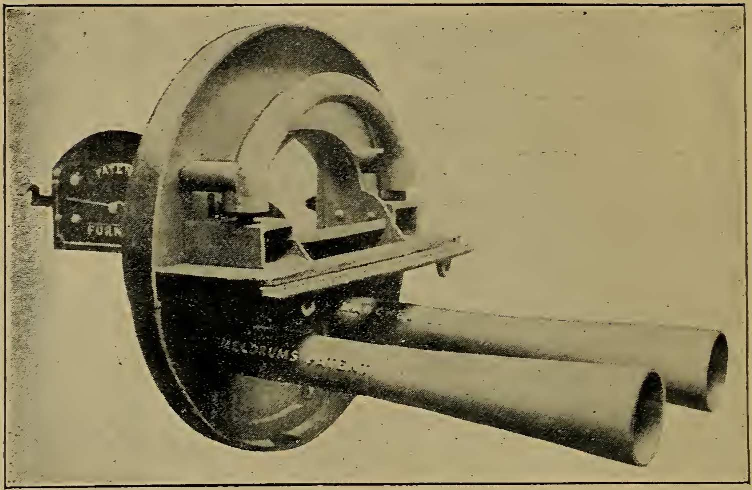


Fig. 4.—Longitudinal Section, Meldrum's Furnace.



Internal View of Meldrum's Forced Draught Arrangement.

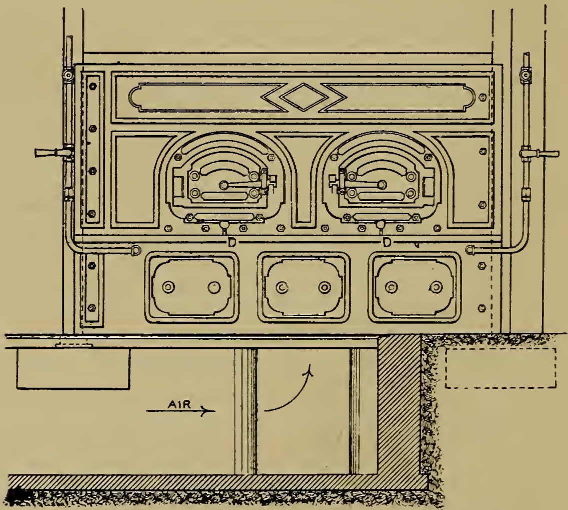


FIG. 5.—Front View of Meldrum's Silent Blower, as Applied to Water-tube Boiler.

becomes a nuisance when the boiler is in a confined space, Messrs. Meldrum have introduced their silent blower, in which the air is taken in from a conduit under the floor of the boiler house, and the steam jet is also under ground with no connection to the atmosphere in the boiler house. This has been much appreciated in electric lighting and similar works.

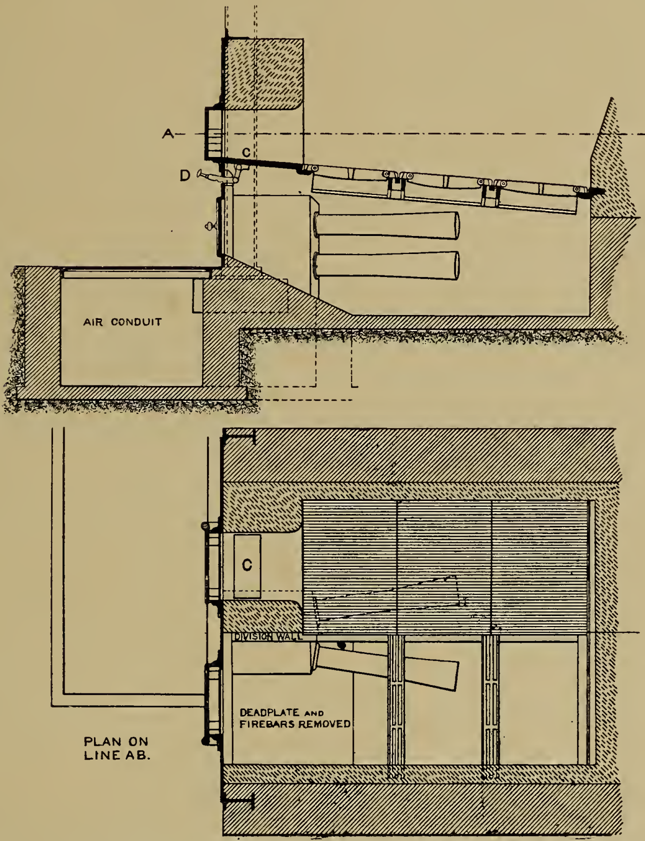


FIG. 6.—Sectional Elevation and Sectional Plan of Meldrum's Silent Blower.

Another modification of the silent blower is shown in the illustrations, Figs. 5 and 6. Here the blowers are fixed in a cast-iron box, which is directly connected to an air conduit running along the front of the boiler. The adaptation is to a Babcock and Wilcox boiler.

The application of forced draught produces a greatly increased rate of evaporation, generally accompanied by an increased duty of the furnace. This, at first sight, might appear an anomaly, but we must bear in mind that the artificial draught is very easily controlled, and consequently the best ratio of air to fuel is easily obtained. Further, it is not necessary that the products of combustion should leave the boiler flues at a comparatively high temperature for the purpose of producing sufficient draught, hence means may be adopted to extract as much heat as possible from the chimney gases.

The addition of the steam in the blast from the steam jet also probably has something to do with the rapid carrying away of heat almost as soon as it is produced by combustion. At the high temperature of the furnace the hydrogen and the oxygen forming the steam become dissociated, and in so doing absorb an enormous quantity of heat

(about 53,000 B.T.U. for every 9 lb. of steam);

which is given back again to the products of combustion in the combustion chamber further on down the flue, where the temperature is such as to allow them to reunite again; thus distributing the heat more evenly over the heating surface of the boiler. It is often found that the temperature of the products of combustion, as they leave the boiler flues for the economiser, is higher with forced draught than without it. Here, I believe, lies one reason for the same or increased duty with forced draught. The higher temperature of the gases surrounding the economiser tubes enables heat to pass into the feed water more rapidly than at a lower temperature, with the result that the feed water receives more heat, and, therefore, enters the boiler at a higher temperature, which is well known to conduce towards increased economy, similar to that of the live steam feed heater.

Mason's Forced Draught Furnace.—The accompanying illustrations, Figs. 6A and 6B, show a form of forced draught furnace suitable for application to boilers of the Lancashire and Cornish type, constructed by W. F. Mason, Limited, Engineers, Longsight, Manchester, in accordance with Mr. Duff's patents, and which possesses some special features. The furnace, it will be seen, is of somewhat peculiar construction. It is not furnished with the usual firegrate, but has, instead, an oval-shaped tube, built up

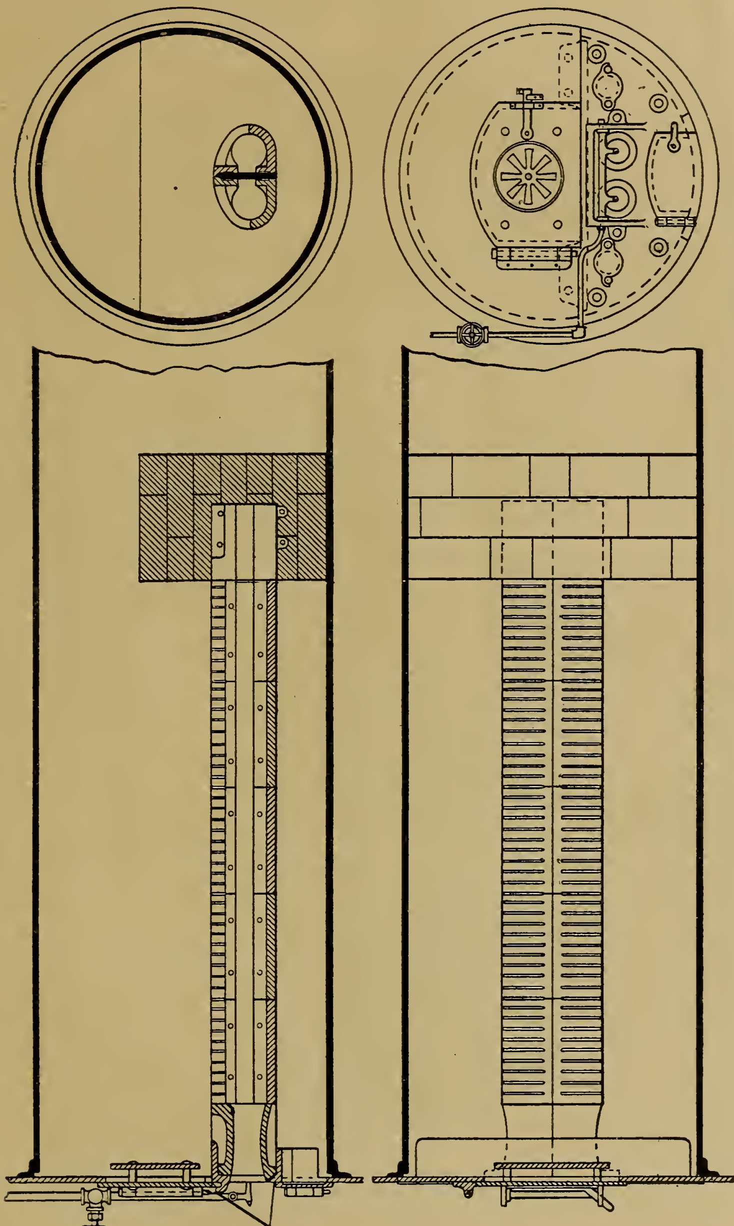


Fig. 6a.—Views Showing General Arrangement of Mason's Forced Draught Furnace.

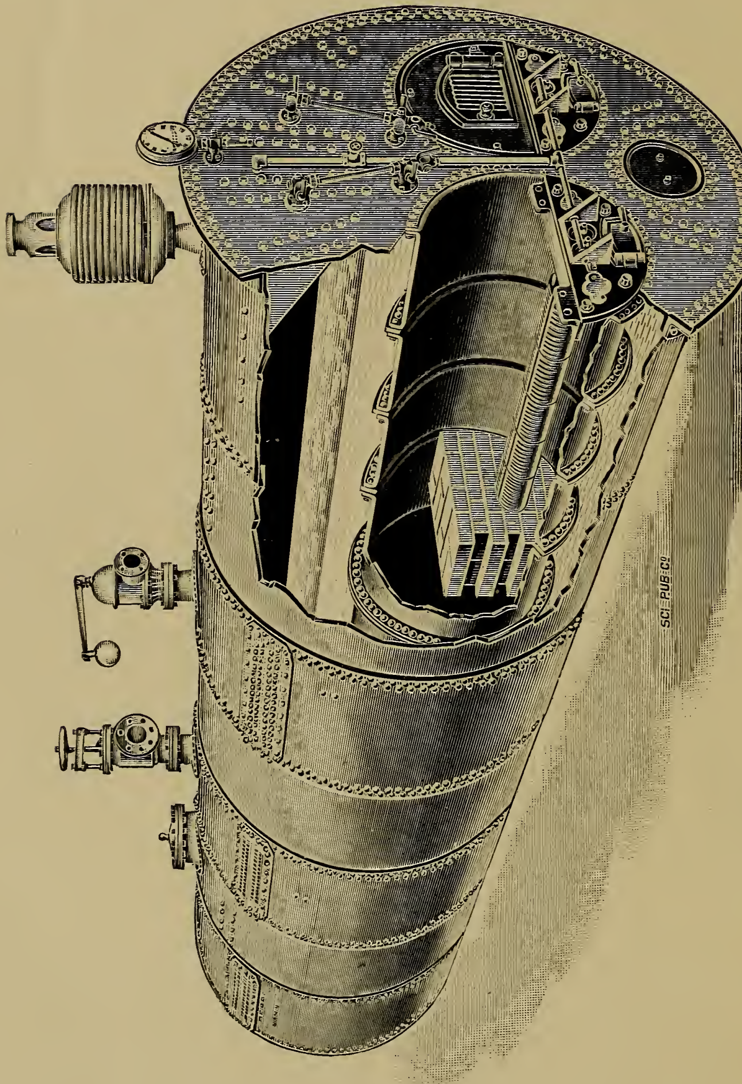


FIG. 6B.—Mason's Forced Draught Furnace Applied to Lancashire Boiler.

in sections extending from the fire door to the bridge a little above the bottom of the furnace tube. The perforated tube is provided with a vertical longitudinal diaphragm, so arranged that the bolts with which the various sections are held together are protected from the action of the fire. At the same time the diaphragm acts as a supporting rib for the tube. The forced draught, which is supplied by a steam blower, passes through the interior of the tube and escapes through the circumferential slits into the mass of fire which is built straight up from the bottom of the furnace tube.

By this arrangement the quantity of fuel which can be operated upon is obviously largely in excess of anything that can be obtained with the use of an ordinary grate, a point of considerable importance when dealing with low-grade fuels, since it permits of heavy charges, and hence avoids the necessity for firing at frequent intervals and the inrush of cold air which then, of course, takes place. In starting the fire, ashes are first filled in through the fire door up to the level of the top of the blower. A fire is then built upon the top of the ashes, and, as more ashes are produced, some are raked out from below the furnace tube through the ash door. The process of firing and cleaning can then be made continuous without any interruption in the raising of steam.

One of the advantages claimed on behalf of this furnace over others of a similar kind is that the furnace can be operated so that the combustion of fuel is not interrupted at the time the ashes are being removed. This not only gives steady and continuous steaming, but is of further advantage when using inferior fuels, since they contain a larger proportion of incombustible matter than good coal, and hence cleaning becomes oftener necessary, and it is hardly necessary to say that if the fires have to be brought to a stand for any length of time in order to rake out the ashes the steaming of the boiler is interfered with.

Proctor's Coking Stoker.—This machine and furnace is shown in section and end elevation in Figs. 7 and 8. Its action is altogether different to that of the same maker's sprinkling stoker. The fuel is fed into a pair of hoppers A, from which it gravitates on to feeding rams B, a pair being fitted to each furnace. These rams are given a reciprocating motion by the oscillating arms C, which derive their motion from the cam plate D, fixed upon the driving shaft

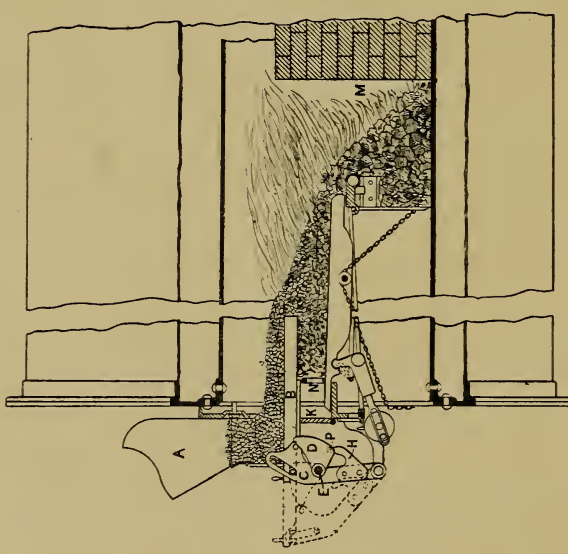


FIG. 7.—Longitudinal Section of Proctor's Coking Stoker.

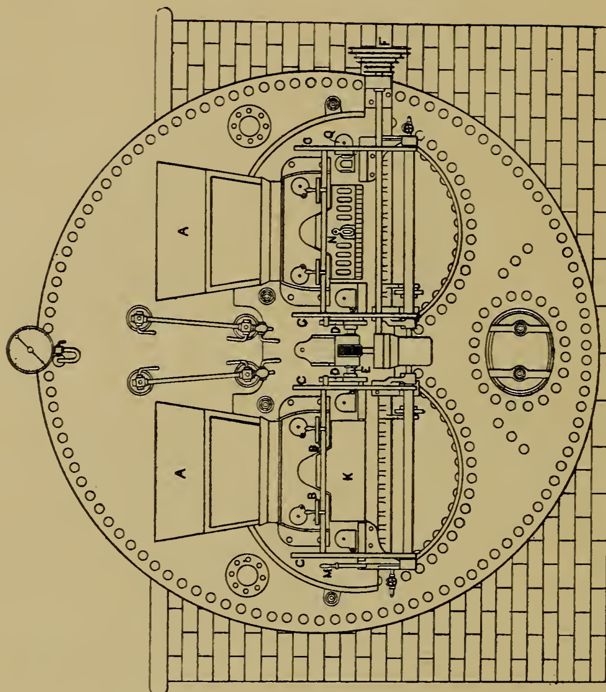


FIG. 8.—Front Elevation of Proctor's Coking Stoker.

E, which rotates uniformly, being driven by the shaft and cone pulleys F through two worms and worm wheels.

The arm C has a pin fixed in it engaging with and driven by the cam plate D, which turns in anti-clockwise direction. When the arm has arrived in the dotted position, the cam D disengages itself from contact with the pin and continues to rotate, leaving the arm C behind, until the pin P in the cam engages with the scolloped plate H on the arm C, when it returns this arm with a greater speed than that at which it was withdrawn. This reciprocation of the distributing rams B carries a charge of fuel forward towards the fire at the quicker rate, and at the same time skims over the top layer of more or less coked fuel, distributing it evenly over the fire. The slower withdrawing of the rams B leaves the charge of fuel behind on the fire, because the head of fuel in the hopper prevents the return of the charge. The reciprocating motion of every other bar carries the incandescent fuel along the grate from which it falls into the ashpit M. The bars receive their motion in the same manner as those of the sprinkling stoker.* The feeding rams can be worked by hand if such should at any time be desired. A steam bridge is fitted as in the sprinkler stoker. The firehole door K swings about a centre, and is adjusted by the handle M. Inside the door at N is a grid for the admission of air, a corresponding sliding grid being situated at Q. In the right hand furnace, Fig. 8, the fire-hole door is removed.

It is further claimed for this stoker that, on account of the shape of the fire, the flames never touch the ring joint at the junction of furnace and end plate, consequently the joint is not likely to give any trouble.

The stoker is entirely smokeless when not forced beyond the coking capacity of the furnace.

The Murphy Furnace, manufactured by Messrs. Clench and Co., of Chesterfield, is of a novel kind. It is external to the boiler, and has its firebars placed transversely in two rows, while they slope downwards at a considerable angle, like an inverted roof.

Fig. 9 shows a transverse section of one of these furnaces. On each side of the fire is a coal magazine A from which the coal gravitates on to a ledge or coking plate B. It is pushed into the fire by pusher plates or castings C, the

* A description of the sprinkling stoker is given later (p. 33).

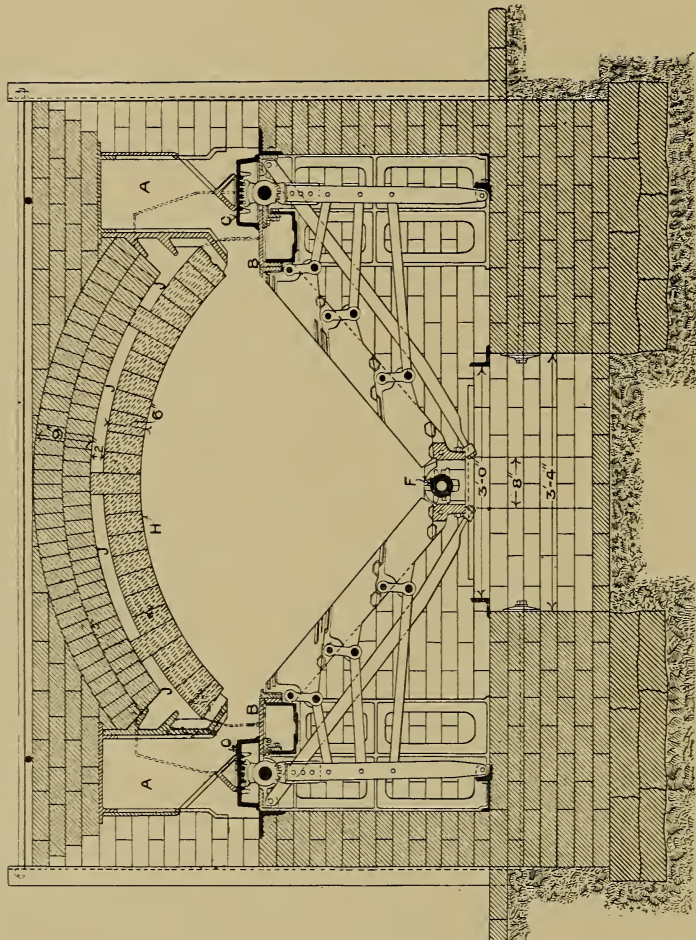


FIG. 9.—Transverse Section of Murphy Furnace.

undersides of which are provided with a toothed rack. This rack gears with the quadrant of a spur wheel, which is made to oscillate slowly; the shaft upon which it is fixed being connected to a long oscillating rod D (Fig. 10) by a crank and a small connecting link E. This long rod runs across the front of one or more boilers, and operates the pusher plates as well as the clinker breaker F at the lower ends of the fire bars. This latter is driven by means of a ratchet G, and thus continues to rotate during the time that coal is being fed upon the fire. It breaks up any clinker that happens to fall down the bars, by teeth on its exterior surface, and prevents the ash accumulating in the lower

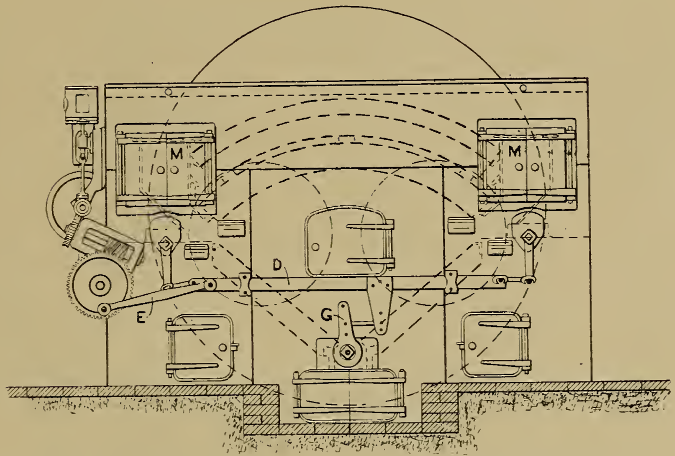


Fig. 10.—Front Elevation of Murphy Furnace as applied to a Lancashire Boiler.

part of the fire. It is hollow and connected to the chimney flue so that a current of air is continually passing through, keeping it cool. The bars are made to reciprocate slightly by the same mechanism that operates the pusher plates, so that the fuel is continually travelling down the bars, being coked while at the coking plate near the top of the bars. A firebrick arch H covers the fire. Air is admitted from the air chamber J above the arch in small jets along the top of the green fuel at the skewback, and the large number of these small air ducts permits a thorough admixture of air and the hydrocarbons given off by the distillation of the green fuel during the process of coking, the incandescent coke that is left being burned upon the firebars. The heated air and hydrocarbons, after mixing together, pass between the incandescent firebrick arch above and the incandescent fuel on the bars below,

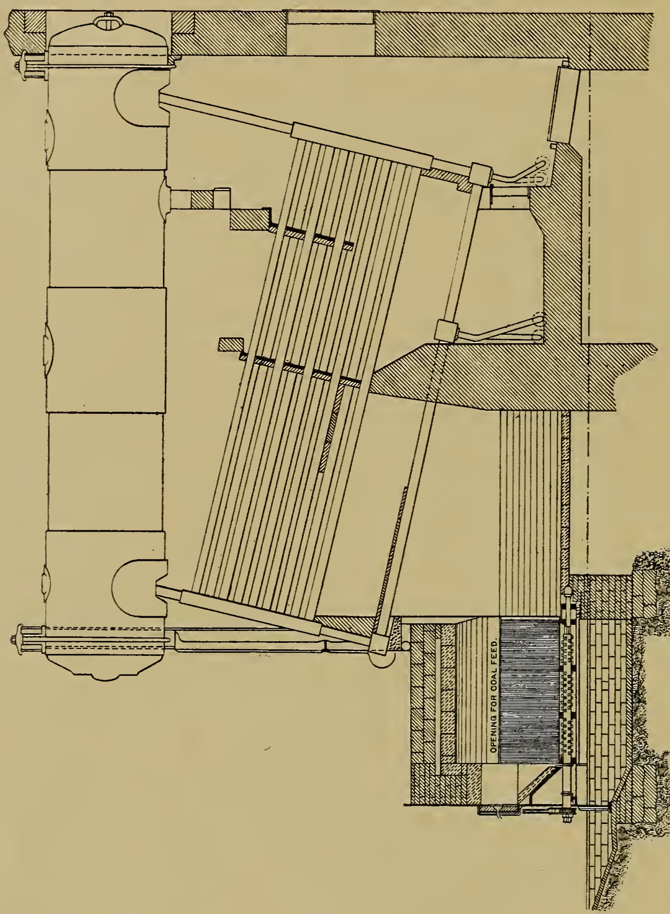


Fig. 11.—Longitudinal Section of Murphy Furnace as applied to a Water-tube Boiler.

and can hardly fail to be thoroughly burnt before they emerge from the furnace to the boiler-heating surfaces.

This permits of the most complete combustion, and consequently an entire absence of smoke.

Figs. 11 and 12 show the application of this furnace to a water-tube boiler, for which it seems well adapted. Figs.

10, 13, and 14 also show one way of applying it to a Lancashire or Cornish boiler.

The channel through which the air enters above the firebrick arch is well shown in these figures. The arched covering to the furnace is hollow, the cavity between the outer and inner parts being used as the channel through

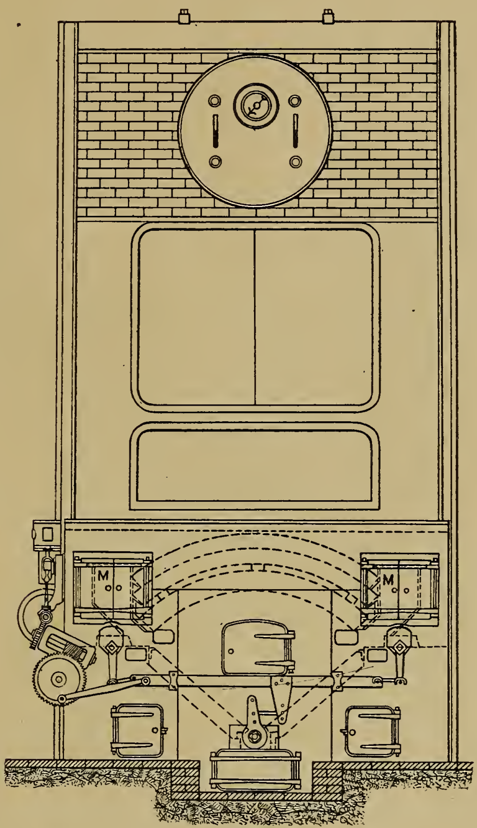


FIG. 12.—Front Elevation of Murphy Furnace as applied to a Water-tube Boiler.

which the air must pass on its way to the green fuel on the coking plates.

Heat that would otherwise be radiated to the atmosphere is thereby caught by the incoming air, and while radiation is diminished, the higher temperature of the air promotes more perfect combustion.

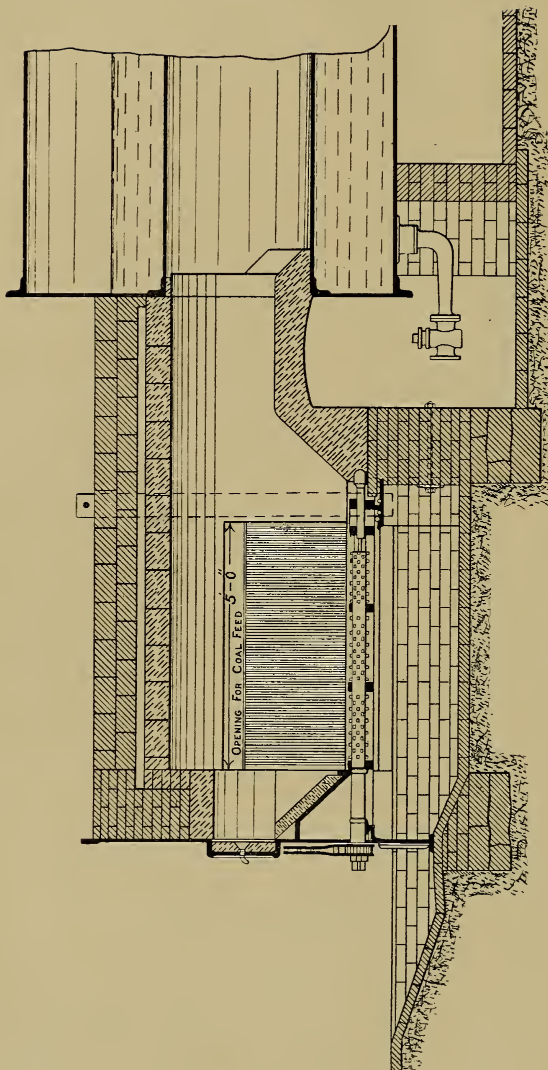


Fig. 13.—Longitudinal Section of Murphy Furnace as applied to a Lancashire Boiler.

The chief peculiarity of this furnace is the length of aperture through which green coal can be fed to the fire; allowing a thin layer and perfect coking before it comes well on to the firebars. The same also allows a very perfect mixing of the air, and fuel distillates, which tends to prevent smoke.

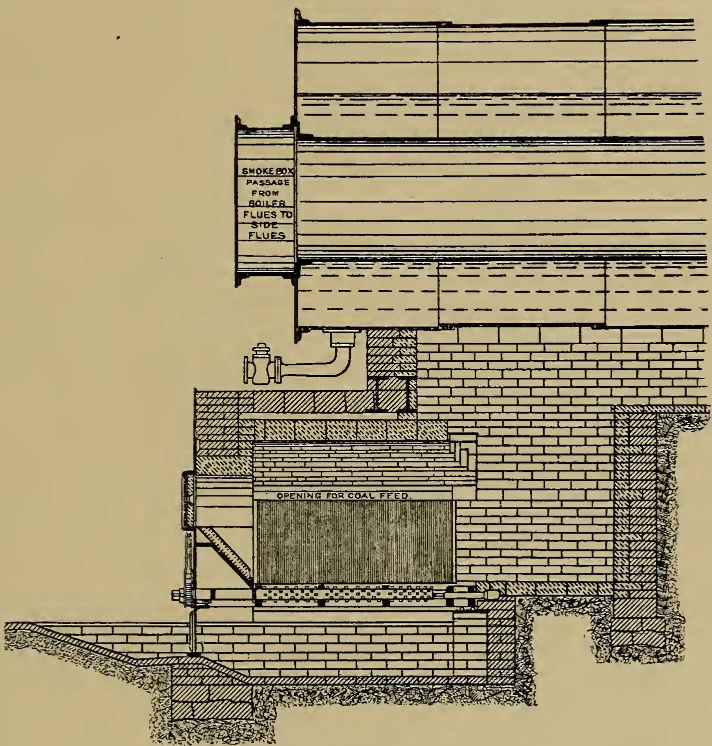


FIG. 14.—Longitudinal Section of Murphy Furnace as applied to a Lancashire Boiler.

The fuel is supplied to the magazine through the doors M shown in the front of the boiler, and the air supply to the coking plates over the fire-brick arch is regulated by a grating for the purpose on the front of the boiler.

Recently the makers of this furnace have had one of them tested by Professor Ripper, and one paragraph of his report, referring to the prevention of smoke, is very pertinent to the question, and I venture to repeat it here.

"The chimney was closely observed during the trials, and was found to be perfectly free from smoke. Nor was this due to the composition of the fuel (Boythorpe slack), for it was found that by raking down the green fuel from the coking plates (a procedure contrary to the rules prescribed for working the furnace) dense volumes of black smoke were emitted from the chimney."

At times, faint grey smoke was observed for periods not exceeding $1\frac{1}{2}$ minutes, generally following any disturbance of the fires. It was found that the fires might be raked to any extent without causing smoke provided that the green coal was not prematurely taken from the coking plates. To further test the furnace as a smoke burner, a short trial was subsequently made with Shire Oak slack. With this coal, although it is noted for smoke making, the chimney could be kept perfectly free from smoke without any unusual precautions being taken.

In the trials above referred to the rate of combustion was such as to consume 15 lb. and 23 lb. of fuel per square foot of grate per hour. Up to 50 lb. can be burnt in this furnace, which should be well adapted for the destruction of refuse, with some little modification.

Meldrum's "Koker" Stoker.—The mechanical stoker introduced by this firm is of the coking type. (See Figs. 15 and 16.) It is extremely simple, and is arranged for use with the same makers' system of forced draught. Fuel is fed into a hopper A, at the base of which is a casting B in the shape of a quarter cylinder, which is fixed to, and oscillates with, a spindle driven by a crank and connecting rod, as shown in the front view of the stoker at C. The backward movement of the quarter cylinder or rocking plate allows the fuel to fall towards the opening into the furnace, while the forward motion pushes the fuel on to the coking plate D. The fire bars have a wave-like contour, for the purpose of breaking up any clinker that may form on them. They are all moved forward together, but are withdrawn one by one, thus leaving the incandescent fuel that much nearer the clinker chamber. The bars are operated by a series of cams on a hexagonal shaft E traversing the front of the boiler and driven by a belt from an overhead shaft and through worm gear in the box F.

The blowers H are of the silent type, and deliver into a shallow box K opening directly into the ashpit under the

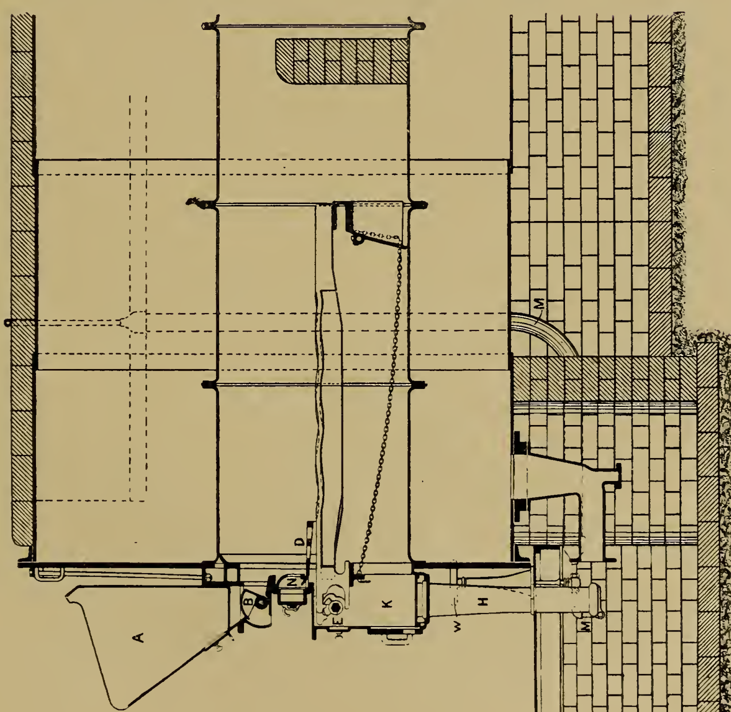


FIG. 15.—Longitudinal Section of Meldrum's "Koker" Stoker.

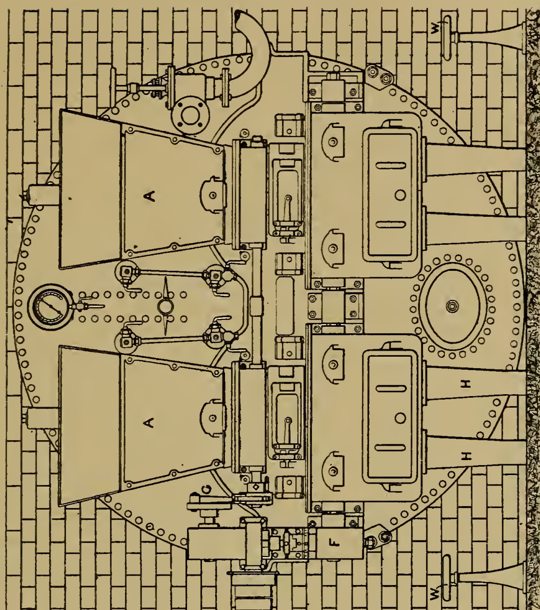


FIG. 16.—Front Elevation of Meldrum's "Koker" Stoker.

bars. Steam is supplied to the blowers by a pipe M, which traverses the ends of the side flues for the purpose of superheating it.

By a very simple arrangement this stoker is able to overcome the difficulty which some coking stokers labour under, while relying on natural draught, of not being capable of being forced. The fuel on the coking plate is then propelled on to the bars so rapidly that the coking process has not time to approach completion, with the result that the green fuel travels down the bars in too great a quantity and smothers the fire. To get over this difficulty Messrs. Meldrum have arranged a perforated coking plate D to receive the fuel from the pusher, the perforations allowing a supply of air to percolate through the green fuel at the back of the fire from the ashpit, and thus aid combustion in that region, which allows of the fuel being worked forward more rapidly on to the bars, but in a state of coke instead of green fuel. The makers prefer to arrange for a supplementary supply of air just above and behind the coking plate at N, because this supply can be nicely regulated to suit the rapidity of combustion and prevention of smoke. The handwheels W are for the purpose of regulating the supply of steam to the blowers.

Messrs. Meldrum have burnt as much as 40 lb. per square foot of grate per hour, without smoke, with this stoker.

Appended are details of a test of a "Koker" stoker applied to a Lancashire boiler:—

Date of test	Sept. 9, 1898.
Duration	8 hours.
Size of boiler	27 ft. 6 in. by 7 ft. 6 in.
Fuel	slack.
Total fuel burnt	7,000 lb.
Fuel burnt per hour	875 lb.
,, ,, per sq. ft. grate	29·1 lb.
Total ash	234 lb.
,, per cent	3·3.
Total water evaporated	67,000 lb.
Water per hour	8,375 lb.
,, lb. fuel, from cold feed	9·57 lb.
,, ,, from and at 212 deg.	11·02 lb.
Steam pressure	65·6 lb.
Feed temperature	99·9 deg. Fah.
Temperature of downtake gases	980 deg. Fah.

Orsat gas apparatus readings :
CO_2 ....11·9 per cent.
O ....7·4 per cent.

Observations taken every half hour with Orsat apparatus.

Proctor's Shovel or Sprinkling Stoker.—The main principle of this machine is the feeding of the fuel into a small box, from which it is kicked on to and scattered over the fire by a shovel or beater.

A longitudinal section of the machine and furnace is shown in Fig. 17 and a front view in Fig. 18.

Fuel is fed by hand or by mechanical means into the cast-iron hopper A, from which it gravitates into the ram box B, which communicates with the shovel boxes C. It is pushed into the shovel boxes by the ram I in definite quantities at regular intervals, and is then scattered over the fire by the sudden forward motion of the shovel W. The tappet cams compel the sprinkling shovel to withdraw different amounts at three consecutive movements, thus giving to the coal three different impulses and completely covering the whole grate. The ram I receives its reciprocating motion from the arm V, fixed upon the short shaft T, which in turn is actuated by the arm N. This latter arm is made to oscillate by a pin in the disc O, which is driven continuously by the vertical shaft J, which is driven by the shaft K. This latter shaft is driven by a rope on the speed cones L to allow of varying rates of feed, and consequently of combustion.

The shaded pin fixed in the rotating disc O engages in the slot of the arm P, and gives it an oscillating motion, turning about a pin not shown in the figures. The arm P is really a bell crank lever, having a couple of horizontal arms, with teeth at their extremities which gear with teeth on the ends of the arm N. In this way a reciprocating motion is given to the pusher rams I.

The shovels W are made to recede from the fire by tappet cams Z (see Fig. 19) coming in contact with a tappet arm F, fixed upon the shovel spindle M in the tappet box X, which also contains lubricant, that is continually supplied to the parts subject to wear by a chain in the ordinary way. After the cam shaft has turned through a given angle, the tappet arm is released, and the shovel, shovel shaft, and attached arm Y are suddenly moved together by the recoiling of the helical spring H,

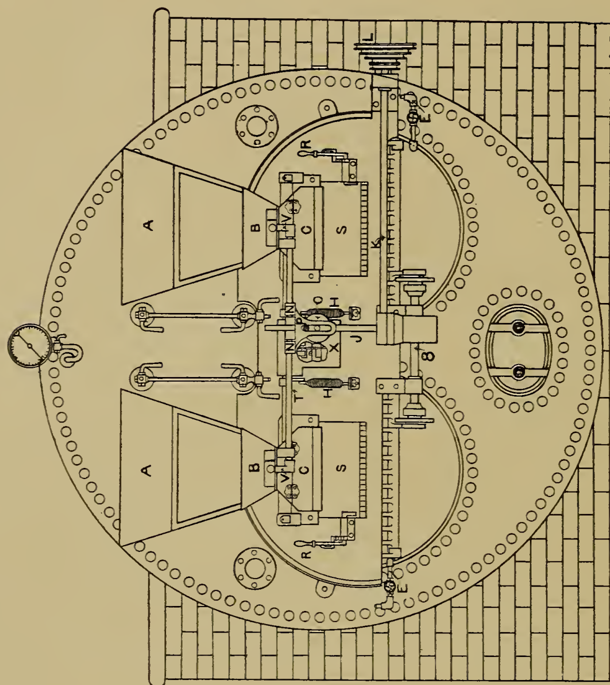


Fig. 18.—Front Elevation ; Proctor's Sprinkling Stoker.

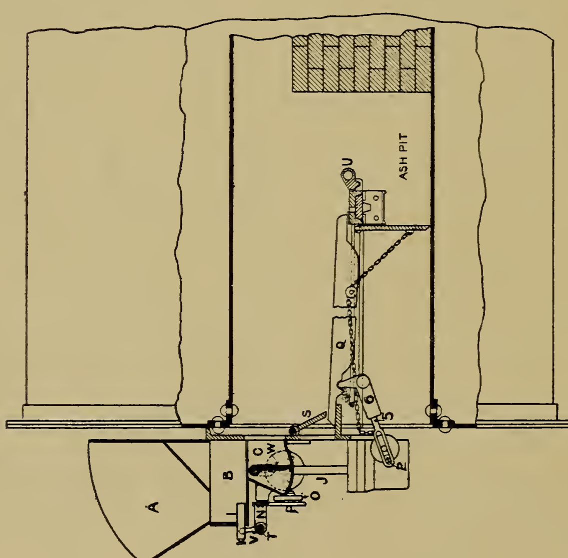


Fig. 17.—Longitudinal Section ; Proctor's Sprinkling Stoker.

and coal is sprinkled thereby over the fire (see Fig. 20). The firedoor S is moved and adjusted by the lever R, and is used for hand-firing if necessary, when the mechanical

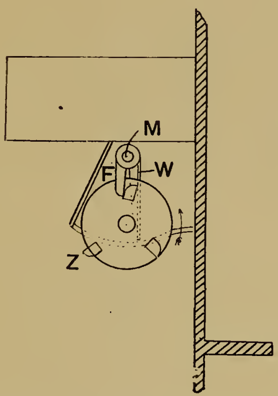


FIG. 19.—Tappet Cam Arrangement ; Proctor's Sprinkling Stoker.

stoker is not being used, and also for the admission of supplementary air above the fuel on the bars.

The fire-bars Q are supported at their extremities by cast-iron bearing plates, that at the back end of the furnace

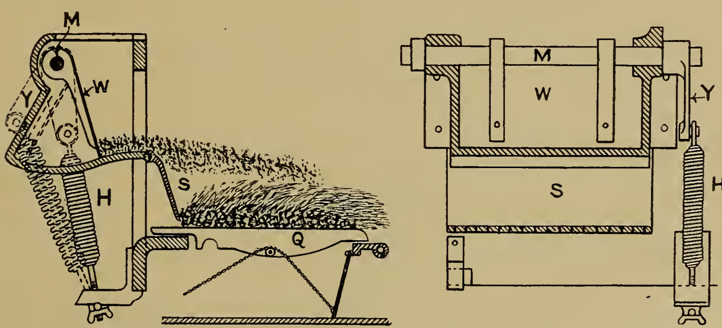


FIG. 20.—Showing Action of Sprinkling Shovel ; Proctor's Stoker.

U containing a channel through which steam passes from the pipe E. The object of this steam bearer is to prevent the bar ends from burning away, and allowing an active fire to be kept up the whole length of the bars, without fear of burning the backs down and thereby reducing the duty at that part of the furnace. Only a relatively small quantity of steam is used to protect the back end of the bars.

Every alternate bar is made to reciprocate constantly by the rocking shaft and arms 6, which are driven by the pin 2, gearing in the slot of the arm 5. The pin 2 is fixed in the rotating disc secured upon the shaft 8, and driven by a worm on the vertical shaft J. The reciprocating motion of the alternate bars prevents clinker from adhering to them, and eventually delivers it over the steam bearer into the ashpit, from which it may be withdrawn at intervals through the flap door.

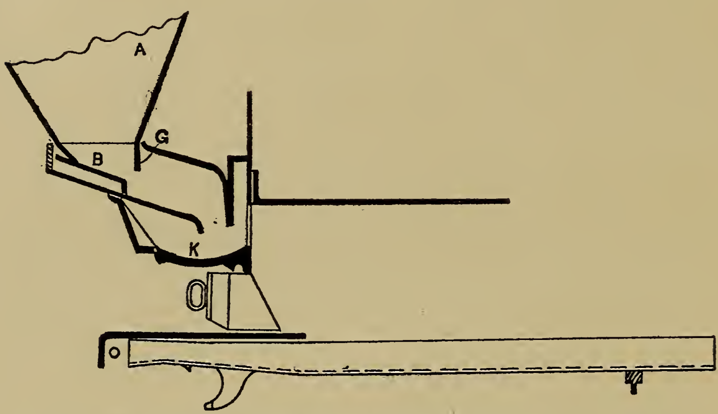


FIG. 21.—Longitudinal Section of Feeding Arrangement ; Bennis' Sprinkling Stoker.

It is not claimed for this stoker that smoke is entirely avoided, but with ordinary attention very little smoke need be made. The duty of the furnace is very good, and is specially adapted for work in which a sudden and heavy demand for steam occurs.

Bennis' Sprinkling Stoker.—Fuel is fed into the hopper A, from which it gravitates on to the plate B (Fig. 21), which is made to move forward periodically by the cam D and bent lever C (Fig. 22). The cam D is adjustable by means of the lever E and screw F, so that any quantity of fuel from $\frac{1}{2}$ lb. to 2 lb. can be pushed forward into the shovel chamber K at each forward stroke of the sliding plate B. In Fig. 23 will be seen a curved arm M, swinging about a pin O, having on its lower extremity a shovel or striker L. The arm M is attached to

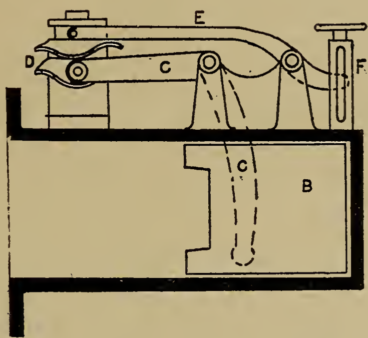


FIG. 22.—Sectional Plan of Feeding Arrangement; Bennis' Sprinkling Stoker.

a piston rod R, which carries the piston U. This piston is propelled forwards by the helical spring V in the cylinder

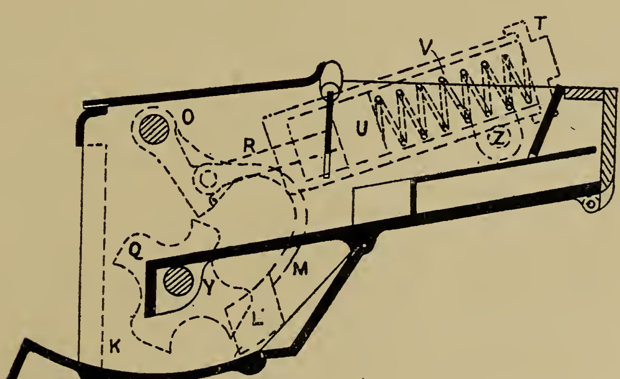


FIG. 23.—Showing Action of Sprinkling Shovel; Bennis' Stoker.

T, which oscillates about a fixed centre Z attached to the fuel box. The shovel arm is propelled backwards against the spiral spring by the arms of the cam Q fixed upon the shaft Y. This shaft, which also contains the cam D, is continually and uniformly rotated by a worm gear in the gear box on one side of the boiler. It derives its motion from an overhead countershaft driving the speed cones on the outside of the gear box.

After a charge of coal has been deposited in the shovel chamber by the plate B, the shovel arm is released from one of the arms of the cam Q, and the spring V propels it forward, suddenly striking the fuel on to the fire.

The shovel is brought to rest silently and without shock by compressing between it and the cylinder head the air in that end of the cylinder. This naturally prolongs the life of the striking mechanism considerably. It will be noticed that the arms of the cam Q are of different sizes, and consequently the shovel and piston U is made to travel different amounts, thus producing four different amounts of compression of the spring V. This variation of compression produces a corresponding variation in the impulses with which the fuel is struck over the fire, with the result that the fuel is delivered on to four different zones of the grate, producing an even distribution of fuel. This, the makers claim, secures that each unit of grate area shall burn an equal amount of fuel, and consequently contribute an equal amount towards the evaporation of the feed water. At the same time it permits of very rapid combustion, and an exceedingly high and uniform temperature in the furnace. This, of course, conduces towards economy. A front elevation of this stoker is shown in Fig. 24, and a side elevation in Fig. 25.

The firebars upon which the fuel is burnt are all moved forward together by a cam shaft for the purpose, and then withdrawn one at a time. The forward motion of the bars carries the fuel forward bodily, while the backward motion of each bar singly does not carry any of the fire with it, so that the ash and clinker is always being carried towards the ashpit, and the clinker has not the opportunity of cementing itself on to the bars. Each bar is hollow, and contains along its top surface a series of grids with narrow apertures. Air is blown into the bars by a steam jet, and issues through the grid apertures into the fire, producing an even distribution of the blast. The apertures being very narrow the ash does not get into the bar in any quantity.

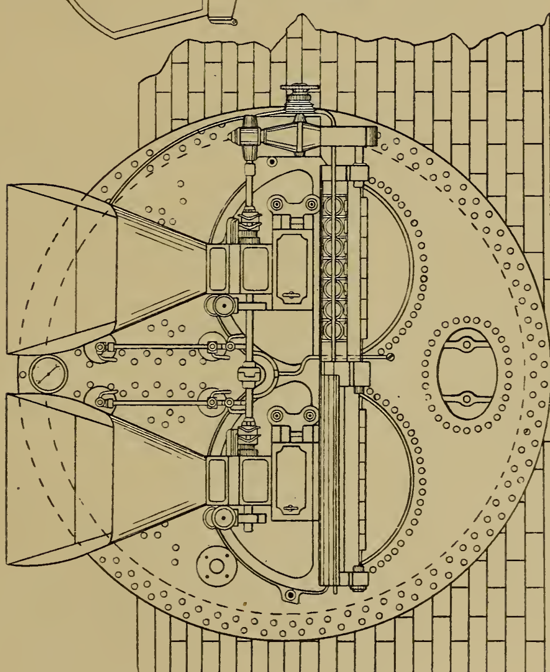


FIG 24.—Front Elevation; Bennis' Sprinkling Stoker.

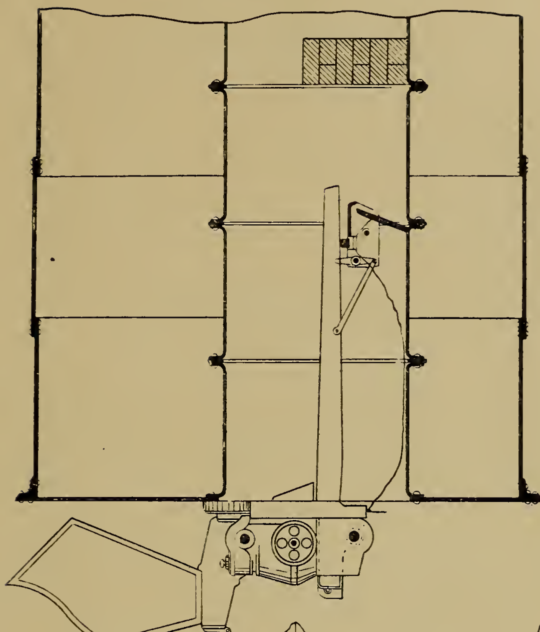


FIG. 25.—Side Elevation; Bennis' Sprinkling Stoker

TRIAL OF BENNIS' COMPRESSED AIR FURNACE AND SPRINKLING STOKER. JULY 13TH, 1898.

Lancashire boiler	9ft. diameter, 30 ft. long, 3 ft. 7 in. flues
Heating surface	1,200 sq. ft.
Duration of trial	8 hours
Fuel used	Sharlston Nuts
Coal burnt per hour	1,637 lb.
Coal per square foot of heating surface per hour	1·36 lb.
Steam pressure	67 lb. per sq. in.
Water evaporated per hour	16,250 lb.
Water evaporated per lb. fuel at boiler pressure	9·9 lb.
Water evaporated per lb. fuel from and at 212 deg.	10·18 lb.
Temperature of water entering economiser	100·3 deg. Fah.
Temperature of water leaving economiser	222 deg. Fah.
Temperature of downtake gases	1,325 deg. Fah.
Temperature of gases entering economiser	678 deg. Fah.
Temperature of gases leaving economiser	370 deg. Fah.
Temperature of atmosphere	74 deg. Fah.
CO_2	11·8 per cent
Oxygen	6·8 per cent
Nitrogen	81·4 per cent
Calorific value of coal determined from analysis	14,374 B.T.U.
Efficiency of boiler and economiser	84·6 per cent.

In this trial the coal was burnt at the rate of over 30 lb. per square foot of grate per hour.

Ransome and Rapier's Sprinkling Stoker.—A front elevation of this stoker is shown in Fig. 26, as applied to a Lancashire boiler, while a longitudinal section of one of the furnaces is shown in Fig. 27. A detail of the sprinkling shovel arrangement is shown in Fig. 28.

Fuel is fed into the hoppers A in the usual manner, and gravitates on to a pusher feed-plate C, in the box B. This pusher is given a reciprocating motion by a small crank not shown in the figure, but driven by the series of spur wheels on the right of each hopper, the lowest wheel being secured upon the little crank shaft, while the highest wheel is fixed upon the cam spindle running along the front of the boiler behind the fuel hoppers.

The cam shaft derives its motion from the overhead countershaft W, through the cone pulley S, and two pairs of worm and worm wheels.

The travel of the pusher plate C is regulated by turning a thumb nut inside the box B, the door of which is held by a spring catch. The little crank works in a vertical slot in

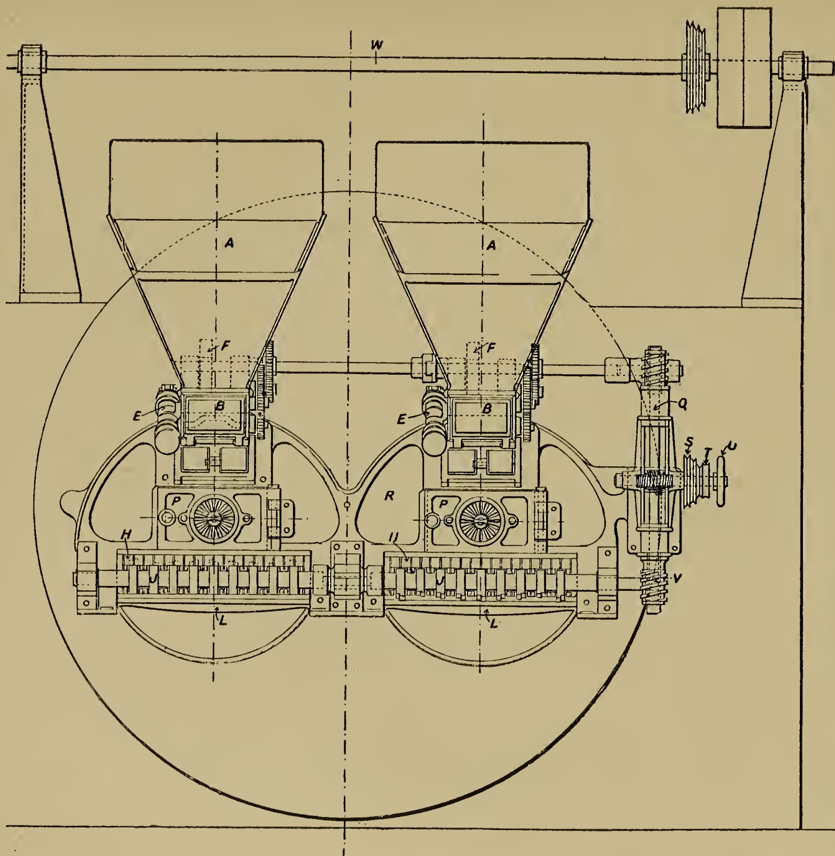


Fig. 26.—Front Elevation; Ransome and Rapier's Sprinkling Stoker.

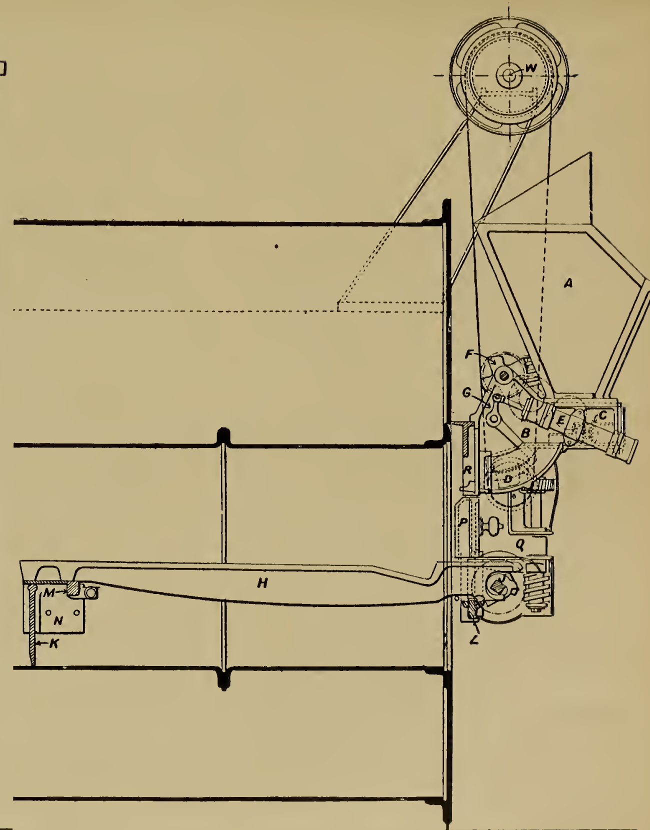


Fig. 27.—Longitudinal Section.

the pusher plate, the width of the slot being adjustable by turning the thumb nut. Screwing up the nut enlarges the slot, and consequently the crank pin travels further without touching the sides of the slot, and therefore the travel of the pusher plate is diminished. If the nut is unscrewed the sides of the slot approach each other, diminishing the lost motion, and the travel of the pusher is increased. In this way the rate at which the fuel is fed upon the fire is easily regulated to suit the demand for steam.

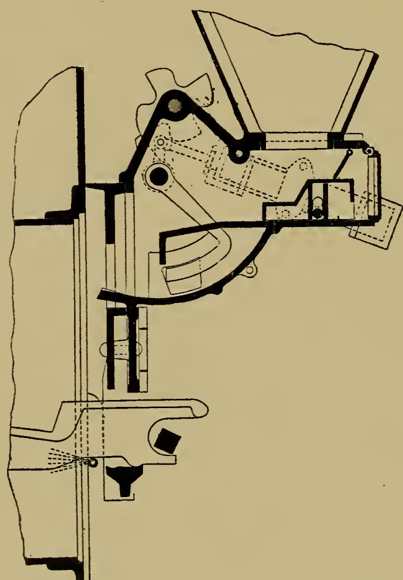


FIG. 28.—Section of Sprinkling Shovel Arrangement; Ransome and Rapier's Stoker.

The pusher plate delivers a charge of coal in front of the sprinkling shovel, and the rapid forward movement of the shovel kicks the fuel on to the grate. This action is more readily seen on referring to Fig. 28. The shovel is supported by a pair of arms, one on each side, which swing about a fixed centre. To the same spindle is keyed the arm G, which is coupled to a small piston in the casing or cylinder E by a short connecting rod. In the cylinder E are two helical springs, one on each side of the piston; one for giving motion to the sprinkling shovel, and the other for taking up the recoil and bringing the shovel to rest.

The shovel is withdrawn and one of the above springs compressed by the cams F coming into contact with suitable arms on the shovel spindle. These four cams are of different sizes, for withdrawing the shovel corresponding distances, and thus imparting to the coal four different impulses, for the purpose of spreading it uniformly over the fire. The bars are pushed forward into the fire all together, and withdrawn one by one, by the cams threaded on the square shaft J, driven by the worm and worm-wheel V, on the right of the boiler. The back ends of the bars rest and slide upon a bearing-plate M, and in the illustration is shown a small steam pipe which provides jets of steam which play upon the under side of the bars, and prevent clinker from adhering to them. One of these stokers, which the writer saw at work, had a similar pipe in connection with the front bearer for the same purpose. The bars in this instance, which were stated to have been in use for twelve months, were perfectly clean, and appeared as sharp at the edges as when they left the mould. North country small coal was being used, and there was an entire absence of smoke at the chimney top.

The cam shaft is raised well above the fire, and all its bearings can be easily and efficiently lubricated. This applies to the other bearings as well.

The Cass Coking Stoker.—This mechanical stoker is shown in Figs. 29 and 30. The regulation of the fuel is accomplished by the wedge in the fuel hopper, by whose position the size of the aperture through which the fuel gravitates to the fire is controlled. It is supported by a chain shown in Fig. 28B, and can be adjusted by the hand lever on the side of the hopper. After falling on to the coking plate the fuel is carried along by the reciprocating motion of the bars, being coked before it gets well on to the fire. The ash and cinder is delivered over the ends of the bars into the cinder chamber. The bars are worked by a pair of cam shafts in a very simple manner, as shown in the figure, and it will be noticed that the front end is supported on a beam resting on a couple of uprights, so that there is no actual connection to the boiler plates or necessity for drilling holes. The firebrick arch immediately over the coking plate tends to assist and perfect the coking action, and at the same time protect the ring joint in the front of the furnace. The illustrations, being clear, need no further description.

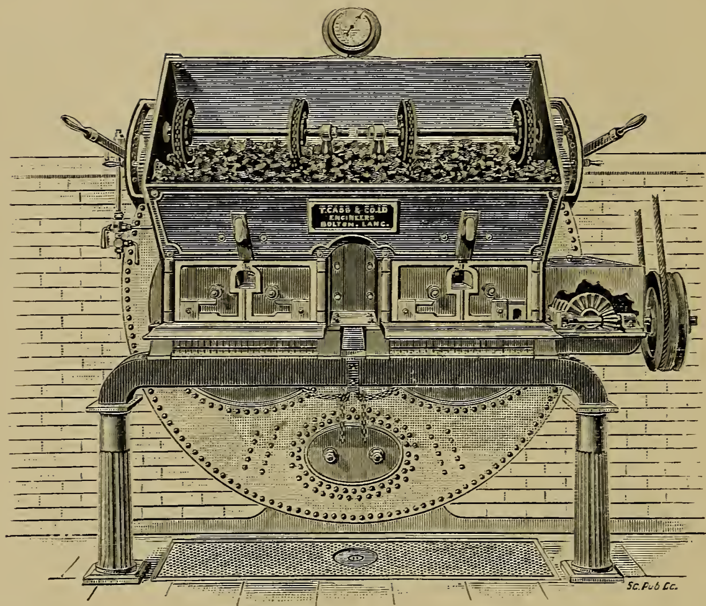


FIG. 29.—Front Elevation; Cass Coking Stoker.

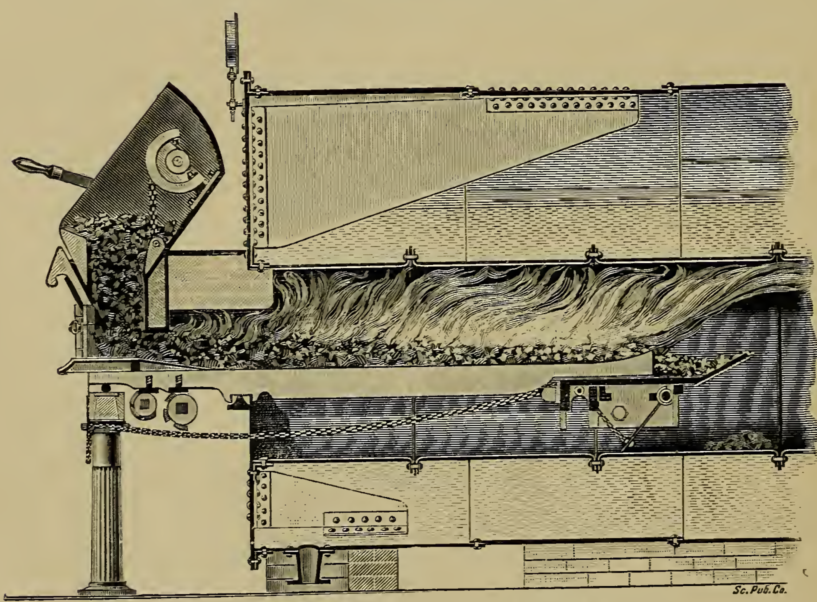


FIG. 30.—Longitudinal Section; Cass Coking Stoker.

Conclusions.—We may say that for economical and smokeless combustion of fuel it is desirable that—

(1) The air to support combustion should be thoroughly intermixed with the constituents of the fuel to be burnt at the time of ignition, and especially is this the case with the hydrocarbons distilled from green fuel as it is put on the fire.

(2) The air supply must be in excess of the theoretical quantity, but the excess should be carefully regulated not to waste more heat than is absolutely necessary in the chimney gases.

(3) The air should be delivered to the fire at as high a temperature as possible, and should be regulated to the needs of combustion.

(4) The temperature of the furnace should be as high as possible, so that the heat of combustion shall be rapidly transmitted to the water.

(5) The firing should be done uniformly, and a uniform thickness of fire is very desirable. The firehole door should be opened as seldom as possible, and all air leakages should be stopped.

(6) The heating surfaces of the boiler should not be too near the gases when they are igniting, as the transmission of heat rapidly cools the gases and may prevent complete combustion.

The problem of burning fuel without smoke is a comparatively simple one, as may be gathered from what has been already said, *if the rate of combustion is of no consequence.* Natural draught coking stokers can and do burn all sorts of fuel with an entire absence of smoke, except while the fires are being cleaned; but they do it on a comparatively low and uniform rate of combustion.

They must not be forced, or the fires become smothered with green fuel, and smoke must appear, after which they go right out. Further, coking stokers with natural draught cannot be started suddenly and made to furnish a quantity of steam in case of emergency.

It is on this account that they are unsuitable for electric lighting stations laid down in the heart of a town, where land is expensive, and a large margin of boiler power cannot be secured. Many existing central stations labour under this difficulty, and cannot obtain more accommodation at any cost, with the result that their boilers have to be forced to their utmost limit to furnish sufficient steam during the heavy load. They are at the same time handicapped by being prevented by the local authorities from producing smoke.

It is here that the best hand firing must be resorted to, or sprinkling stokers adopted, which, with a little care, produce little smoke, and at the same time permit of a wide range in the rate of combustion. The one thing to be looked after in a sprinkling stoker, as with hand firing, is that the feed of fuel and the draught shall be commensurate. If the fuel supply is reduced with too much draught the thin fire may burn into holes, and a loss of economy will immediately begin; whereas, if the draught is small with a heavy feed, smoke must be produced.

With hand firing, the fires are carefully thickened as the period of heavy load approaches, so that when necessary, they may be opened out and the maximum evaporation carried on for the short interval of heaviest loads, principally by the thick mass of incandescent fuel.

Dense black smoke can always be avoided if the proper means are adopted to prevent it; but the conditions under which many steam boilers have to be worked do not permit of an absolutely smokeless chimney.

Mechanical stokers are not intended to be used with large coal, and, generally speaking, the same applies to forced draught, but with these appliances small coal and very inferior kinds of fuel, such as slack or coke breeze, may be burnt with ease and economy.

It must not be forgotten that the domestic hearth is often a most wanton offender, and the smoke produced by it per pound of fuel burnt generally far exceeds that of any steam boiler. This must be so from the crude manner in which combustion is expected to take place.

Estimation of the Density of Smoke. — There is considerable difficulty in estimating the quantity of smoke and its density as it emerges from a chimney. Probably the best method so far suggested is that of Ringelmann's. He has drawn five diagrams, Fig. 31, consisting of black lines of varying thickness and distance apart, upon pieces of white cardboard; and these are suspended in a good light 50 ft. or 60 ft. from the observer, but so situated that the smoke to be estimated is seen near or behind the diagrams. Whichever diagram appears to coincide most nearly with the density of the smoke, that is the comparative number of the density. The following are the dimensions from which the diagrams can be constructed.

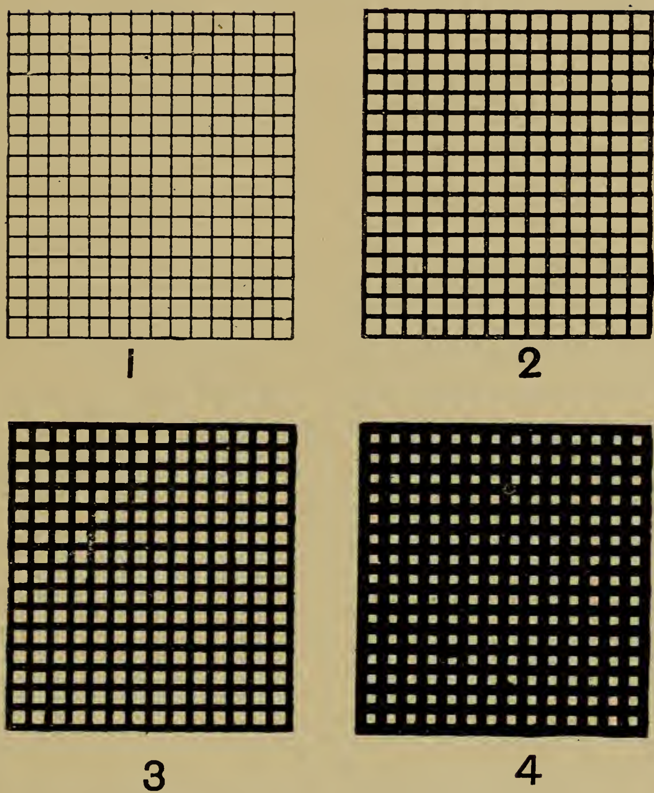


FIG. 31.—Ringelmann Smoke Test.

						Smoke.
No. 0	All white					None.
,, 1	Black line,	1 mm. thick,	white spaces,	9 mm.	wide,	light grey.
,, 2	,, ,,	2·3	,, ,, ,,	7·7	,,	darker grey.
,, 3	,, ,,	3·7	,, ,, ,,	6·3	,,	very dark.
,, 4	,, ,,	5·5	,, ,, ,,	4·5	,,	black.
,, 5	All black					dense black.

Reduced copies of four out of the five scales are shown in the accompanying Fig. 31.

Smoke Commissions.—The principal commissions instituted for the purpose of inquiring into the smoke nuisance were the Prussian 1894, English 1895, and the Paris Municipal 1897. The last of these did the most thorough work, and it is proposed to give here a brief *résumé* of it.

By a resolution of the Municipal Council of Paris, of June 2nd, 1894, a Technical Commission was formed to draw up a programme for a competition of smoke consuming apparatus, to take charge of the trials, and to draw up a report of the trials.

After three and a half years the Commission finished its work and presented its report, which extends through a couple of hundred pages of printed matter, including diagrams.

The report is divided into five parts :—

1. Analysis of the different projects.
2. Carrying out of the experiments.
3. Detailed results of the trials.
4. Historical summary.
5. Examination of the results of the competition, and conclusions.

Competitors were requested to send in to the Commission full information respecting the particular system which they intended to present for competition. This information was examined in detail by the Commission, and as a large number did not appear to present sufficient chance of success, these latter were discarded. There then remained 30 projects which appeared to warrant further investigation.

It was then decided to form a number of sub-commissions to visit actually existing examples of the remaining 30 projects, for the purpose of examining them at work and reporting upon them, with a view of further elimination before the final trials were decided upon. The result was that 10 projects were finally retained for trial.

These 10 competitors were then advised of the Commission's decision, of which eight agreed to submit apparatus for trial.

Each different apparatus was then allotted a definite date for trial, which was designed to last for one month.

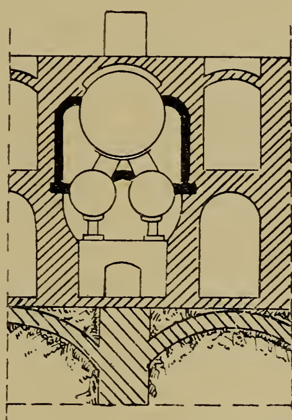


Fig. 32.—Transverse Section of Boiler Setting.

There were originally 110 schemes submitted, of which 76 were French, 19 English, four German, and three American. Three prizes of 10,000 francs, 5,000 francs, and 2,000 francs were offered for the three most successful schemes. The different schemes were applied to two out of three similar boilers belonging to the municipality of Paris, and used for supplying steam to a pair of pumping engines.

The boilers were all of the same kind and dimensions, views of one of which are given in Figs. 32 to 34. The large cylinder contains a number of smoke tubes, but these are not shown in the sketch.

The principal dimensions were :—

Upper Drums—Diameter		1·38 metres
	Length	3·5 ,,
Lower Drums—Diameter		·72 ,,
	Length	5·3 ,,
Smoke Tubes—Number		50 ,,
	Outside diameter	80 m.m.
	Thickness	3 ,,
Heating Surface		68 sq. m.
Grate—Length		1·15 metres
	Width	1·3 ,,
	Area	1·5 sq. m.
Chimney—Height		30 metres
	Sectional area at top	·385 sq. m.
	Sectional area at base	1·21 ,,

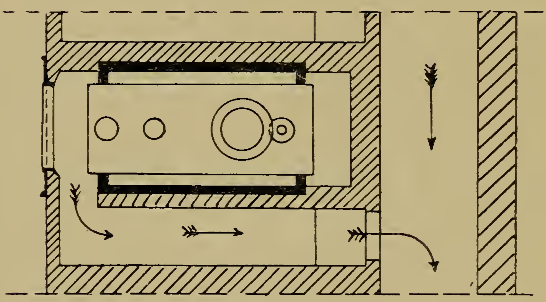


FIG. 33.—Sectional Plan of one of the two Boilers experimented upon.

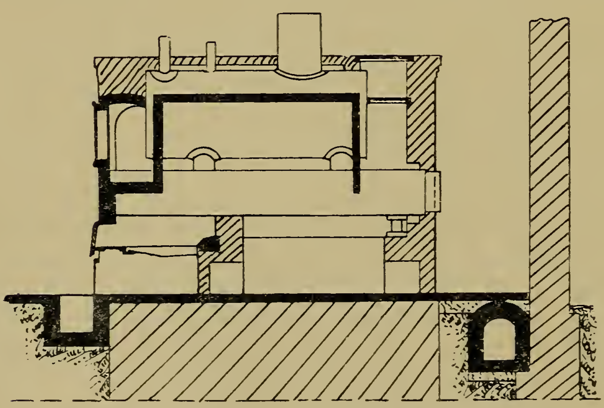


FIG. 34.—Longitudinal Section of Boiler Setting.

Fuel.—The fuel used was briquette d'Anzin, of ordinary quality, which was described in the report as "passably smoky," but it possessed one feature which recommended it for these trials—namely, uniformity. A number of analyses gave an average of 8·2 per cent ash and 17·8 volatile matter.

Each competitor was informed of the particular time allotted to his apparatus for trial, and every opportunity was afforded for thoroughly testing the capability of each contrivance.

Four official trials were carried out with each apparatus, each trial beginning at eight o'clock in the morning, and terminating at six o'clock in the evening.

1st. Moderate rate of combustion, with only one engine at work, the apparatus being under the control of a stoker furnished by the competitor.
2nd. Same as 1st, but stoker furnished by the administration.
3rd. Same as 1st, but at higher rate of combustion.
4th. Same as 3rd, but with stoker furnished by the administration.

If preferred, the competitor need not furnish a stoker for trials Nos. 1 and 3, but could direct one of the stokers of the administration if he preferred.

In addition to the official trials mentioned above, each apparatus had to work continuously for one month, the official trials taking place within that time.

Preliminary Experiments.—It was thought necessary to carry out a preliminary trial on one of the boilers, with the ordinary grate, bars, &c., for the purpose of checking the apparatus about to be used, and as a means of familiarising the observers with their work.

These preliminary trials were conducted in every way by the same observers, and in precisely the same manner as the competitive trials.

Estimation of Smoke.—It was considered by the Commission that some direct means of estimating the volume and density of the smoke emitted from the chimney was most desirable. For obtaining a fairer average it was decided to take the mean of the observations of two separate and careful observers, stationed in two opposite positions, one about 300 metres to the north, and the other 300 metres to the south of the chimney. In both instances the observers were practically on the same level as the top of the chimney.

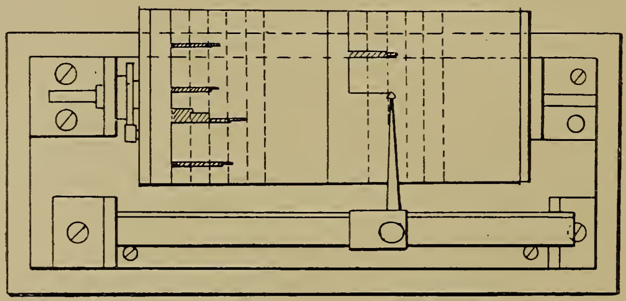


FIG. 35.—Plan of Recording Apparatus.

The five gradations used were—

1. No smoke.
2. Faint smoke.
3. Medium smoke.
4. Black smoke.
5. Opaque smoke.

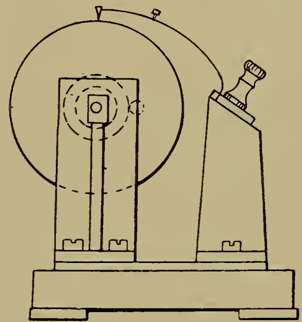


FIG. 36.—End View of Recording Cylinder.

Each observer recorded his estimation of the intensity of the smoke by sliding the handle (Figs. 35 and 36) until the pen was in the position required by the observer, which could be seen upon the graduated paper placed on

Summary of Results of Smoke Commission Trials at Paris.

Number and Name of Competitor.	Kind of Apparatus.	MODERATE RATES OF COMBUSTION.					HIGH RATES OF COMBUSTION.					
		Fuel burnt per hour per sq. m. of grate in kilograms.	Evaporation of water per hour per sq. m. heating surface.	Smoke area per kilogram of combustible.	Smoke area per kilogram water evaporated.	Evaporation per kilogram of fuel. Kilo-grams.	Fuel burnt per hour per sq. m. of grate in kilograms.	Evaporation of water per hour per sq. m. heating surface in kilograms	Smoke area per kilogram of combustible.	Smoke area per kilogram water evaporated.	Evaporated per kilogram of fuel. Kilo-grams.	Average percentage of smoke.
85 Jas. Proctor	Coking stoker	58·5	11·8	·36	·045	8·1	106·3	22·24	·8	·095	8·4	7
24 M. Donneley	Vertical external grate .	78·6	11·24	·32	·037	8·6	88·2	12·93	·2	·022	8·9	3
19 M. Ckiandi	Double grate, up and down draught	25·7	11·47	2·57	·27	9·5	38·6	16·64	2·2	·24	9·1	26
26 M. Dulac	Inclined coking grate...	56·3	11·87	4·67	·55	9·2	104·3	20·2	1·3	·15	8·4	28
47 M Hinstin	Coking grate	39·8	12·07	2·02	·24	8·3	68·0	21·93	2·15	·24	8·7	24
74 M.M. Muller and Roger	Steam jets over fire... .	59·5	11·64	5·71	·64	8·8	103·1	19·75	2·9	·33	8·6	44
29	Smoke washer	55·7	11·22	10·12	1·0	9·2	102·4	19·03	9·66	1·02	8·5	99
81	Dust fuel	......	11·38	3·27	·37	8·9	......	19·17	3·4	·40	8·4	38
....	Ordinary grate	51·7	9·64	11·43	1·22	8·5	95·5	17·44	7·96	1·0	8·2	100

the drum, which was rotated by clockwork. The distance from the left-hand margin denotes the intensity of the smoke, and the area denotes the quantity.

It was especially remarked in the report that both the details and the averages of the two sets of records agreed remarkably well, showing the probability of the accuracy of this mode of estimation.

The other quantities in connection with the trials were measured in the usual manner.

The Commission's Award.—It was the opinion of the commission that the schemes of Mr. James Proctor and M. Donneley proved themselves practically equal in value as smoke consumers and evaporators of water, and they awarded them each second prize and 5,000 francs. The third prize and 2,000 francs was awarded to M. Ckiandi.

It is gratifying to find Mr. Proctor's machine appearing at the top of the list, especially as he was practically the pioneer of successful machine stoking.

Meldrum's Refuse Destructor.—A subject which must be of great moment to those interested in sanitary matters is that of the successful destruction of domestic refuse, and on this account I venture to describe a few forms of destructor which have proved to be successful and economical. The accompanying illustrations show the

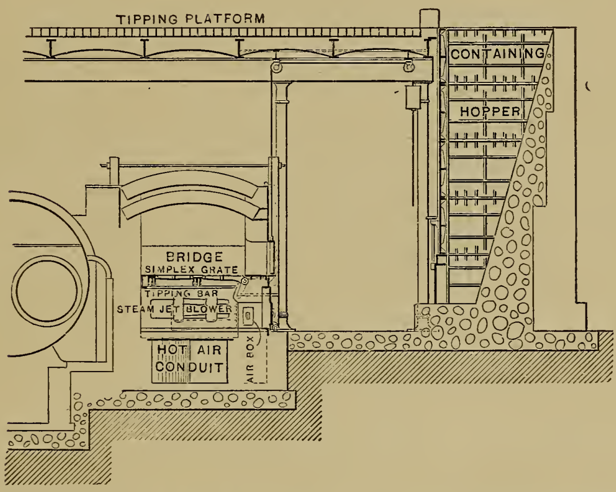


Fig. 37.—Section of Refuse Hopper, Grate, and Tipping Platform; Meldrum's Refuse Destructor.

construction of a destructor, and its application to the generation of steam in Lancashire or Cornish boilers, made by Messrs. Meldrum Bros., of Manchester.

The green refuse is tipped into the containing hopper from the tipping platform, Fig. 37. It is withdrawn through vertical sliding doors at the foot of the hopper, from which it is shovelled by hand on to the destructor furnace grates. These grates are placed side by side (Fig. 38) so that any unburnt gases emitted from one grate during the

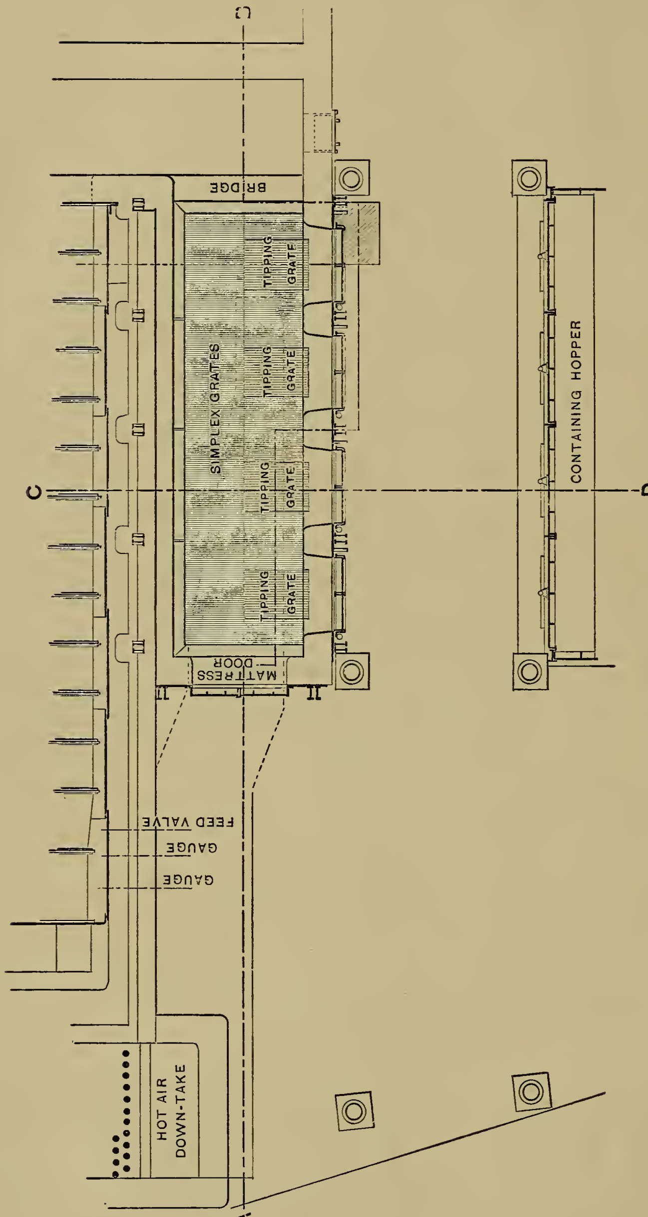


Fig. 38.—Plan; Meldrum's Refuse Destructor.

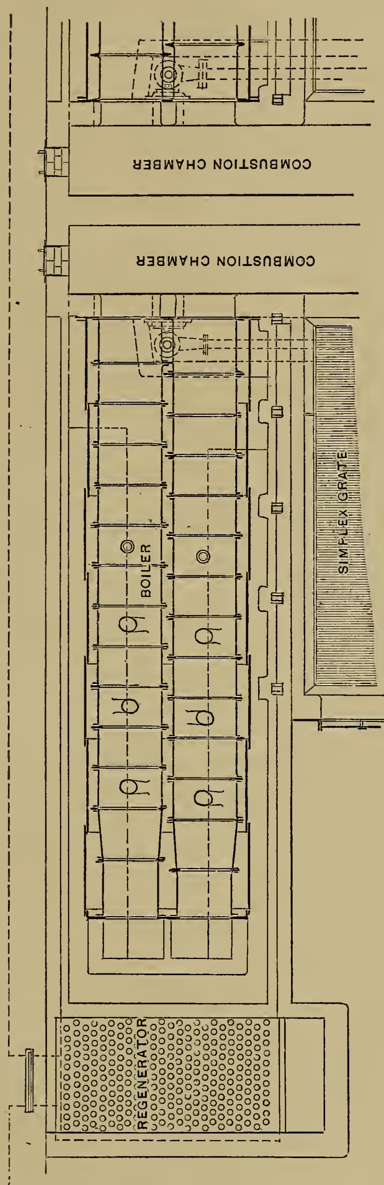


FIG. 39.—SECTIONAL PLAN OF FLUES AND REGENERATOR; MELDRUM'S DESTRUCTOR.

process of charging will be cremated during their passage over the incandescent matter on the grates between it and the combustion chamber, Fig. 39. The grates being so situated, the products of combustion from all the grates become thoroughly mixed, resulting in a practically uniform temperature throughout the furnace. This is of much importance on account of the non-uniformity of the material to be burnt, and of the fact that it often contains much moisture, and is of very low calorific value. The products of combustion after leaving the furnace enter a spacious combustion chamber in which is deposited much of the dust and cinder that may be carried over with the products of combustion. The temperature of this chamber is about 2,000 deg. Fah. After leaving this chamber the gases circulate through the flues of a boiler and give up their heat to generate steam which may be used for various purposes. At the end of the boiler is situated a regenerating air heater. This consists of a battery of cast-iron pipes surrounded by the products of combustion on their way to the chimney. Through these pipes travels the air which is used to support combustion, and which is thereby raised in temperature some 200 deg. before it reaches the refuse furnace. This very materially assists the rapid combustion of damp refuse.

The necessary draught is produced by Messrs. Meldrum's steam jet blowers as applied to boilers in general. The clinkering is much facilitated by the adoption of tipping bars or dead-plate (Figs. 37 and 40), which can be so arranged that the clinker and cinder is dropped into a trolley running along the ashpit, which, after being allowed to cool, may be withdrawn at the convenience of the attendant, thus getting rid of the nuisance of cooling the clinker with water in front of the cells.

A large door is provided at one end of the furnace for the introduction of condemned mattresses and similar refuse (see Fig. 38).

No fuel is used in these destructors, so that there is no expense incurred in that direction; at the same time those plants so far put down have furnished a supply of steam for sewage and water pumping, sewage presses, and the generation of electricity. The rate of destruction of refuse varies from 45 lb. to 55 lb. per square foot of grate per hour, and repeated tests have shown that the water evaporated from and at 212 deg. per pound refuse has varied from 1·6 to 2 lb. with unscreened refuse.

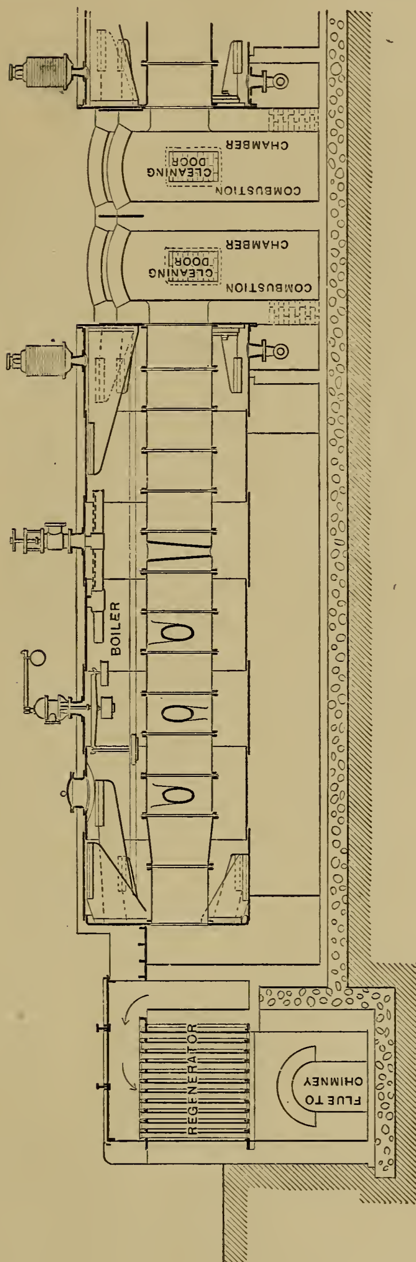


FIG. 40.—LONGITUDINAL SECTION OF FLUES, SHOWING REGENERATOR, AND COMBUSTION CHAMBER; MELDRUM'S DESTRUCTOR.

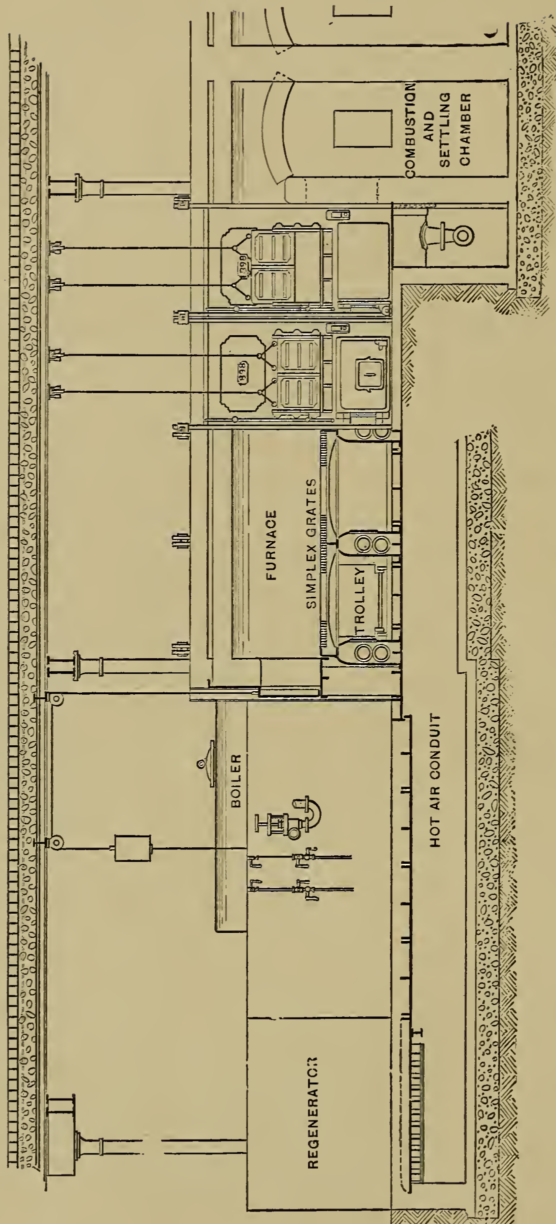


FIG. 41.—SECTION SHOWING HOT AIR CONDUIT FROM REGENERATOR TO FURNACE; MELDRUM'S DESTRUCTOR.

The results of a test at the Rochdale Corporation Works are given below:—

Date ....March 1st, 1895.

Duration..6 hours.

Refuse burnt per sq. ft. grate per hour.....47·3 lb.

Water evaporated per pound refuse from and at 212 deg. ....1·97 lb.

Number of boilers used...............................2.

Water evaporated per hour ....7,012 lb.

Steam pressure...............113 lb. per square inch.

Size of boilers (Lancashire).............30 ft. by 8 ft.

CO_2 ....15·9 per cent.

CO ....None.

Free oxygen...............................2·2 per cent.

Highest observed temperature combustion chamber ....1,980 deg. Fah.

Lowest observed temperature, combustion chamber..........................1,290 deg. Fah.

Cost of labour for burning refuse.....7½d. per ton.

The doors to the furnace are of the lifting type, as shown in Fig. 42.

It is claimed for this system of firing that the refuse is only handled once instead of three times, as in the overhead system of charging, where the refuse is first dried, then fed to the furnace and then levelled. The makers state that actual experience has proved a saving in labour over the overhead system of charging.

The records of three other tests carried out at the Hereford Sewage Works are given on page 63. The fuel was entirely unscreened ashpit refuse.

The size of the Lancashire boiler was 22 ft. by 6 ft. 6 in.; flues, 2 ft. 9 in. diameter.

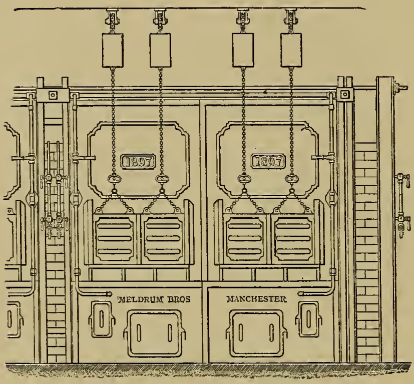


FIG. 42.—Furnace Doors; Meldrum's Destructor.

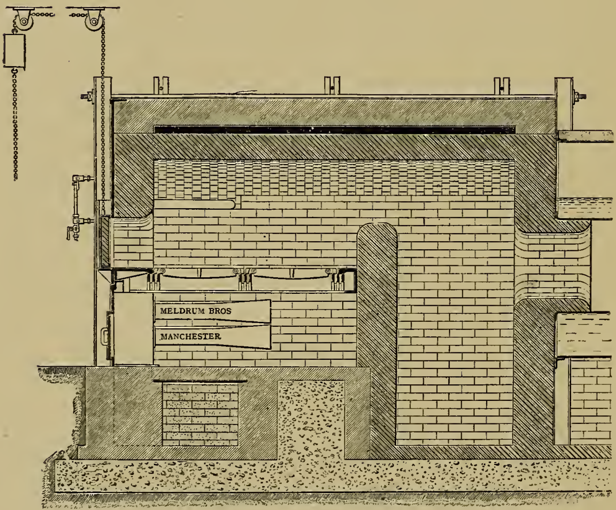


FIG. 43.—Longitudinal Section of Furnace, Showing Steam Jet Blowers; Meldrum's Destructor.

The temperatures and the analyses of the chimney gases given below are each the average of about twenty observations.

TEST MADE WITH A MELDRUM REFUSE DESTRUCTOR AT THE HEREFORD SEWAGE WORKS.

	1898.	1898.	1898.
Date of test	May 4.	May 5.	May 6.
Duration of test	10 hours.	$10\frac{1}{4}$ hours	10 hours
Weight burned per hour	1,976 lb.	1,855 lb.	1,971 lb.
Weight burned per sq. ft. of grate area per hour	54·88 lb.	51·52 lb.	54·75 lb.
Percentage of clinker and ash	33·9%	35·7%	25·6%
Percentage of moisture	24·5%	27·0%	25·0%
Water evaporated per hour	2,625 lb.	2,494 lb.	2,980 lb.
Water evaporated per lb. of refuse (actual)	1·32 lb.	1·34 lb.	1·51 lb.
Water evaporated per lb. of refuse from and at 212° F.	1·58 lb.	1·60 lb.	1·82 lb.
Temperature of feed water	48°	48°	48°
Average steam pressure	70 lb.	70 lb.	71 lb.
,, ,, ,, at blowers	64 lb.	64 lb.	65 lb.
Average air pressure under grates by water gauge	1·45 in.	1·37 in.	1·82 in.
Chimney pull, by water gauge	$\frac{3}{8}$ in.	$\frac{3}{8}$ in.	$\frac{3}{8}$ in.
Temperature in combustion chamber, by copper test	Over 2,000° F.	Over 2,000° F.	Over 2,000° F.
Temperature of waste gases, leaving damper	611 F.	639 F.	715 F.
Percentage of carbonic acid (CO_2) by Orsat apparatus	14·92%	16·83%	16·38%
Percentage of free oxygen (O) by Orsat apparatus	5·40%	3·54%	3·74%
Percentage of carbonic oxide (CO) by Orsat apparatus	nil.	nil.	nil.

Mason's Refuse Gasifier.—The accompanying illustrations, Figs. 44—51, show a form of destructor furnace or gasifier constructed in accordance with Duff's patents, which possesses a number of special advantages.

The general design of the destructor-furnace—or, more strictly speaking, gasifier—is clearly shown in the accompanying diagrams, Figs. 46—48, showing the one-cell plant as supplied to the Moss Side Urban District Council, and Figs. 49—51 the general arrangement of sixteen-cell plant. The cell, which may be rectangular or circular in cross-section, is built up of cast-iron plates (see Fig. 45), and lined with firebrick, the top being closed in and provided with a hopper and bell opening for charging purposes. At the bottom the cell is open, and supported on two sides across a water trough, which covers the whole area of the base, the level in the trough being maintained at such a height as to effectually seal the interior of the cell from the outer atmosphere. Running transversely across the water trough is a cast-iron chamber fitted at the top with two inclined grates above the water level, which form a ridge running from side to side of the cell.

The air required for combustion is supplied by means of a steam-jet blower fixed at one side of the cell, the air being blown into the cast-iron box described, and escaping through the two sloping grates into the mass of burning refuse situated above the water level.

The quantity of air admitted through the blower is limited to that required to maintain a low temperature of combustion of the refuse, and distil off, or convert into a gaseous state, all the carbonaceous or organic matter with which it is charged. These gases are then led through an opening near the top of the cell into a separate chamber, where they mingle with a secondary supply of air, by the aid of which their ignition and complete combustion is secured at a temperature of about 1,800 deg. Fah. The combustion chamber, it will be observed, is surrounded with an annular chamber or jacket. Through this the secondary air supply is drawn and becomes considerably heated before it reaches the gases, thus adding materially to the efficiency and temperature of the combustion chamber.

The working of the cell is a continuous operation, and not interfered with by cleaning operations, the refuse being fed at intervals from the platform at the top, and the clinker and ashes drawn out of the water trough at the bottom as occasion requires. The process of gasification is not in any way interrupted either by the charging of the refuse fuel at the top or the withdrawing of the ashes and clinker at the bottom. No additional fuel of any kind is required except that for lighting the cell in the first instance. At the week ends the cells can be banked up with refuse and started again on Monday morning by merely opening the blower. The regulation of the air to the combustion chamber can be adjusted so as to meet various grades and qualities of refuse which may have to be dealt with, and in this way the highest efficiency of combustion is secured.

In the illustrations, Figs. 46—48, the gases are shown as being discharged direct from the combustion chamber to the chimney, but they can obviously be utilised when desired for steam-raising purposes (see Figs. 49—51), as the temperature of the gases escaping from the combustion chamber is, as stated, about 1,800 deg. Fah., and with average town's refuse an evaporative duty of about 1 lb. of water can be obtained for each pound of fuel.

The cell illustrated in Figs. 46—48 measures 6 ft. 3 in. by 5 ft. in cross-section, giving a burning area of 31 sq. ft. as nearly as may be, while the grate surface measures 14½ sq. ft.* The burning fuel in the cell is generally maintained at a thickness of about 4 ft. above the grate, and the air required for gasification is easily supplied by means of a ¼ in. jet blower working at about 40 lb. on the square inch. With such a cell it is found that 6 tons of refuse can be dealt with in the course of 24 hours with perfect ease, this refuse being reduced to about 25 per cent of its original weight, in which state it is drawn as ashes or clinker from the bottom of the cell of a character suitable either for grinding up into mortar or using as ballast for footpaths or roads.

* This cell is rather less than the standard size, which affords a grate area of 24 sq. ft., and a burning area of 49 sq. ft.

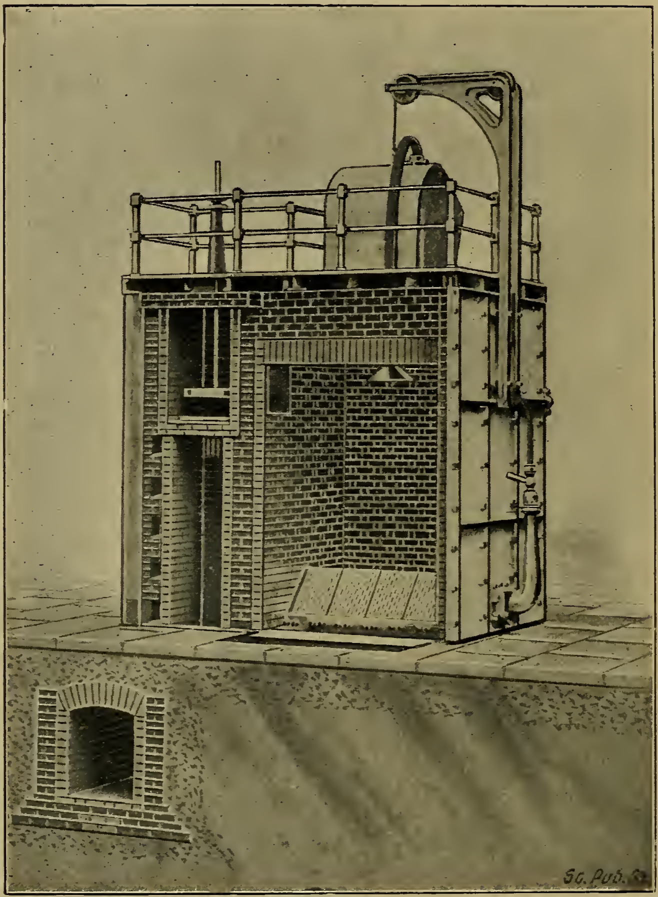


FIG. 44.—VIEW SHOWING INTERIOR CONSTRUCTION OF MASON'S SINGLE CELL REFUSE GASIFIER.

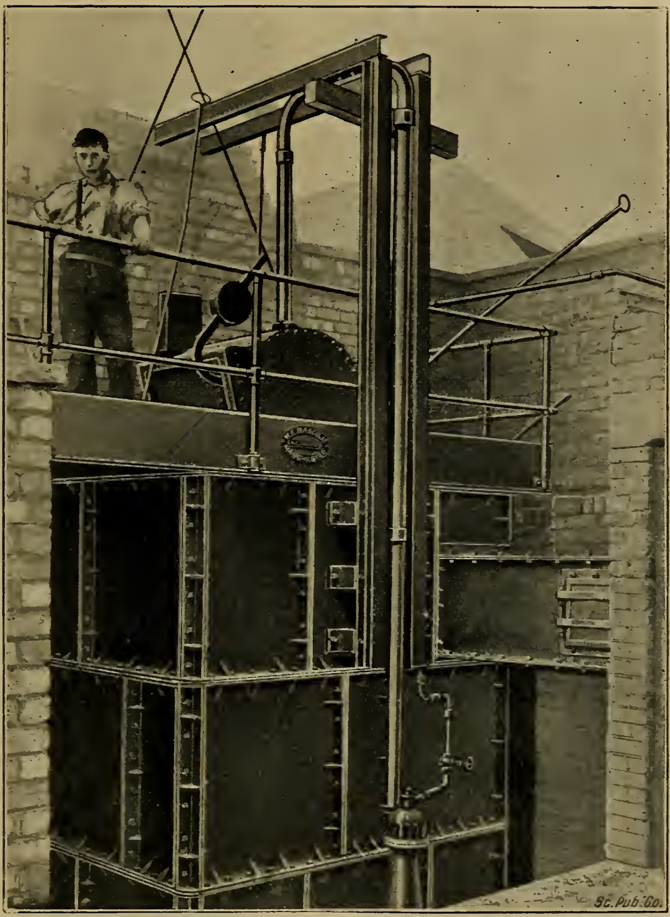


FIG. 45.—PERSPECTIVE VIEW SHOWING EXTERIOR OF MASON'S REFUSE GASIFER.

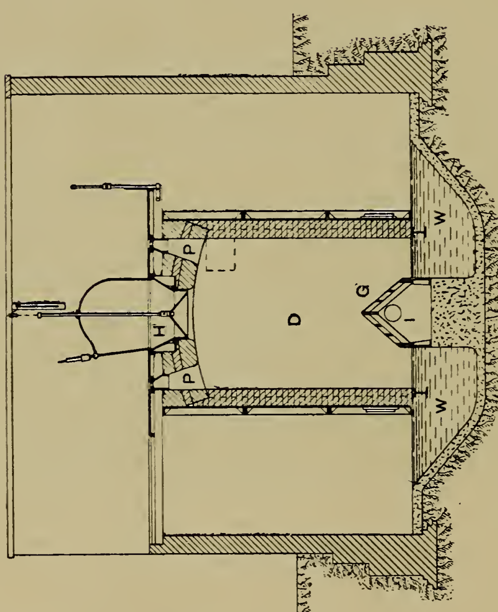


Fig. 46.—Cross Section.

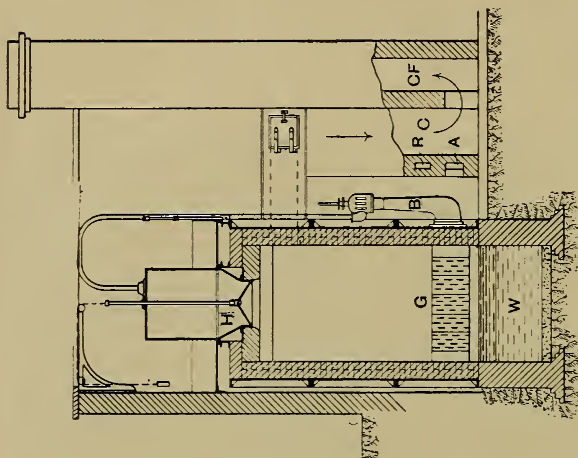


Fig. 47.—Longitudinal Section.

Mason's Refuse Gasifier; Arrangement of One-cell Plant as supplied to the Moss Side Urban District Council.

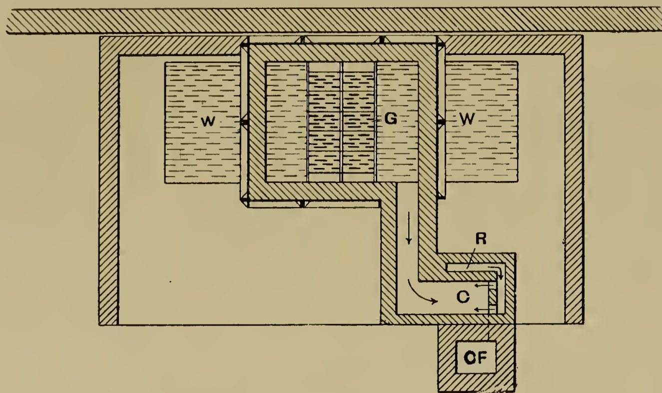


FIG. 48.—Plan.

INDEX.

A—AIR INLET TO REGENERATOR.
B—STEAM JET BLOWER.
C—COMBUSTION CHAMBER.
C F—CHIMNEY FLUE.
D—GASIFIER.
G—GRATE.
H—FEEDING HOPPER.
I—INLET FROM STEAM JET BLOWER.
P—POKER HOLES.
R—REGENERATOR.
W—WATER SEAL.

MASON'S REFUSE GASIFIER; ARRANGEMENT OF ONE-CELL PLANT AS SUPPLIED TO THE MOSS SIDE URBAN DISTRICT COUNCIL.

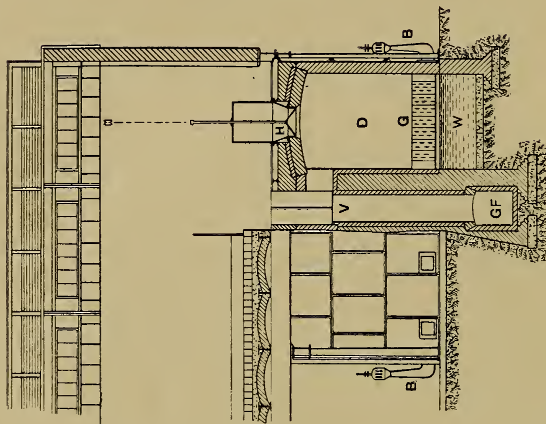


FIG. 50.—Longitudinal Section.

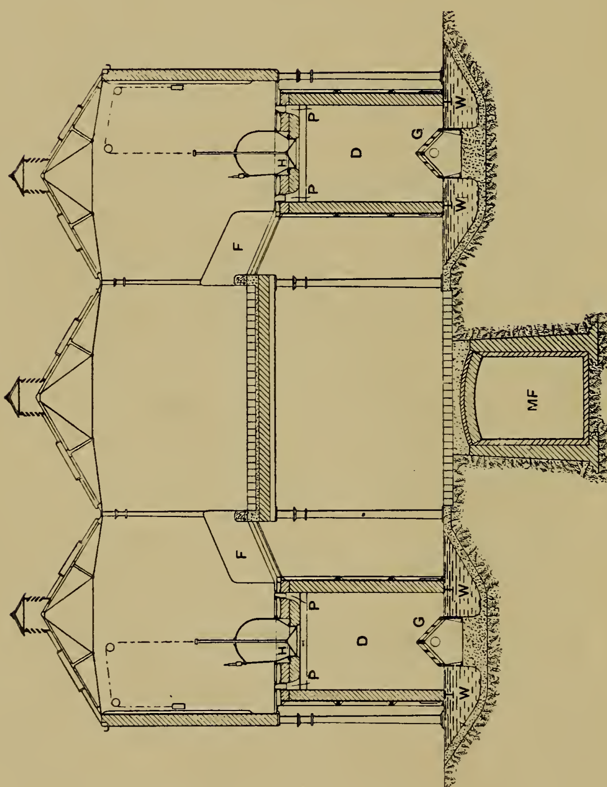
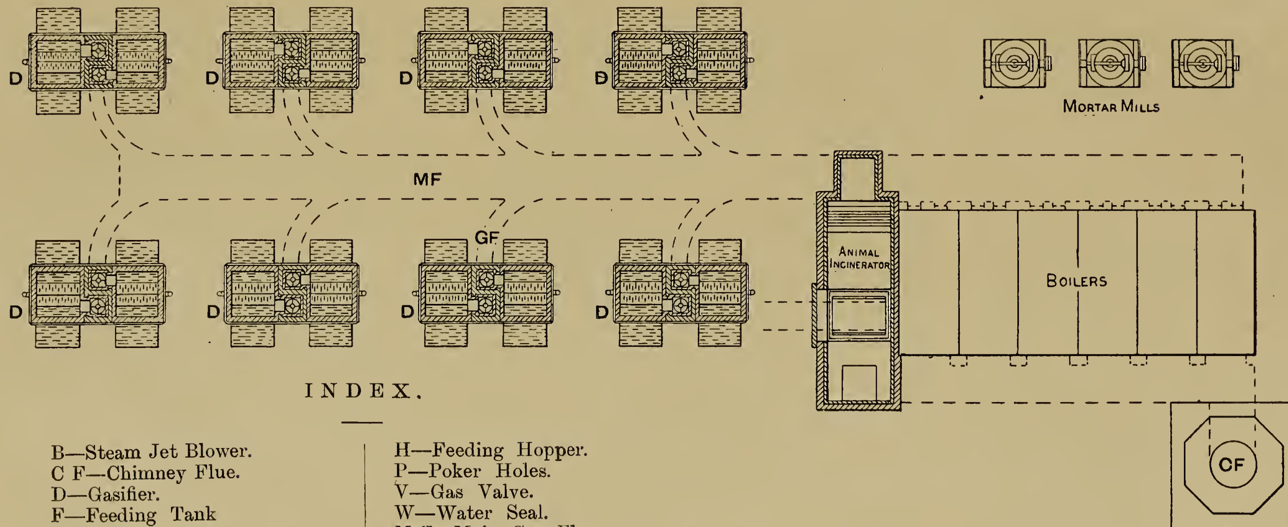


FIG. 49.—Cross Section.

MASON'S REFUSE GASIFIER; ARRANGEMENT OF SIXTEEN-CELL PLANT.



INDEX.

B—Steam Jet Blower.
C F—Chimney Flue.
D—Gasifier.
F—Feeding Tank
G—Grate.
G F—Gas Flue.
H—Feeding Hopper.
P—Poker Holes.
V—Gas Valve.
W—Water Seal.
M F—Main Gas Flue.

FIG. 51.—Plan.

MASON'S REFUSE GASIFIER; ARRANGEMENT OF SIXTEEN-CELL PLANT.

The following particulars of a test recently made with one of Mason's gasifiers at the yard of the Moss Side Urban District Council, under the supervision of Mr. D. Ainley, the superintendent of the cleansing department; Mr. George Darley, superintendent of the cleansing department, Leeds; W. Lawrence Gadd, F.I.C., etc.; and William H. Fowler, Wh. Sc., Assoc. M. Inst. C.E., M.I. Mech. E., etc., will serve to illustrate the efficiency of the apparatus for the purpose of refuse destruction. The refuse dealt with, it may be remarked, was of a heavy, damp character, containing 30·3 per cent of moisture, and was not screened or assorted in any way.

TEST MADE WITH A MASON'S REFUSE GASIFIER

For the Destruction of Town's Refuse at the Yard of the

MOSS SIDE URBAN DISTRICT COUNCIL

Under the Supervision of

Mr. D. Ainley, Superintendent of the Cleansing Department;

Mr. George Darley, Superintendent of the Cleansing Department, Leeds;

W. Lawrence Gadd, F.I.C., &c.,

and

William H. Fowler, Wh. Sc., Assoc. M. Inst. C.E., M.I. Mech. E., &c.

Date of Test, August 21st and 22nd, 1899.

Duration of Test	24 hours.
Sectional Area of Cell	6 ft. 3 in. × 5 ft. = 31·25 sq. ft.
Area of Grate	16 sq. ft.
Kind of Fuel	Unscreened Ashpit Refuse
Percentage of Moisture in Fuel	30·3 per cent.
Total Weight of Fuel Burned	13,552 lb.
Weight of Fuel Burned per hour	565 lb.
Weight per square foot of Grate per hour	35·25 lb.
Pressure in Boiler supplying Steam to Jet Blower	60 lb.
Weight of Steam used for Jet Blower per hour	140 lb.
Pressure of Forced Draught under Grate	2¼ in. water column.
Percentage of Residue (clinker and ash wet)	25 per cent.
Smoke from Chimney	None.

In the course of the test observations were made of the temperature in the gasifier cell, and also in the combustion chamber. The readings of a Bailey's pyrometer indicated a temperature of 750 deg. Fah. in the cell, and a Siemens pyrometer of 1,625 deg. Fah. in the combustion chamber. This latter reading, however, was probably under the mark, since silver readily fused in the combustion chamber, showing that the temperature must have been over 1,733 deg. Fah. (the melting point of silver).

During the course of the test samples of gas were drawn from the gasifier and also from the base of the chimney. Analyses of these showed their composition to be as follows:—

ANALYSIS OF GASES FROM GASIFIER.

	Per cent.
Carbon-dioxide (CO_2)	13·0
Carbon-monoxide (CO)	10·0
Oxygen	2·4
Hydrocarbons (C_2H_4)	1·6
Hydrogen	13·6
Nitrogen	59·2
	99·8

GASES FROM BASE OF CHIMNEY.

(Average of three analyses.)

	Per cent.
Carbon-dioxide (CO_2)	11·5
Carbon-monoxide (CO)	1·9
Oxygen	4·6
Hydrocarbons (C_2H_4)	1·3
Hydrogen	2·0
Nitrogen	78·7
	100·0

The steam required for the jet blowers was supplied by a small independent boiler, and the heat evolved by the combustion of the gases distilled from the refuse in this test was permitted to escape freely into the atmosphere from a chimney only 25 ft. in height, and it is of interest here to remark that although this gasifier has been in operation for more than 18 months, and is surrounded by good residential property within a radius of 50 yards of the site, not a single complaint has been made by any resident. As already stated, the heat from the gasifier, which gave a flame 19 ft. in length, can, if desired, be utilised for raising steam or other useful purpose.

The Horsfall Refuse Destructor. — A longitudinal section of this destructor is shown in Fig. 52, and a sectional plan in Fig. 53. It consists of a series of grates arranged side by side, and in the larger destructors two sets of these grates placed end to end, as in the figures.

The refuse to be destroyed is tipped on to the platform at the top of the structure, from which it is shoveled into the feed holes by hand. Immediately below the feed hole is the top of the main flue, on to which the garbage is first fed. The heat from the flue gases maintains the flue structure at a considerable temperature, and hence the green refuse tipped on its upper surface must be dried to a certain extent, and perhaps raised in temperature.

On either side of the "table" is a sloping hearth down which the refuse gravitates until it reaches the back end of the grate. The hearth also forms part of the flue structure, and hence the refuse is dried and heated all the way from the feed hole to the grate upon which it is burnt.

The products of combustion pass away from the burning refuse into the exhaust flues immediately over it, and from thence along the cross flues, Fig. 55, to the downcast apertures through which they pass to the main flue beneath. These cross flues also assist in maintaining the whole upper structure at a higher temperature than the atmosphere, to assist in drying and heating the refuse.

Running by the side of the main flue are a couple of smaller flues which convey air from the blast apparatus to the grates.

In Fig. 53 will be seen a number of rectangular boxes on each side of the grates. These are cast-iron ducts through which the air-blast passes on its way from the blast flues to the ashpits. The chief use of these ducts is not so much to warm the blast, although that is desirable, but to maintain the sides of the grate intact. The constant clinkering eventually wore away the brick sides of the grate and undermined the walls, until the cast-iron boxes were put in.

The incandescent condition of the firebrick lining of the furnace tends to produce a very high temperature in the furnace and consequently the fumes given off from the burning refuse are completely cremated before reaching the chimney stack.

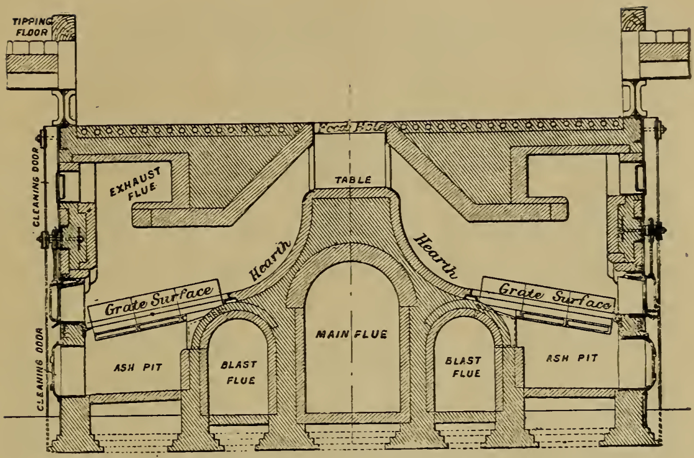


FIG. 52.—Longitudinal Section ; Horsfall Destructor.

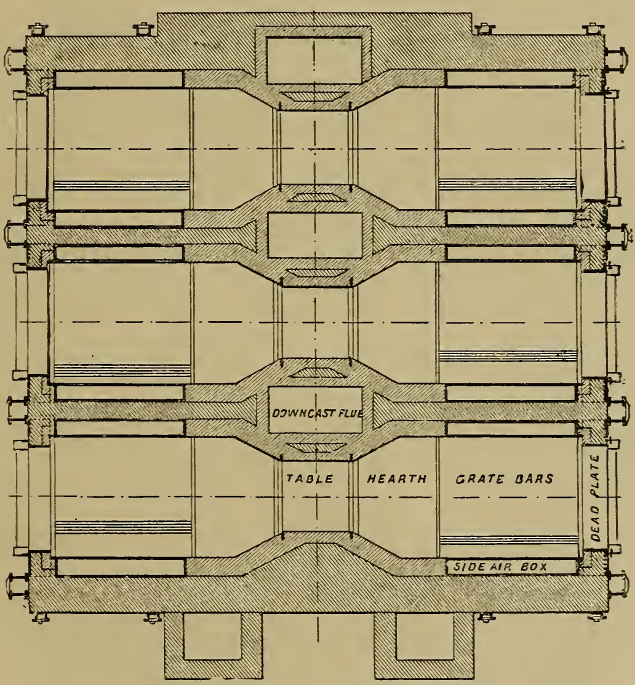


FIG. 53.—Plan at Grate Bar Level ; Horsfall Destructor.

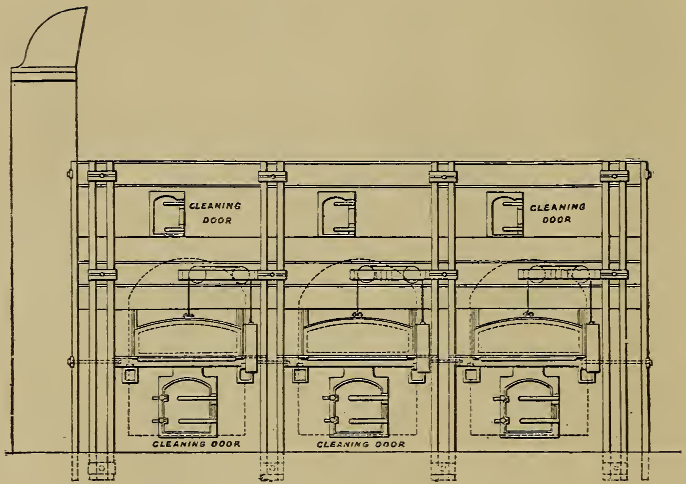


Fig. 54.—Front View ; Horsfall Destructor.

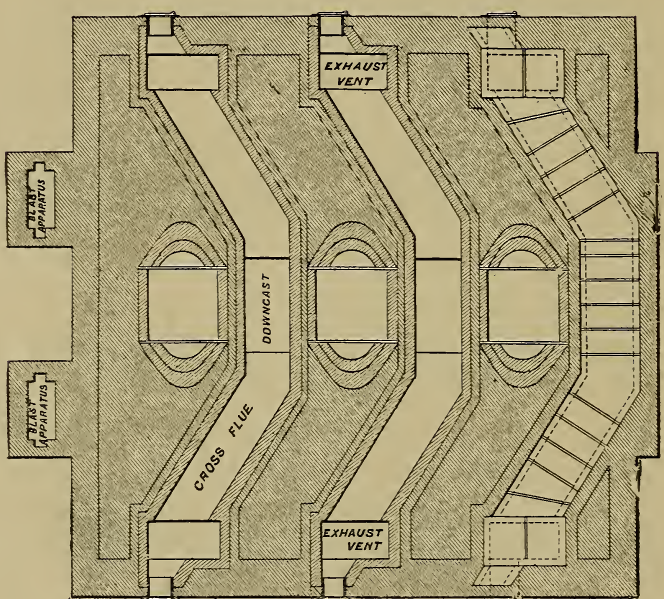


Fig. 55.—Plan at Level of Cross Flues ; Horsfall Destructor.

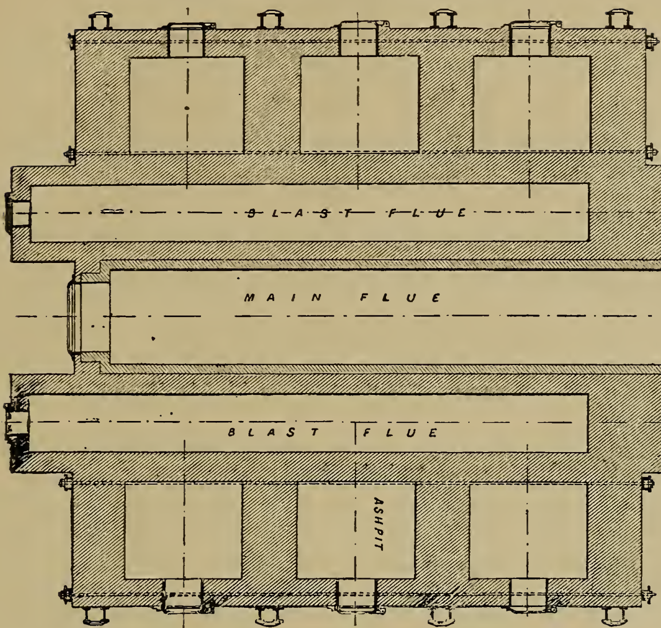


FIG. 56.—Plan at Ashpit Level ; Horsfall Destructor.

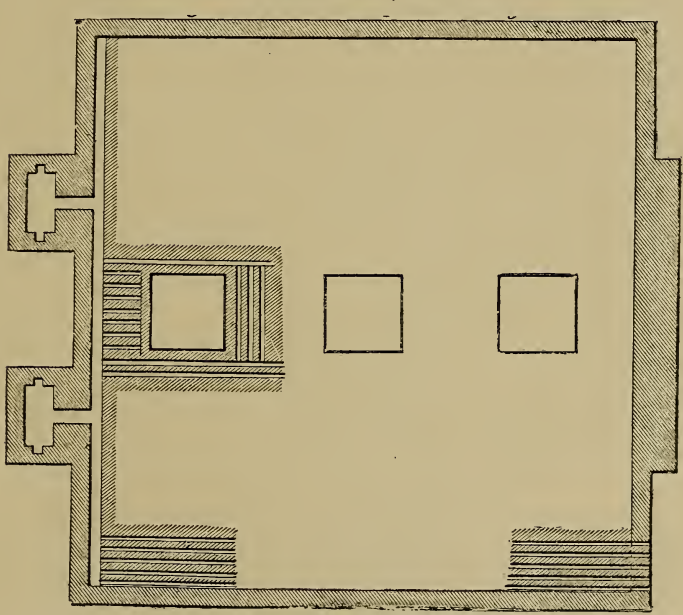


FIG. 57.—Plan Showing Air Passages ; Horsfall Destructor.

Fig. 54 shows a front view of the furnace with cleaning and clinkering doors.

A sectional plan of the furnace at the level of the ash-pit is shown in Fig. 56, and another, showing the air passages leading to the blast apparatus, in Fig. 57. These air passages can also be seen in Fig. 52 in the tipping platform, and the air, which passes through them to the fire, picks up some of the heat which otherwise would be radiated and lost.

It is found that a blast pressure of not more than 1 in. of water is quite sufficient for all purposes; in fact, superior results have been obtained with this over higher pressures. It is also noteworthy that the chimneys attached to these destructors are free from smoke, showing that the carbonaceous matter has been completely consumed.

In places where the refuse contains much matter, which is likely to escape from the chimney as dust, a collecting chamber is interposed between the destructor and the chimney, and this is found to completely get rid of any nuisance in this direction. The amount of dust is considerable. At Edinburgh the amount collected was about 50 cubic feet per week. Its density is about 30 lb. per cubic foot, and it closely resembles finely ground reddish fire-brick.

At Bradford the density is nearly double that at Edinburgh, the original refuse containing about 40 per cent of nightsoil and 5 per cent of vegetable refuse.

At Oldham the waste heat is used to generate steam for mechanical purposes, and to assist in supplying steam to the electric lighting station.

The following table of flue-gas analysis is reproduced from Professor Barr's report on the Oldham destructor:—

Samples.	A	B	C	D	E
Carbonic acid	8·6	15·5	18·1	8·5	13·3
Oxygen	10·9	3·9	1·4	10·7	6·3
Nitrogen	80·5	80·6	80·5	80·8	80·4
Excess of air per cent	113	23	7	70	43

No hydro-carbons or carbonic oxide were found in the gases, and the average temperature was about 1,600 deg Fah. The samples A, B, and C were taken from a four-cell furnace, while D and E were taken from a six-cell furnace.

In the following tables the results are given of some trials carried out by Professor Barr and Lord Kelvin:—

Rhodes Bank Destructor, Oldham.

Date and Duration of Trial: 8 a.m. 5th May, to 8 a.m., 6th May, 1898. Twenty-four hours.

	Four Cell Group.	Six Cell Group.	Total.
Refuse consumed in lbs.	71,320	106,980	178,300 (79·6 tons)
,, ,, per cell per 24 hours	17,830	17,830	17,830 (7·96 tons)
Clinker and ashes produced in pounds	......	......	56,690 (26·2 tons)
Proportion of clinker and ashes produced to refuse burned per cent.	......	......	32·9
Average boiler gauge pressure in pounds per square inch	128	128	......
Average temperature of feed water	57 deg. Fah.	57 deg. Fah.	......
Water evaporated in pounds	78,900	78,100	157,000
Equivalent evaporation in pounds of water from and at 212 deg. Fah.	95,100	94,100	189,200
,, ,, per cell per 24 hours	23,800	15,700	18,900
,, ,, per pound refuse	1·33	·88	1·06
Temperature of gases before passing through economiser	......	......	700 deg. Fah.
,, ,, after ,, ,,	......	......	555 deg. Fah.
Air consumption per pound refuse (calculated approximately)	25·8 cubic ft. (1·96 lb.)	28·6 cubic ft. (2·16 lb.)	27·5 cubic ft. (2·08 lb.)
,, ,, per cell per hour ,, ,,	18,650 cubic ft. (1,410 lb.)	20,620 cubic ft. (1,560 lb.)	19,830 cubic ft. (1,500 lb.)
Average draught in ashpit in inches of water	$\frac{7}{8}$	$1\frac{3}{8}$	......

HAMMERTON STREET DESTRUCTOR, BRADFORD, AND RHODES BANK DESTRUCTOR, OLDHAM.

The following table has been drawn up from information kindly supplied by Mr. McTaggart, the Superintendent at Bradford, and Mr. Jessop, the Superintendent at Oldham.

	Bradford.	Oldham.
Number of cells	12	10
Number of stokers and weekly wages	8 at 28s.	12 at 30s.
,, fillers ,, ,,	4 at 25s.	
Number of boiler and mortar mill attendants, and weekly wages	2 at 28s. 1 at 23s.	1 at 27s. 1 at 24s.
Extra man at mortar mill occasionally employed	6s.	......
Total wages of furnacemen per week	324s.	360s.
Total wages of furnace, boiler, and mortar mill men per week	409s.	411s.
Hours of work of furnacemen per week	66	48
Shifts of furnacemen per week	5 of 12 hours 1 of 6 hours	6 of 8 hours
Time of working destructor per week	(Start) Sunday midnight (Finish) Saturday noon	Sunday 10 p.m. Saturday 10 p.m.
Hours of working the destructor	132	144
Frequency of clinkering of each cell	Every $1\frac{1}{2}$ hours	Every 2 hours
Average amount of muck burned per week	650 tons	480 tons
Rate of working of each cell per 24 hours	10 tons	8 tons
Average bulk of muck in cubic feet per ton	40	50
Cost of labour of furnacemen per ton	6d.	9d.
,, ,, boiler, and mortar mill men per ton	$7\frac{1}{2}$d.	$10\frac{1}{4}$d.

Warner Perfectus Refuse Destructor.—The accompanying illustrations, Figs. 58 and 59, show the latest type of destructor constructed by Messrs. Goddard, Massey, and Warner. The drawings in question are illustrations of the destructor as erected at Torquay, Fig. 58 being a section through one of the four cells, and Fig. 59 a section of one

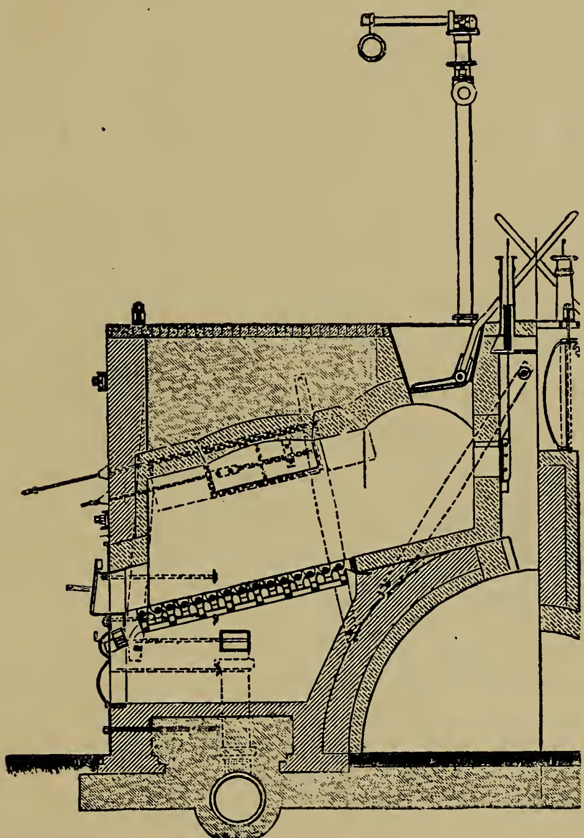


FIG. 58.—Section through one of the four Cells.

of the two boilers. The installation comprising four cells back to back, have each about 26 superficial feet of firebars, of the rocking type, upon the wedge-shape principle. At the back of the firebars directly under the hoppers is a firebrick drying hearth with a reverberatory arch built over so as to radiate heat upon the newly-fed refuse upon the hearth, thus partially drying it before it reaches the fire. Two multitubular boilers are built in between the cells, the shells of which are 3 ft. diameter by 12 ft. 3 in. long, with steam drum 3 ft. diameter by 9 ft. long, and each is set at a working pressure of 80 lb., but tested

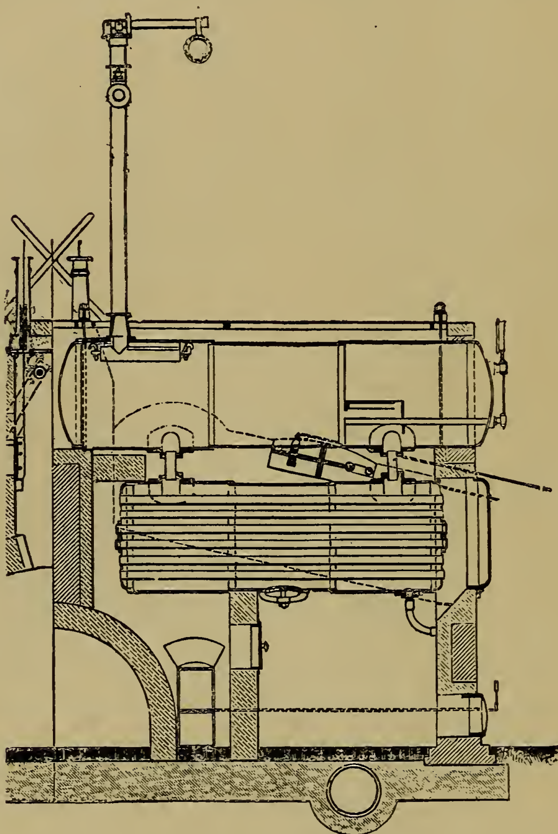


FIG. 59.—Section through one of the two Boilers.

up to 140 lb. upon the square inch. There are two engines, one horizontal, having a steam cylinder 10 in. by 20 in. stroke, and one vertical engine with steam cylinder 6 in. diameter.

The horizontal engine is used for driving a heavy mortar mill, having a pan 7 ft. diameter, and a Warner's clinker mill, also for driving a dynamo for producing electricity for lighting the works and the district in the immediate vicinity of the destructor. The vertical engine is used for driving the high-pressure fan, air from which is drawn through an 18 in. iron pipe from over the top of the tipping platform, so that the foul air from the refuse may be extracted from the main building and passed under the firebars.

An oil-jet cremator has been provided in the main flue, but this has not yet been made use of, as the temperature in the cells has been found sufficient to consume without nuisance all the refuse delivered to the destructor.

The circular chimney shaft, constructed of red brick and surmounted by a cast-iron cap, rises to a height of 150 ft. above the ground line, and rests upon a solid bed of concrete 25 ft. 6 in. square, 12 ft. thick, carried down to a depth of 19 ft. below the ground level. In addition to being used in connection with the destructor, a 15 in. pipe from the main line sewer in the immediate vicinity has been brough to and connected to the cremator chamber. The shaft thus acts as a sewer ventilating column. The shaft is lined with firebrick to a height of 50 ft. At the base of the shaft is constructed a special dust-catching chamber, which prevents the possibility of any dust being carried out at the top of the shaft.

The following test of the Torquay destructor, was made on the 21st December, 1898, and quite independently of the manufacturers.

Number and type of furnaces.........	Four "Warner Perfectus."
Number of boilers and position	Two, between the furnaces.
Nature of refuse burned	Unscreened ashpit refuse, very dry and containing a large quantity of waste paper, straw and packing paper. The first four loads delivered, being very light, were absolutely destroyed in the first hour and a quarter
State of weather............................	Very fine and dry.
Duration of test	12 hours, 8-30 a.m. to 8-30 p.m.
Number of men engaged	Three in addition to half time of contractor's representative superintending running of the machinery.
Wages of above	12s. 8d., including above.
Total weight of refuse delivered to destructor during the day	19 tons 7 cwt.

Total weight of refuse burned during the 24 hours	16 tons 7 cwt. = 36,624 lb.
Cost of burning per ton	9·29d.
Colour of smoke from chimney	First observation, 9-30 a.m., light brown; 2-20 p.m., almost colourless; and at 4 p.m., light brown.
Total quantity of water evaporated. Starting at 8 a.m. from a cold-water feed and steam gauge standing at 00	1,224 gallons = 12,240 lb.
Refuse burned per pound of water evaporated under disadvantageous conditions above referred to	2·99 lb.
Average steam-pressure maintained during 12 hours in each boiler (31 readings)...........................	57 lb.
Highest reading, 11-30 a.m............	105 lb.
Lowest reading, 8 p.m.	38 lb.
Total I.H.P. per hour continuously at 20 lb. of water per I.H.P..........	51 indicated horse power.

		Tons	cwt.	qrs
Residuals from total quantity of refuse delivered and burned, including that left on completion of test	Clinker	0	54	0
	Fine ash	0	16	2
	Old tins and the like ..	0	2	3
	Total...........	3	13	1
Percentage of residuals	18·93			

The residuum from the destructor has been analysed by Dr. Bernard Dyer, of London, with the following result :—

	Ground Clinker.	Flue Dust.
Moisture, organic matter, and water of combination	1·00	6·52
* Phosphoric acid	1·06	0·96
Lime	10·47	8·40
Oxide of iron and alumina	33·54	33·34
Carbonic acid, &c.	4·41	10·38
Silicious matter	49·52	40·40
	100·00	100·00
Nitrogen ....practically none	...	0·17
* Equal to ammonia	...	0·21
Equal to tribasic phosphate of lime	2·31	2·09

The information relating to the Warner Perfectus Destructor has been abstracted from a paper read by Mr. Henry A. Garrett, before the Institution of Mechanical Engineers.

CONSTANTS RELATING TO COMBUSTION.

(PROF. PULLEN.)

	Atomic Weight. H=1.	Molecular Weight. H_2=2.	Specific Gravity at 32° F. and Atmospheric Pressure. Water=1.	Density in Pounds per Cubic Foot.	Specific Heat at Constant Pressure *Cp*.	Specific Heat at Constant Volume *Cv*.	Co-efficient of Expansion of Volume at Constant Pressure per degree C.	Co-efficient of Expansion of Volume at Constant Pressure per degree F.	B.T.U. given out during Combustion with Oxygen.
Air	....	....	·00130	·0809	·2377	·1690	·003665	·002036	....
Carbon	11·97	....	2·33*	....	·2411	....	....	....	14540
Carbonic Acid Gas	....	CO_2 43·89	·00198	·1225	·2164	·15[illegible]5	·003688	·002049	....
Carbonic Oxide	....	CO 27·93	·00126	·0784	·2479	·1758	·003667	·002037	4370
Coal Gas (rough average)	....	....	·00054	·0335	....	....	....	....	17800
Hydrogen	1	H_2 2	·00009	·0056	3·4046	2·414	·003667	·002037	61260
Nitrogen	14·01	N_2 28·02	·00126	·0784	·2440	·1730	·003668	·002038	....
Marsh Gas	....	CH_4 15·97	·00072	·0448	·5929	·4701	....	....	26400
Olefiant Gas	....	C_2H_4 27·94	·00126	·0784	·404	....	....	....	21300
Oxygen	15·96	O_2 31·92	·00144	·0896	2182	·156	....	....	....
Steam at 212° F.	....	H_2O 17·96	·0008	·05	·4750	·34	....	....	....
Sulphur	31·98	S_2 63·96	2·07	·127	·2026	....	....	....	4000
Sulphur Dioxide	....	SO_2 63·9	·00288	·1792	....	....	·003845	·002136	....
Refined Petroleum	....	....	·8	....	....	....	....	....	22000
Crude Petroleum	....	....	·9	....	....	....	....	....	20000

* Graphite. Charcoal = ·2 approximate.

Specific heat of ash = ·2.

Specific heats of gas engine exhaust gases when coal gas is used = ·258 at constant pressure, and ·189 at constant volume.

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