H. L. DOHERTY.

METHOD OF HEATING.

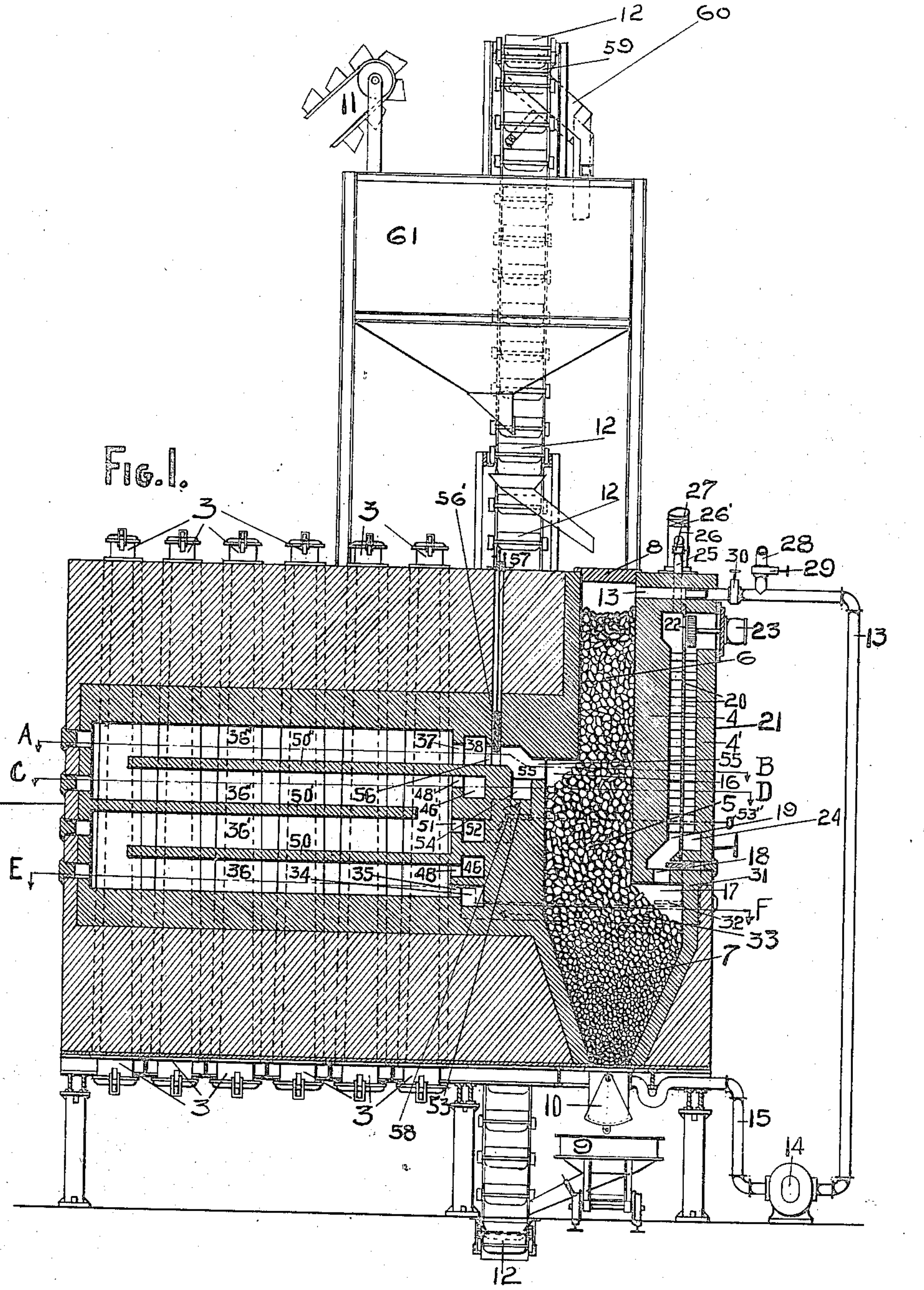
APPLICATION FILED JAN. 9, 1912.

1,194,151.

Patented Aug. 8, 1916.

2 SHEETS—SHEET 1.

FIG. 1.



Witnesses:

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2 SHEETS—SHEET 2.

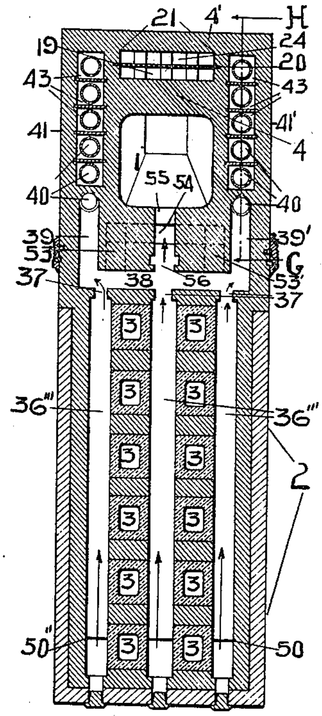


FIG. 2.

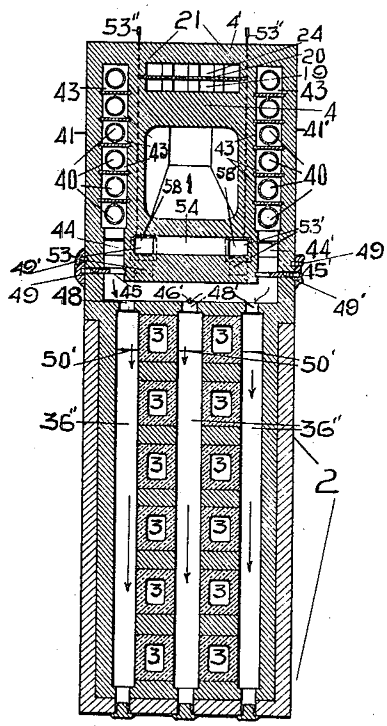


FIG. 3.

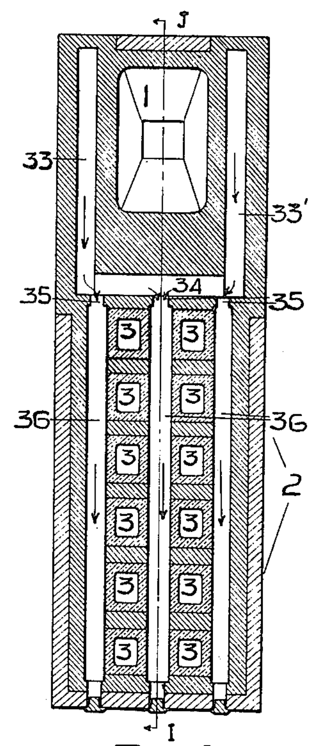


FIG. 4.

FIG. 6.

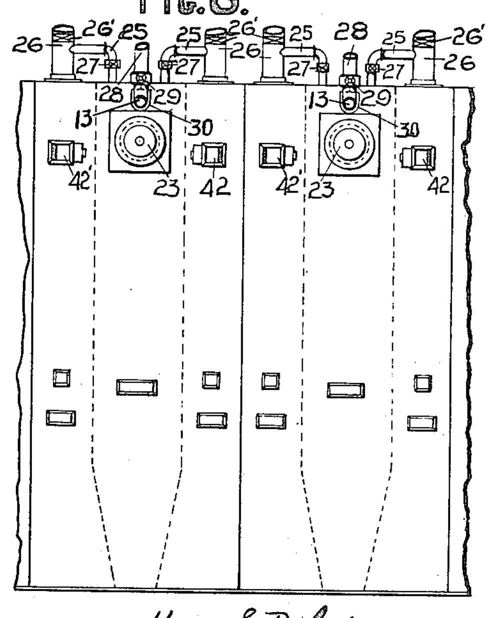
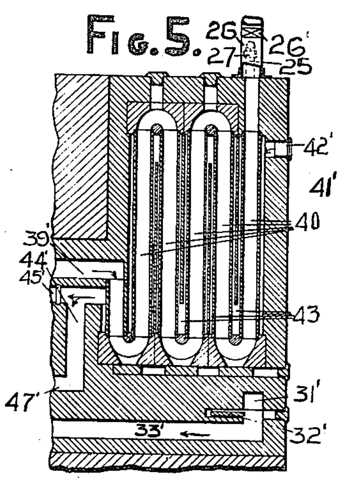


FIG. 5.



Witnesses:

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UNITED STATES PATENT OFFICE.

HENRY L. DOHERTY, OF NEW YORK, N. Y.

METHOD OF HEATING.

1,194,151. Specification of Letters Patent. Patented Aug. 8, 1916.

Original application filed November 15, 1911, Serial No. 660,450. Divided and this application filed January 9, 1912. Serial No. 670,339.

To all whom it may concern:

Be it known that I, HENRY L. DOHERTY, a citizen of the United States, and resident of New York city, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Heating, of which the following is a specification.

My invention relates to a method of heating.

The object of my invention is to supply to the art an improved method of heating which will permit of the easy regulation of the temperature of the heating oven and the furnace, promote the rapidity of the heat transfer from the heating gases to the objects to be heated, by insuring a high velocity of circulation of the heating gases and at the same time secure a high degree of recuperation of the heat of the rejected gas.

Briefly stated, my invention comprises the maintaining of a continuous circulation of gases from a furnace to a heating oven and back again to the furnace—the return circulation to the furnace consisting of a balanced stream of completely burned and incompletely burned gas with the continuous rejection of completely burned gases from the circulation to an air recuperator to heat the air used in the combustion, the volume of the gases so rejected being that corresponding approximately to the increment in volume of the gaseous body due to the air used in the combustion.

In the accompanying drawings I have shown an embodiment of my invention as applied to the heating of retorts for the carbonization of coal.

In the drawings, Figure 1 is a vertical longitudinal cross-section through the furnace and heating chamber or oven of the apparatus on the line I—J of Fig. 4. Fig. 2 is a horizontal cross-section of the same on the line A—B of Fig. 1. Fig. 3 is a horizontal cross-section on the line C—D of Fig. 1. Fig. 4 is a horizontal cross-section on the line E—F of Fig. 1, and Fig. 5 is a vertical cross-section through one of the recuperators on the line G—H of Fig. 2. Fig. 6 is an elevation of the furnace end of two units of the apparatus.

This application is a division of my application Ser. No. 660,450, filed Nov. 15th, 1911, which describes my method of heating in detail without claiming the same.

My present invention is in the nature of an improvement upon the invention which is described and claimed in my copending application Ser. No. 603093, filed Jan. 17th, 1911, in which the gas generator of a heating apparatus is run on a current of flue gases, alone, without the addition of extraneous air. In this present invention I have improved the process of said application by substituting a volume of incompletely burned gases as the principal vehicle for carrying heat to the generator in place of using an excess of flue gases (comprising combustion gases, alone, or combustion gases and air) as the heat carrier and depending upon regulation of the velocity of passage of the gases through the fuel bed to control the temperature of the bed and the quantity of combustible gas made.

In the drawings, 1 refers to the furnace.

2 is a heating chamber or oven of the apparatus (in this case a retort oven).

4 and 4′ refer to the two sections of the outer walls of the furnace which incloses the heat interchanger 21.

5 is a gasifying chamber of the furnace.

6 is a preheating chamber.

7 is the cooler.

8 is the fuel charging opening of the furnace.

9 indicates a movable fuel hopper below the cooler 7 of the furnace.

10 is the discharge door of the furnace, which is preferably opened and closed by a mechanical arrangement.

11 is the elevator which elevates the raw coal to the fuel bin 61.

12 is an ash and coal conveyer which, as shown, serves at the same time to convey away the fuel and ash withdrawn from the cooler 7 and to convey to the fuel bed at the top of the furnace the mixture of raw fuel and carbonized fuel which constitutes the charge.

13 is a gas off-take from the top of the preheating chamber 6 of the furnace through which gas is drawn by the blower 14 and forced through the pipe 15 into the lower part of the cooler 7.

As shown in the drawings, the walls of the furnace at the gasifying chamber 5 are offset to permit the fuel in the same to form two free surfaces on its angle of repose. The upper of these spaces, which is designated 16 in the drawings, provides a space for the distribution of the primary current to the furnace, while the space 17 furnishes a free space over the fuel through which is drawn off the gases formed by the combustion taking place in the gasifying chamber 5.

18, 18, etc., designate the nostrils through which the gas formed in the furnace is withdrawn from the space 17. These nostrils communicate with the upcast flue 19 of the heat interchanger 21.

20 is a diagram separating the upcast flue 19 from the downcast flue 24 of the heat interchanger 21, while 23 is a blower which draws the gas from 19 through the aperture 22 in the diaphragm 20 and forces it through the downcast flue 24 and through the connecting flues to the lower combustion flues 36 of the furnace. The passages 25 connect the upper part of flue 19 with the stacks 26 of the recuperators.

26′ indicates the dampers on the stacks 26.

27, 27 are valves on the connections 25.

28 is a connection from the gas off-take 13 to the atmosphere, and is provided with a valve, 29.

30 is a valve on 13 between the atmospheric connection 28 and the preheater 6.

31 and 31′ refer to gas off-take flues which communicate with either side of the lower part of the downcast flue 24 of the heat interchanger 21.

32 and 32′ are dampers on 31 and 31′, respectively.

33 and 33′ indicate, respectively, connections from the off-take flues 31 and 31′ to the cross-flue 34.

35, 35, etc., are gas nostrils permitting the discharge of the gas which enters flue 34 from both ends into the lower combustion flues 36 of the retort oven 2.

36′, 36′, etc., refer to a second set of combustion flues which are located immediately above the flue 36.

36′′ refers to a set of combustion flues above 36′, while 36′′′ refers to the uppermost set of combustion flues of the retort oven.

37 are the combustion gas off-take nostrils which establish communication between the uppermost combustion flues 36′′′ and the cross-flue 38.

39 and 39′ are flues establishing communication between the cross-flue 38 and the combustion gas flue 40 of the respective recuperators 41 and 41′.

42 and 42′ are the air dampers on the respective air recuperators, while 43 indicates the air flues of these recuperators.

44 and 44′ indicate, respectively, the off-take air passages from the flues 43 of the respective recuperators.

45 and 45′ are connections from 44 to the uppermost cross-flue for air, which is designated 46′.

47 and 47′ are connection from, respectively, 44 and 44′ to the lower cross-flue for air, 46.

48′ are the air nostrils which establish communication between the uppermost cross-flue for air 46′ and the combustion gas flue 36′′, while 48 refers to the nostrils which establish communication between the lowermost cross-flue for air 46 and the lowest set of combustion flues 36 of the retort oven.

49 and 49′ are dampers on, respectively, 45 and 45′.

50 is the baffle which separates the lowest group of combustion flues 36 from the second tier of combustion flues 36′.

50′ refers to the baffle separating flues 36′ from flues 36′′, while 50′′ refers to the set of baffles separating 36′′ from the uppermost combustion flues 36′′′.

51, 51, etc., refer to the gas off-take nostrils from the flues 36′ to the cross-flue for gas 52.

53, 53′ are connections from the ends of the cross-flue 52 to the cross-flue 54 which conducts the gas to the primary inlet flue 55.

58′, 58′ are dampers on the flues 53 and 53′, operated by rods 53′′, 53′′.

56 is a flue establishing communication between the uppermost cross-flue for the combustion gases 38 to the primary air inlet flue 55.

56′ is a damper on 56 which is operated by the rod 57.

In starting operations either coarse cinder or fuel is charged into the cooler 7 of furnace 1 and then kindling charged on top of the mass in the cooler. The kindling is ignited, air being supplied for combustion through the atmospheric connection 28 of the pipe 13 by blower 14 which forces the air through the pipe 15 into the lower part of the cooler. At this stage of operations the valve 29 on 28 is of course opened and the valve 30 between 29 and the preheating chamber 6 is closed. When the kindling has been properly ignited, fuel is charged onto it from the charging opening 8. When this fuel has been properly ignited more fuel is gradually charged until a mass of ignited fuel has been built up through the shaft to the point of offset of the walls of the shaft; or, in other words, until the gasifying chamber 5 has been completely filled with a mass of ignited fuel. Fuel is now rapidly discharged until the preheating chamber 6 has been completely filled.

During the preliminary combustion the gases may be permitted to escape directly to the atmosphere through the charging opening 8 at the top of the preheating chamber 6. When the fuel bed in the furnace chamber 5 is in proper condition to establish normal operating conditions, the valve 29 on 28 is closed and valve 30 on 13 is opened. The blower 14 now draws a part of the gases from the gasifying chamber 5 through the cold fuel occupying the preheating chamber 6 and forces the cold gases into the bottom of the cooler 7 through which they pass in contact with the fuel mass occupying the same and join the main draft current of the furnace.

As hereinafter explained, in this embodiment of my invention, I move the fuel mass through the furnace at a rate greater than the rate of combustion of the fuel therein. The material occupying the chamber 7 therefore consists of a mixture of fuel and ash. The cooled gases entering the lower part of 7 and passing up through the fuel therein, of course, take up heat from the material, being themselves raised in temperature. By properly proportioning the volume of the cooling gases to the rate at which the material is drawn from 7 the mixture of fuel and ash may be cooled down to the temperature desired before it is withdrawn from 7.

The normal gas circulation thus established in the apparatus under normal operating conditions is as follows: The gases drawn off from the gasifying chamber 5 pass off from the off-take space 17 through the gas nostrils 18 into the upcast flue 19 of heat interchanger 21 under the inductive action of the fan 23 and are forced down through the flue 24, thence through the flues 31 and 31′ which communicate with either side of the bottom of the downcast flue 24 to the flues 33 and 33′, respectively, which discharge into the cross-flue 34. From 34 the gases pass through the gas nostrils 35 into the lowermost set of combustion flues 36 of the furnace, where they are burned by air admitted from either or both the air nostrils 48 or 48′.

The function of the heat interchanger 21 is the cooling of the gases approaching the fan 23 by transferring their heat to the gases discharging from the fan 23 in order to reduce the temperature of the gases passing through the same to a point which will not injure it. It is obvious that at the start of operations the gases will be subjected to a gradual cooling as they pass through the flues since the setting is cold and contains more or less moisture. The gases therefore at first reach the fan at a lower temperature than that at which they enter the lower end of the flue 19. Discharging from the periphery of the fan, however, they are impelled down through the outer flue 24 and thus subjected to reheating by the hotter gases passing in the reverse direction through the flue 19. It is plain that a heat differential that has once been established between the two streams of gas will thereafter be maintained as long as no extraneous heating or cooling action is introduced. The amount of this heat differential will, in the absence of any extraneous influence, depend entirely upon the superficial area and heat transmitting power of the diaphragm 20 and upon the velocity of the draft. In any case, however, within certain limits, should the size of the flues 19 and 24 be too small (or, rather, should the heat transferring surface of the diaphragm be too small) the normal differential may be increased by admitting to the upper part of flue 19 a portion of the relatively cool gases of complete combustion which are drawn from the stacks 26 through the flues 25. The volume of the combustion gases which are thus drawn down into the flue 19 I regulate by means of the valves 27 on the connections 25. The addition of this relatively cold gas of course lowers the temperature of the gas mixture reaching the fan and thus permits the establishment of the required temperature difference between the two currents. In this case the differential is further increased as the gas flows through the downcast flue 24 by the increased heat capacity of the current discharging from the fan due to the volume of gas which has been added at the top of flue 19. There is obviously no actual loss of heat from the gas save the small loss by conduction and radiation to the setting but simply a transfer of heat from the current approaching the fan to the current discharging from the same. By these features, therefore, I am able to move the hot gases with ordinary fan blowers with substantially no sacrifice of the heat of the gases. This method of moving hot gases by ordinary fan blowers I will claim specifically in another application.

In normal working only sufficient air is admitted through the nostrils 48 to burn somewhat more than one-half of the combustible constituents in the gases introduced through the gas nostrils 35, while at the air nostrils 48′ sufficient air is introduced to insure the complete combustion of all the residual combustible constituents entering the flues 36″ which were unburned by the air introduced through the nostrils 48. The combustion gases flow through the flues 36, 36′, 36″ and 36‴ in a serpentine course along the walls of the retorts 3. Discharging from the uppermost combustion flues 36‴ through the off-take nostrils 37, the combustion gases enter the cross-flue 38. In 38, the combustion gases divide into two separate streams, one stream flowing to the recuperators while the second stream joins the primary draft of the furnace 1. The first of these streams is drawn off through the flues 39 and 39′, respectively, in two sub-divisions to the combustion gas flues 40 of the recuperators 41 and 41′. Passing through the combustion gas flues 40 of the recuperators the gases discharge to the atmosphere through the stacks 26. The second stream flows through the flue 56 to the primary draft inlet 55 of the furnace. The distribution of the combustion gases between these two streams is controlled by the dampers 56′ and 26′ on 56 and 26, respectively.

The air for supporting the combustion in the combustion flues 36 and 36‴ enters the recuperators 41 and 41′ through the air dampers 42 and 42′, respectively. Passing through the air flues 43 the air is heated by the heat of the hot combustion gases which are at the same time flowing in the opposite direction through the flues 40 of the recuperators. The heated air discharges from the flues 43 through the flues 44 and 44′, which are connected, respectively, with the air flues of the respective recuperators 41 and 41′. From 43 the hot air is distributed to either one or both of the cross-flues 46 and 46′, respectively. By means of the dampers 49 and 49′, respectively, on the connections 45 and 45′ between the cross-flue 46′ and the downcast air flues 44 and 44′, the distribution of the air between the cross-flues 46 and 46′ may be regulated as desired. Since the inductive action on the stacks and the fans 23 is exerted to a greater extent on the higher combustion flues 36″ than on the lower combustion flues 36, the air will then by preference flow to and through the cross-flue 46′ and thence into the combustion flues 36″, when the connection to 46′ is free for the passage of the air owing to the opening of the dampers on the flues 45 and 45′. By partially closing these dampers the flow of air may be diverted in part to the lower cross-flue 46, from which it enters the lower combustion flues 36; or by entirely closing the dampers the entire volume of the secondary air may be forced to take the path through the flues 46 into the lower combustion flues. In operating the apparatus it is my object, however, to secure a diffused combustion of the gases through the four sets of combustion flues. To this end, I so regulate the distribution of the air between the nostrils 48 and 48′ as to maintain a fairly uniform combustion throughout the flues.

In the operation of the furnace, I support the combustion of the fuel in the gasifying chamber 5 by supplying thereto a highly heated primary current composed of partially burned gases withdrawn from the second tier of combustion flues 36′ through the off-take nostrils 51, cross-flue 52, side flues 53 and 53′ to the upcast flue 54 which discharges into the primary inlet 55, and a portion of the gases of complete combustion which are withdrawn from the main combustion gas flue 38 and the flue 56 connecting 38 with the primary current inlet 55.

Owing to the fact that it is always necessary in order to secure the complete combustion of the combustible constituents of the gas to introduce air through the nostrils 48′ in excess of the volume which is required to completely burn the residual combustible constituents of the gas by the time it has reached the flues 38, there is usually more or less free oxygen in the combustion gases which are drawn from the flue 38. On the other hand, the gases withdrawn from the combustion flues 36′ usually contain a greater or less proportion of unburned gases. Since the two streams, however, are at a high temperature when they mingle in the primary inlet flue 55, any free oxygen in the portion of the primary current thus drawn from the flue 38 will combine with some of the incompletely burned gas in the portion of the draft which is drawn from the flue 36′. Since this limited combustion takes place, however, in close proximity to the gasifying chamber 5 practically all of the heat thus generated is available in the fuel bed in 5 for assisting in the dissociation of the carbon dioxid of the primary draft. In describing the method of carrying out the combustion in the chamber 5, therefore, I will assume that the two sub-divisions of the primary draft enter the gasifying chamber 5 without mingling; or, in other words, that such combustion as takes place between the two sub-divisions of the primary current will take place in the space 16 above the fuel bed. Since the carbon dioxid or water vapor which has been formed by this limited combustion between the two sub-divisions of the primary draft current is reduced to carbon monoxid in passing through the fuel bed by reaction with the carbon of the same at the expense of the heat which was formed in its combustion, this limited combustion exerts practically no effect on the temperature conditions prevailing in the gasifying chamber 5.

Both the portion of the primary current drawn off from 36′ and the portion drawn off from the flue 38 are at a comparatively high temperature—from 2200° to 2500° F. While the initial temperature of the primary current is somewhat reduced by the time it reaches the furnace, still it should enter the fuel bed in the latter at a temperature above 2000° F., and usually at about 2200° F. In passing through the fuel bed in 5 more or less of the carbon dioxid of the primary draft (and the water vapor carried by it) reacts with the carbon of the fuel to form carbon monoxid and hydrogen, according to the reactions

$$(a) \quad CO_2+C=2CO$$

and

$$(b) \quad H_2O+C=H_2+CO.$$

Both of these reactions absorb a large amount of heat which in normal operation is supplied by the sensible heat carried by the primary current at its entrance into the fuel bed. Since, by my method of combustion, the water vapor present in the gases is always exclusively the vapor derived from the air and the fuel, its action in the furnace is relatively unimportant. We only need, therefore, to consider the action of the carbon dioxid. This reacts energetically with the carbon of the fuel at temperatures approximating 1800° F. and above, but less rapidly as the temperature falls. There is more or less reaction takes place even down to and below 1300° F. It is evident, therefore, that by regulating the quantity of CO_2 carried into the furnace and the quantity of heat accompanying the CO_2 by regulating the draw of gases from 36′ and 38, respectively, I am able to maintain the fuel bed in the chamber 5 of furnace 1 at any temperature desired within the working range.

In order to secure complete combustion of the gases in the combustion flues it is necessary to introduce a slight excess of air into the flues from the nostrils 48′, as already explained. The portion of the primary draft drawn off from cross-flue 38 through flue 56, therefore, will usually contain a small proportion of free oxygen. As explained, this will burn any excess of unburned gases in the portion of the primary current which is drawn from the flues 36′, but in its effect on the fuel in chamber 5 it will act as though it were introduced separately; or, in other words, there will be a portion of the fuel burned in 5 to CO equivalent to the free oxygen in the main branch of the primary current. The result is that there will be developed in the fuel itself an excess of heat which will go to help support the dissociation of the CO_2 of the accompanying draft current. Under normal working conditions, however, this excess of air is kept as low as possible. This portion of the draft current, therefore, has a strong net endothermic or heat absorbing effect. The portion of the primary draft withdrawn from 36′, on the other hand, carries under normal conditions more than enough sensible heat to dissociate its own CO_2 by reaction (*a*) and has thus a net exothermic or heating effect on the fuel bed. By varying the actual volume of the primary current and properly proportioning the two separate streams of gas making up the same I am able to control the temperature of the fuel bed in 5 and also the quantity of combustible gas generated. The volume of the gases drawn through the fuel bed is, of course, controlled by the speed of the fan 23 and the various dampers on the several conduits. This also serves to control the proportion of CO_2 of the primary draft which is dissociated, since by varying the volume of the primary draft I vary the speed at which the gas is passed through the fuel bed and therefore the time it is in contact with the hot fuel.

Contrary to the practice in producer firing, I do not aim to correct the maximum possible proportion of the CO_2 of the draft current in the furnace. On the contrary, in normal working, the gases are circulated through the fuel at such a velocity that the dissociation is usually less than 50 per cent. of the total CO_2 that passes through the fuel. I am thus able to easily maintain the temperature of the fuel at a point that insures its maintenance in an active gas making condition by the sensible heat introduced by the large volume of gases passing through it.

As the combustion proceeds, the proportion of ash in the material occupying chamber 5 increases. By causing the fuel mass to move through chamber 5 at a regulated rate greater than the rate at which the fuel is burned, however, the proportion of ash in the mass is prevented from increasing to the degree at which it would offer objectional obstruction to the draft passing through the furnace. This movement of the fuel is effected by withdrawing portions of the mass (which has been cooled in the manner described above) from the chamber 7, by lowering the door 10 by means of the mechanism provided for that purpose. The cold mixture of fuel and ash falls into the movable hopper 9, and is gradually fed from thence onto the conveyer 12, by which it is elevated and delivered into the hopper 59 of the screening device 60. In passing through 60, the fine ash is separated from the mixture and is rejected while the screened coke discharges into the bin 61. The proper quantity of raw coal to form a fuel mixture of the composition desired is, at the same time, discharged into 61 by the elevator 11. By opening the gate 62 the coal and coke is discharged from 61 onto the return flight of the conveyer 12, and transported to the charging doors 8 of the several furnaces as required. Coke from some other source may, of course, be substituted for the carbonized material withdrawn from the furnace itself. It is advantageous, however, where a coking coal is economically available for use in the furnace, to simply make use of the coke produced by the furnace itself.

The purpose of thus adding the coke to

the charge is that I may utilize as fuel very inferior grades of bituminous coal which usually have more or less tendency to cake, or an actual caking coal. By mixing the coked fuel with the bituminous coal I prevent the formation of the fuel aggregates or clinkers in the combustion region of the furnace which, when the fuel is used without such mixture, would, to a greater or less degree, shut off the draft through the fuel bed, thereby interfering with the operation of the furnace. The coke acts to secure this end by interposing between the softened fragments of the fuel a material which has not been softened by the heat, since it requires a temperature very much above the temperature of its formation to soften pre-formed coke.

The feature of my invention which embodies the method of passing the fuel through the furnace at a rate greater than its rate of combustion is designed, in the same manner, to prevent the formation of clinkers in the ash of the fuel. In preventing the formation of clinkers the coke acts in a manner similar to its action in preventing the formation of aggregates in the unburned fuel mass. It serves to prevent the ash formed from agglomerating, as it would in a combustion method in which the fuel is completely burned. By this method, therefore, I am able to burn fuels which have an easily fusible ash without the formation of clinkers and which, when burned entirely to ash, readily clinker.

In ordinary conditions of working I consider it advantageous to draw the fuel through at such a rate that the mixture withdrawn at the bottom of cooler 7 will not contain more than 10 per cent. of free ash. In fact, I prefer, usually, to work at such a rate that the ash-fuel mixture will contain closer to 5 per cent. than 10 per cent. of ash. The most advantageous rate of passing the fuel through the furnace, however, will vary with almost every variety of fuel which is used. I cannot, therefore, prescribe any definite rate which will be the most advantageous under all conditions, but this must be fixed by experiment with any particular fuel.

As previously stated, before withdrawing the mixture of fuel and ash from the cooler 7 it is cooled by the gas which has been forced into the cooler 7 by the blower 14. As described, this cold gas is derived by drawing off from the cold fuel at the top of the preheating chamber of the furnace a portion of the gas produced in the combustion region of the furnace. While this method of operation possesses marked advantages, I do not limit myself to the use of a cooling current secured in this way. Instead of cold gases withdrawn from the furnace, it is possible to use either steam alone, a mixture of combustion gases and steam, or a cold combustion gas alone. This method of conducting the combustion of the fuel in the furnace, however, I do not claim in this application, but claim it in my application Ser. No. 660,453, filed Nov. 15th, 1911.

The method which I herein claim is that relating to the method of heating as distinct from the specific method of operating the furnace. This heating process may be comprehensively described as the maintenance of a continuous circulation of gases from the furnace to the retort oven and back again to the furnace—the return circulation to the furnace consisting of a balanced stream of completely and incompletely burned gases. A volume of completely burned gases corresponding to the air introduced into the combustion flues of the retort oven is continuously ejected from the circulation and sent through the air recuperator. By thus circulating a large volume of gases at high velocity through the combustion flues and the fuel bed of the furnace, as well as by distributing the combustion through the flues, I am able to secure a proper heating of the retorts without the necessity of maintaining an excessively high temperature in the combustion flues, since, as is well known, the velocity of heat transmission through the retort walls varies with the velocity of the heating gases along the surface of the walls. No increased loss of heat in the rejected gases is occasioned, since the volume rejected from the circulation corresponds to the volume of air used, and the two currents in the recuperators are thus about balanced in their thermal capacities.

Having described my invention, what I claim is:

1. The method of heating, which comprises, withdrawing hot heating gases from a heating chamber before said gases have been entirely consumed, withdrawing completely burned gases from said chamber and mixing said incompletely burned and said completely burned gases, the said gases being withdrawn at such temperatures that the resulting mixture will carry sufficient heat to support the reaction of a regulated proportion of its combustion products with carbon, passing said hot gaseous mixture through a bed of ignited fuel to convert a regulated portion of the combustion products of said mixture into combustible gases by reaction with the fuel of said fuel bed, conducting said gases after their passage through said fuel bed into said heating chamber, and adding air to said gases in said heating chamber to burn the combustible constituents of said gases.

2. The method of heating which comprises, igniting gases containing a proportion of combustible constituents in a heating chamber, withdrawing from said chamber a portion of said gases before the same have

been completely consumed at a temperature at which said gases will carry sufficient sensible heat to support the reaction of a regulated proportion of their combustion products with carbon, passing the said gases through a fuel bed, whereby said regulated portion of the combustion products carried by the said gases is caused to react with the fuel in said fuel bed to regenerate combustible gases at the expense of the sensible heat of the said gases, and returning the effluent gases from said fuel bed to said heating chamber.

3. The method of heating which comprises, passing a mixture of combustible and combustion gases at a comparatively high temperature first through a fuel bed to generate a portion of combustible gases by reaction between the combustion products in the said gases and a portion of the fuel in said bed at the expense of the sensible heat of said gases and then through a heating chamber, adding air to the said gases in said chamber to support the combustion of the combustible constituents of said gases, and repassing a portion of the gases from such combustion before said gases have been entirely consumed through said fuel bed, whereby more or less of the fuel of the said fuel bed is burned by reaction with the products of the combustion carried into the said fuel bed by the said stream of mixed gases.

4. The method of heating which comprises, burning combustible constituents of a stream of circulating gases in a heating chamber by successive additions of heated air, withdrawing from a plurality of localities of said heating chamber regulated portions of hot completely and incompletely burned gases, mingling the several portions of said gases withdrawn and passing the same through a bed of carbonaceous fuel to convert a portion of the products of combustion of the withdrawn gases into combustible gases by reaction with the carbon of said fuel at the expense of the sensible heat of said withdrawn gases, returning the effluent gases from said fuel bed to said heating chamber, and passing through a recuperator to heat the air for sustaining the said combustion in said heating chamber, the portion of the completely burned effluent gases from said heating chamber that is not passed through said fuel bed.

5. The method of heating which comprises, burning combustible constituents of a stream of circulating gases in a heating chamber by successive additions of heated air, whereby the said stream of circulating gases is subjected to gradual combustion, withdrawing from said stream of gases a volume of completely burned gases equivalent to the volume of air added to said gaseous stream in said heating chamber, conducting said volume of completely burned gases through a recuperator to heat the air introduced into said heating chamber, withdrawing incompletely burned gases from said gaseous stream, passing the said incompletely burned gases together with the residue of said completely burned gases in admixture through a bed of carbonaceous fuel to convert a portion of the products of complete combustion in said gaseous mixture into combustible gas, and returning the effluent gases from said fuel bed to said heating chamber.

6. The process of heating which comprises, maintaining a circulation of heating gases through a fuel bed and a heating chamber, sustaining the combustion of combustible constituents of said circulating gases in said heating chamber by successive additions thereto of heated air, withdrawing from said gaseous circulation a volume of completely burned gases approximately equivalent to the volume of air added to said gases in said heating chamber, passing the said completely burned gases through a recuperator to heat said air, withdrawing from said gaseous circulation a volume of said gases before the same have been completely burned, and repassing said incompletely burned gases and the remainder of said circulating gases through said fuel bed to generate combustible gas by reaction between completely burned constituents of said circulating gases and said carbonaceous fuel.

7. The process of heating which comprises, maintaining a circulation of heating gases through a fuel bed and a heating chamber, sustaining the combustion of combustible constituents of said circulating gases in said heating chamber by successive additions thereto of heated air, withdrawing from said gaseous circulation a volume of completely burned gases approximately equivalent to the volume of air added to said gases in said heating chamber, passing the said completely burned gases through a recuperator to heat said air, withdrawing from said gaseous circulation a volume of said gases before the same have been completely burned, and repassing said incompletely burned gases and the remainder of said circulating gases through said fuel bed to generate combustible gas by reaction between completely burned constituents of said circulating gases and said carbonaceous fuel at the expense of the sensible heat of said circulating gases.

8. The process of heating which comprises, maintaining a circulation of heating gases through a fuel bed and a heating chamber, sustaining the combustion of combustible constituents of said circulating gases in said heating chamber by successive additions thereto of heated air, withdrawing from said gaseous circulation a volume of completely burned gases approximately

equivalent to the volume of air added to said gases in said heating chamber, passing the said completely burned gases withdrawn through a recuperator to heat said air, withdrawing from said gaseous circulation a volume of said gases before the same have been completely burned, and repassing said incompletely burned gases and the remainder of said circulating gases through said fuel bed to generate combustible gas by reaction between the completely burned constituents of said circulating gases and said carbonaceous fuel at the expense of the sensible heat of the volume of said circulating gases withdrawn, the said circulating gases being withdrawn from said heating chamber at temperatures at which they bear sufficient available sensible heat to sustain the generation of the quantity of combustible gas desired.

9. The process of heating which comprises, passing through a fuel bed a balanced draft current of completely burned and incompletely burned gases in admixture, at a temperature above the temperature of the fuel in same, the proportion of said incompletely burned gases being regulated to that volume required to carry sufficient sensible heat, in addition to the heat carried by said completely burned gases, to maintain the heat of said fuel bed, whereby a portion of the carbon dioxid of the said draft current is caused to react with a portion of the carbon of the said fuel bed at the expense of the sensible heat of the said balanced draft current, and passing the resulting gases through a heating chamber.

10. The process of heating which comprises, passing into an ignited fuel bed a regulated draft current of completely and incompletely burned gases in admixture and at a temperature above the temperature of the said fuel bed, the proportion of said incompletely burned gases in said admixture being regulated to that volume required to carry sufficient sensible heat, in addition to the heat carried by said completely burned gases, to maintain the temperature of said fuel bed to generate combustible gas from a portion of said gases of complete combustion, passing the said draft current through said fuel bed at a velocity such as will restrain the combustible gases generated to the proportion desired, conducting the resulting gas to a heating chamber and subjecting combustible constituents of said gases in said chamber to a prolonged combustion by the successive addition thereto of a plurality of portions of air.

11. The process of heating which comprises, passing a balanced draft current of completely burned and incompletely burned gases through a fuel bed, the said incompletely burned gases being at a temperature such that their sensible heat above the temperature of the fuel will be sufficient to support the dissociation by the carbon of the fuel bed of a portion of the carbon dioxid carried by the said draft current, conducting the gases withdrawn from the said fuel bed to a heating chamber, adding to the said draft current a volume of air insufficient for the complete combustion of the combustible constituents of the said draft current, withdrawing a portion of the incompletely burned gases from the said draft current, adding a second volume of air to the remainder of the said draft current in said heating chamber, the volume of the said second portion of air being that required to completely burn the residual combustible gases from the first combustion, dividing the completely burned gases from the second combustion into two streams, passing one of said streams to a recuperator to heat a fresh portion of air, withdrawing the remainder of the gases of complete combustion from the said heating chamber and introducing them together with the said portion of incompletely burned gases withdrawn from the said heating chamber into the said fuel bed to form a fresh volume of combustible gas at the expense of the heat carried by the said gases out of said heating chamber.

12. The process of heating which comprises, subjecting a body of gas containing combustible constituents to successive combustion steps by successive additions thereto of air, withdrawing hot gases comprising substantial proportions of unburned combustible gas from one of the earlier of said combustion steps, and passing the hot gases withdrawn through a bed of hot carbonaceous fuel to bring about reaction between a portion of the carbon dioxid of the gases withdrawn and said hot fuel, the said gases being withdrawn from said combustion at a temperature such that their sensible heat will maintain the temperature of said fuel during said reaction.

13. The process of heating which comprises, subjecting a body of gas containing combustible constituents to successive combustion steps by successive additions thereto of air, withdrawing hot gases comprising substantial proportions of unconsumed combustible gas from the earlier stage of said combustion steps, adding to said withdrawn gases a portion of the completely burned gases from the later stage of said combustion steps, passing the admixed unconsumed combustible gas and said completely burned gases through a bed of ignited fuel to generate fresh portions of combustible gases from a portion of said completely burned gases, the proportion of unconsumed combustible gases withdrawn being regulated to that volume required to carry sufficient heat, in addition to the heat carried by said completely burned gases to maintain the said

fuel at a reactive temperature, withdrawing the gases from said fuel bed and returning the same to said combustion steps.

14. The process of heating which comprises, introducing a draft current containing a proportion of combustible constituents into a heating chamber, adding to the said draft current a volume of preheated air sufficient to burn a portion of the combustible constituents of the said draft current, withdrawing a portion of the resulting incompletely burned gas from the said heating chamber, burning the residual combustible constituents in said gas by the addition to the said draft current of a second volume of preheated air sufficient to completely burn said combustible constituents, withdrawing from the said completely burned gases a portion of the same, combining the incompletely burned gases and the completely burned gases withdrawn from the said heating chamber, and passing the combined current through a fuel bed to burn a portion of the fuel of the same and to generate a fresh volume of combustible gas, the volume of the respective currents of incompletely burned and completely burned gases being so regulated that the sensible heat carried by the combined currents above the temperature of the fuel bed will be sufficient to support the combustion of the desired proportion of the fuel of the said bed by reaction with a portion of the carbon dioxid of the said draft current, and passing the gases withdrawn from the said fuel bed back to the said heating chamber to heat the same.

Signed at New York city, in the county of New York and State of New York, this 8th day of Jan., A. D. 1912.

HENRY L. DOHERTY.

Witnesses:
H. A. MACKENZIE,
JOHN J. MCCLURG.