Aug. 25, 1964 V. MANSFIELD 3,146,175

COAL PROCESSING OVEN AND PRODUCT RECOVERY SYSTEM

Filed June 6, 1960 4 Sheets-Sheet 1

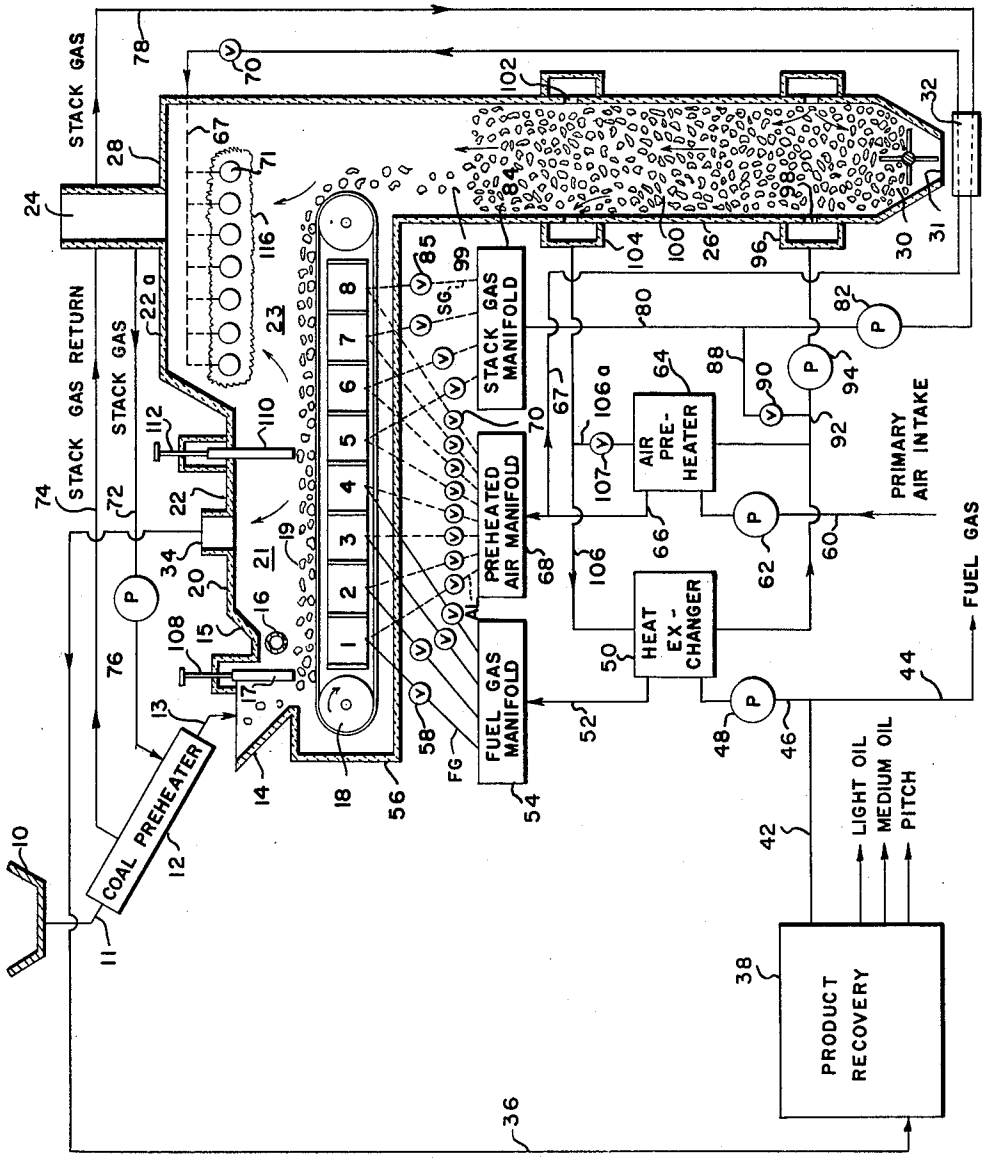


FIG. 1.

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Filed June 6, 1960 4 Sheets-Sheet 2

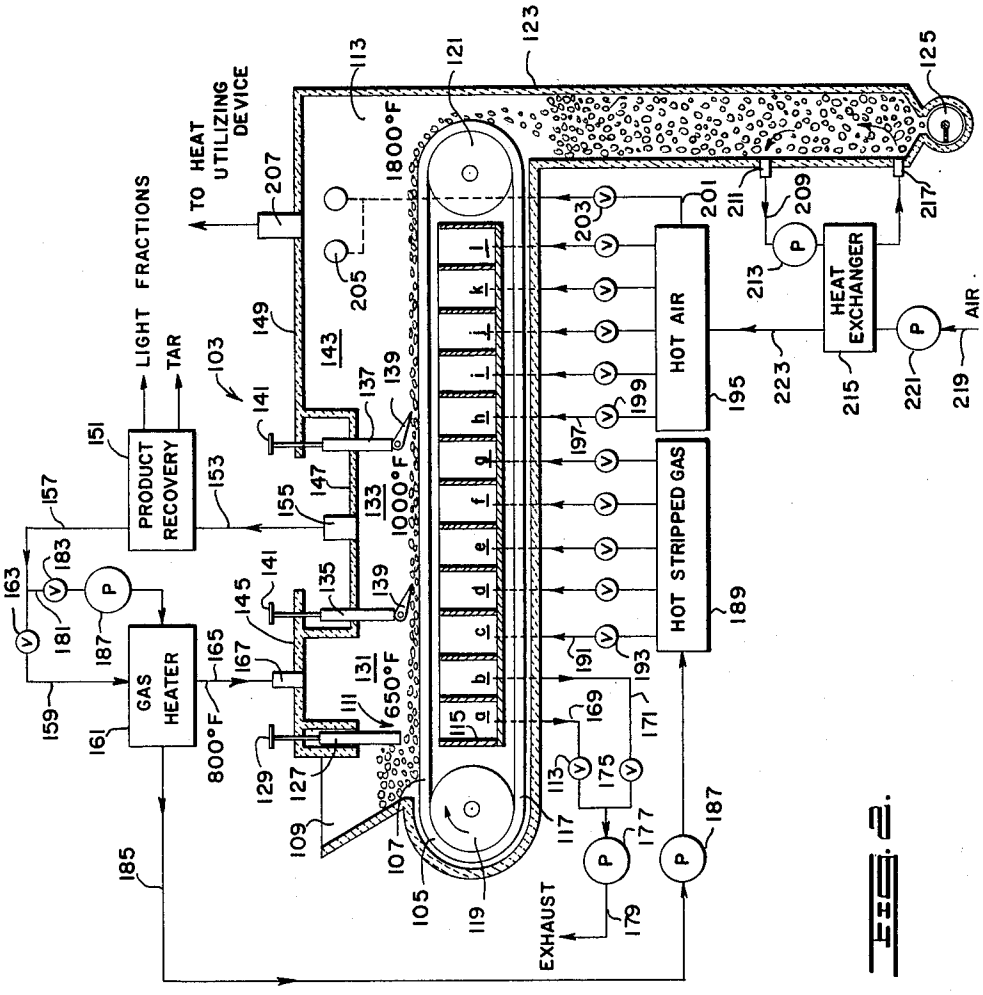


FIG. 2.

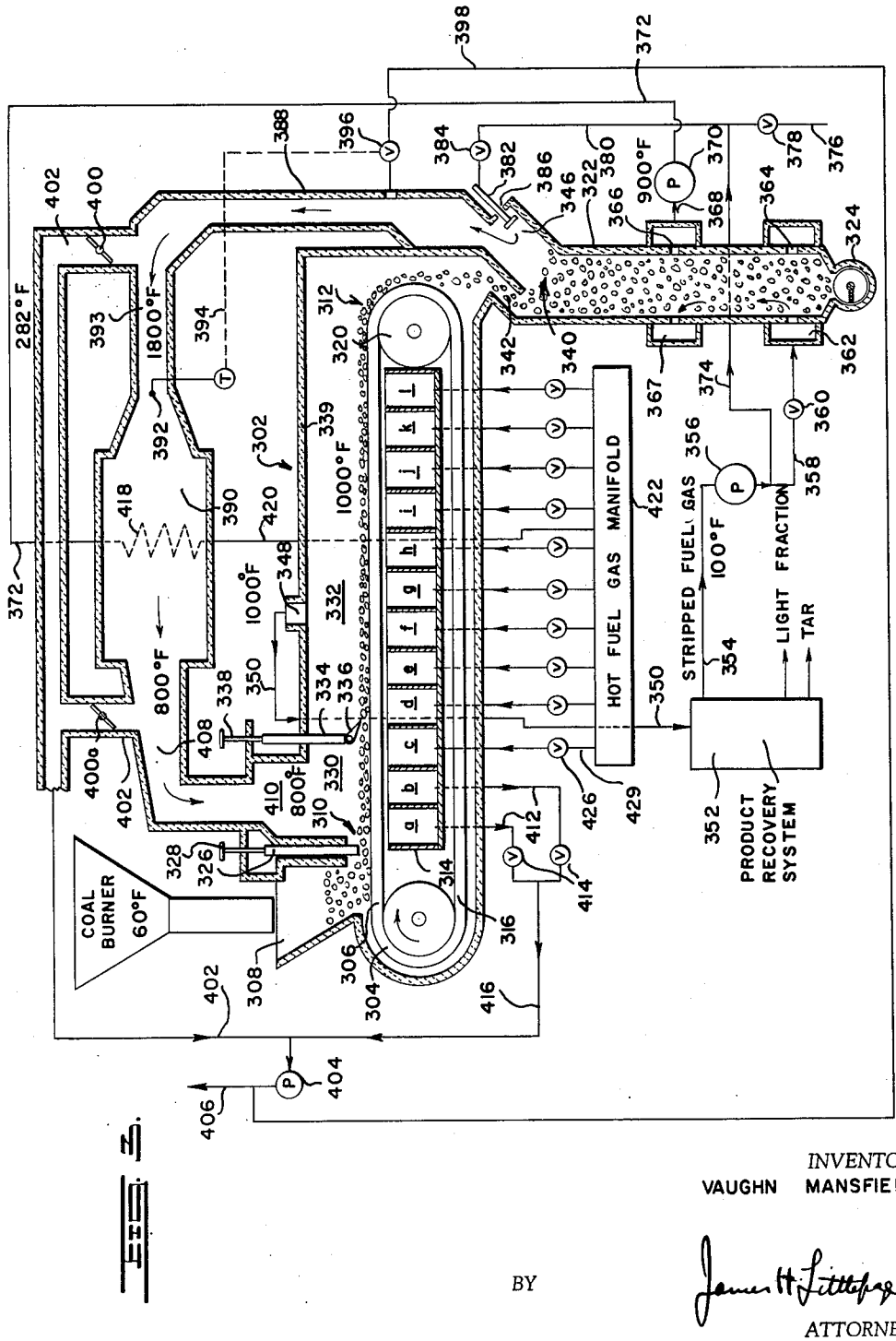
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COAL PROCESSING OVEN AND PRODUCT RECOVERY SYSTEM

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COAL PROCESSING OVEN AND PRODUCT RECOVERY SYSTEM

Filed June 6, 1960 4 Sheets-Sheet 4

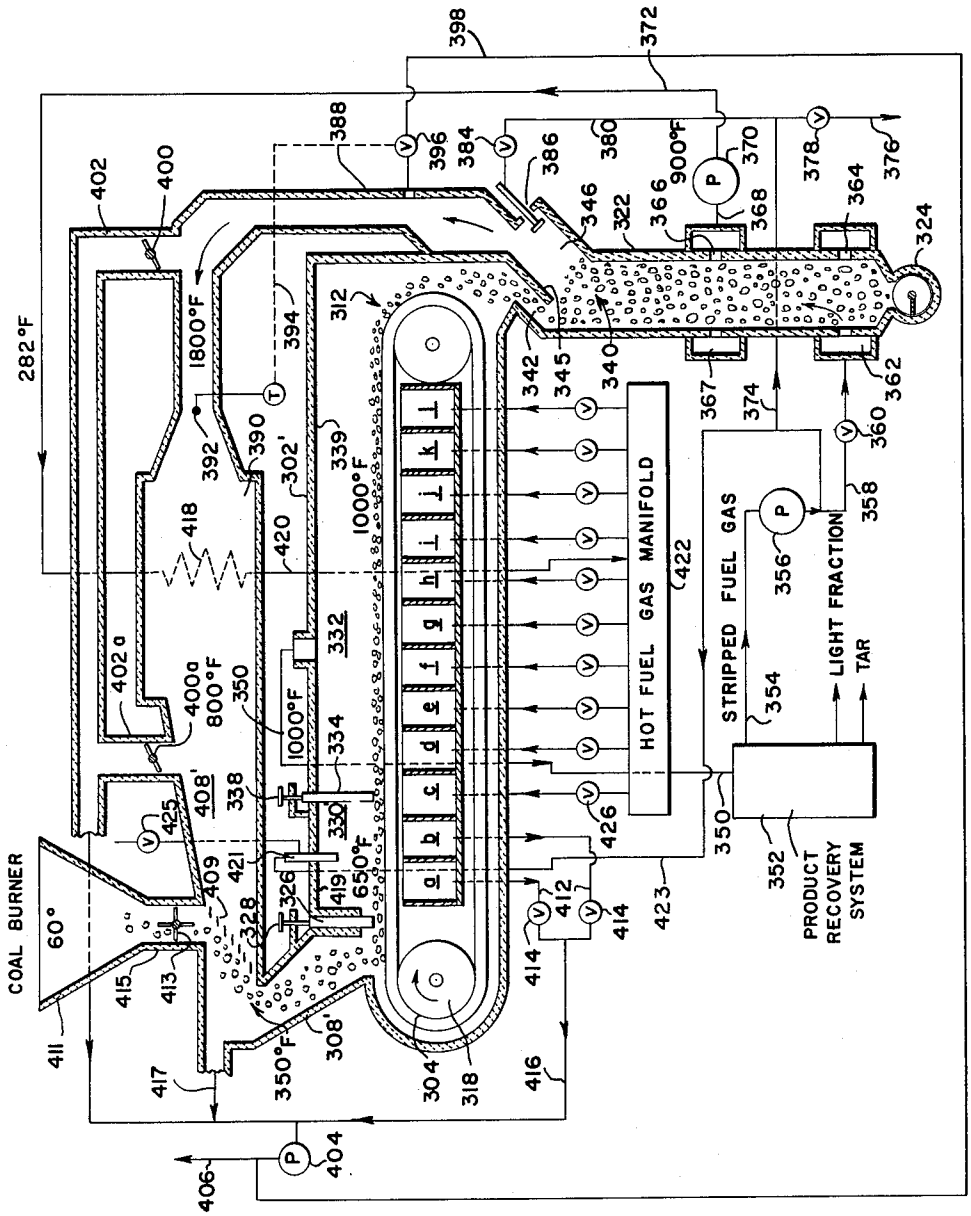


FIG. 4

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3,146,175

COAL PROCESSING OVEN AND PRODUCT RECOVERY SYSTEM

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Filed June 6, 1960, Ser. No. 34,313
1 Claim. (Cl. 202—22)

This invention relates to a method and apparatus for continuous production of coke or char from coal or the like carbonaceous material while extracting therefrom and utilizing volatile matter. This application is a continuation-in-part of my copending applications Serial No. 820,213 filed June 15, 1959, for Method and Apparatus for Continuous Coke Production While Extracting Low-Temperature Volatiles, now U.S. Patent 3,013,951, and Serial No. 850,362, filed November 2, 1959, for Char Producer and Distillate System for Non-Coking Coal, now abandoned.

The primary object of this invention is to provide for the processing of coal on a conveyer, such as a chain grate stoker, moving through an oven so as to drive off all but residual volatile matter and producing, as the end product of the fixed carbon, either coke or char, and extracting, as end products of the volatile matter, tar and the lighter fractions. Although coking ovens of this general type, as exemplified in the patent to Anderson et al., No. 2,209,255, have been operated from time to time for many years, one of the main problems has been to achieve sufficient output with equipment of reasonable size and cost, and also to produce coke of sufficient size and strength for metallurgical uses, and to meet both conditions without burning excessive amounts of the fixed carbons in the coal. In prior operations it was deemed necessary to spread the coal to form a thin bed on the travelling grate because considerable time was required in order to raise the entire cross section of coal in a thick bed to plasticizing temperatures and above. If burning sufficient to raise the bed temperature quickly was permitted, many of the volatiles whose recovery was most desired, and also some of the fixed carbons, were burned. Of perhaps more concern was the tendency of the bed to channelize, either because of uneven distribution of the coal across or along the bed, or because of the natural tendency of the air sweeping through the bed to seek out paths of lesser resistance, the net result being that hot spots of intense burning would quickly form. The volatile matter and disproportionately large amounts of the fixed carbons were consumed in the hot spots, while other portions of the coal within the bed received insufficient heat. While preheating of the coal prior to its entry into the oven decreases the time necessary to heat the coal to coking temperatures within the oven, only limited external preheating could be accomplished lest the low-temperature volatiles driven off ignite and start premature burning in the bed. In raising temperatures in a thick bed from permissible preheat to plasticizing temperatures by passing air alone through the bed in quantities sufficient to produce limited burning within the bed, there still remained the problem of hot spot burning in and adjacent the air channels formed through the coal bed.

The primary object of the invention is to provide a multi-stage coking process wherein the low-temperature volatiles are first removed from the coal with little or no burning of the volatiles, and wherein the coal throughout the entire width and thickness of the bed is first raised to plasticizing temperature, and then subsequently raised to higher temperatures in order to remove the high-temperature volatiles. In its broadest aspects, the invention contemplates the segregation of a coking oven into discrete contiguous zones wherein different functions of coking or charring procedures are sequentially performed

as a continuous bed of carbonizable material, such as coal, progresses through several discrete zones.

According to one embodiment of the invention, disclosed in Serial No. 820,213, preheated coal is passed into a low-temperature devolatilizing discrete zone and small quantities of preheated air and recycle gas are fed through the coal in order to raise the bed temperature to a degree at which the entire bed becomes plastic. As the coal approaches and reaches plasticizing temperatures, the low-temperature volatile matter is removed and fed to a product recovery system wherein the tars and lighter oils are removed, and part of the remaining fuel gas is stripped off heated and recycled through the coal in the devolatilizing zone. If coke is to be formed, the coal is next passed into a contiguous high-temperature zone, wherein the bed temperature is raised sufficiently to drive off most of the high-temperature volatile matter and to set the coke into large strong lumps. The high-temperature heating of the bed is accomplished by feeding preheated air through the bed in sufficient quantities to permit limited combustion of the high-temperature volatiles, and by feeding over-fire air over the bed to create a fireball for raising the zone temperature and for radiantly heating the coal in the bed. Also, as the coal passes through the high-temperature oven zone, hot stack gas may be fed through the bed, along with the preheated air, in order to sweep the high-temperature volatiles off from the bed and into the fireball. Subsequently, the coke is discharged into a cooker, wherein residual high-temperature volatiles are driven off, and wherein the coke is subsequently quenched.

According to other embodiments of the invention, newly disclosed herein, the coal, either preheated or raw, is first passed through a discrete oven zone wherein hot spent gases are downdrafted through the bed as it progresses therethrough so as to raise the bed temperature nearly to the degree at which the coal starts to become plastic, the coal next passing into a black furnace zone wherein the coal, without combustion, reaches plasticizing temperature and the low-temperature volatiles are removed. If coke is to be produced, the plasticized coal then passes into a combustion zone wherein the high-temperature volatiles are driven off and the coke is set; but, if char is to be produced, the black-furnace treatment is extended, the combustion zone is eliminated, and the char is subjected to final heating in a cooker associated with the output end of the oven.

These and other objects will be apparent from the following specification and drawings, in which:

FIG. 1 is a diagrammatic vertical section taken longitudinally through the center of apparatus constructed according to one form of the invention;

FIG. 2 is a view similar to FIG. 1, but illustrating a second embodiment of the invention;

FIG. 3 is a view similar to FIGS. 1 and 2, but illustrating a third embodiment of the invention; and,

FIG. 4 illustrates a modification of the FIG. 3 system.

Referring now to the drawings, in which like reference numerals denote similar elements, FIG. 1 illustrates the system disclosed and claimed in Serial No. 820,213. The flow circuits for the process and apparatus will first be described so that the inter-relationships of the components of the system may be understood and correlated in the description of the details.

Bituminous coal is fed from a supply bin **10** through a suitable chute or conveyer **11** to a preheater **12** in which the coal is brought up to a temperature of about 350° F. to 450° F. The coal should be preheated up to, but not including, the temperature at which the coal starts to give off appreciable volatile matter, this temperature depending on the particular coal being used. From preheater **12** the coal, which, after preheating, is

substantially moisture free, is introduced through the chute or other suitable conveyer 13 to an input hopper 14 having at its outlet end an igniter 16, which may be gas fired or electrically heated, the ignited coal then being evenly distributed by a spreader gate 17 on a travelling grate 18, on which the ignited bed 19 of coal travels through a coking oven 20. In passing beneath the front zone 21 of the oven, wherein the oven roof 22 is low, the low-temperature volatiles (those which are driven off in the temperature range between 848° F. to 1060° F.) are removed from the coal and, as the bed passes through the rear portion 23 of the oven having a raised roof 22*a*, most of the high-temperature volatiles (those which are driven off at bed temperatures between 1060° F. and 1800° F., or 1900° F.) are removed. As the bed reaches the rear end of travelling grate 18, it passes beneath a hot gas outlet 24 which supplies heat to a boiler or the like heat utilizing device (not shown) and is then discharged into a quenching retort 26 which lies beneath the rear end 28 of coking oven 20. The residual volatiles, in the range of 4% to 8% of those originally in the coal, which remain in the then nearly completely carbonized product are driven off, in retort 26, by the latent heat in the coke as the coke stack moves through the upper portion 99 of retort 26, and the coke is quenched in the lower portion 100 of the retort and then discharged by a feeder 30 onto a conveyer 32, the coke then having been quenched to below its ignition temperature.

The low-temperature volatiles removed from the coal as it passes through zone 21 are extracted through an outlet 34 and fed through a suitable conduit 36 to a product recovery unit 38, wherein the low-temperature volatiles are distilled and scrubbed, and taken off as light oil, medium oil and pitch through conventional outlets indicated, as a group, at 40. The fuel gas output of product recovery system 38 is discharged through line 42, a portion of the fuel gas output being fed by a line 44 to a suitable utilization device, which may include igniter 16. The remainder of the fuel gas output of product recovery system 38 is fed through a branch 46 and pump 48 to a heat exchanger 50, wherein it is heated and thence passed through a supply line 52 to a fuel gas manifold 54, from which it is recycled by fuel gas lines, one of which is designated FG to the first four zones of an air box 56 which extends beneath the length of travelling grate 18. The feed of fuel gas from manifold 54 to each of zones 1 to 4, inclusive, is individually controlled by valves, one of which is indicated at 58. Part of the fuel gas output of product recovery system 38 is thus used to sweep off the low-temperature volatiles, and to maintain carbonizing temperature in the coal bed as the latter passes over the first four zones of air box 56, these first four zones lying beneath zone 21 previously designated.

Primary air is supplied through an intake line 60 and thence forced by pump 62 through an air preheater 64. Part of the preheated air is supplied by a line 66 to a preheated air manifold 68, from which the primary air is distributed by individual air lines, one of which is designated AL to all eight zones of the air box 56, the air feed to the separate zones being individually controlled by valves, one being designated 70. The remainder of the preheated primary air is taken off line 66 through a branch line 67 and thence fed through control valves 70 to over-fire air ports 71 which enter the oven in zone 23 beneath the roof 23*a* of the high-temperature section of the coking oven.

Part of the stack gas from furnace 24 is taken off and circulated through coal preheater 12 via supply and return lines 72 and 74, respectively, a pump 76 being provided to force the circulation. Some of the other stack gas is taken off via supply line 78 and forced by pump 82 to stack gas manifold 84, and thence distributed by individual supply lines, one of which is designated SG to the last four zones of air box 56, the supply of stack gas to the separate zones being individually controlled by valves, one being designated 85. A portion of the stack gas is taken off line 80 via branch 88 and thence, through valve 90, into a line 92, in which it is forced by pump 94 to a manifold 96 surrounding the lower part of a quenching retort 26. From manifold 96, cool stack gas, which is substantially inert, passes through ports 98 into the lower portion of the coke stacked in the retort. The stack gas entering ports 98 creates a pressure, sufficiently above atmospheric pressure, to prevent air from entering upwardly through discharge opening 31 at the bottom of retort 26, a small portion of the stack gas leaking outwardly past feeder 30. Most of the stack gases entering ports 98 pass upwardly through the stack of coke in the lower portion 100 of retort 26, and most of the upwardly flowing stack gases then flow outwardly through ports 102, manifold 104 and through return lines 106 and 106*a* and valve 107 to heat exchanger 50 and air preheater 64, which is also a heat exchanger. Heat in the lower portion of the coke stack in retort 26 transfers to the stack gas and is transmitted thereby to heat exchanger 50 and air preheater 64, wherein a large part of the heat is given up to the fuel gas and primary air which flow through heat exchanger 50 and air preheater 64.

A small portion of the stack gas flowing upwardly through the lower portion of the coke stack in retort 26 does not emit via ports 102 but, rather, passes on upwardly through the hot unquenched coke in the upper portion 99 of the coke stack in retort 26 so as to sweep off the residual volatiles which are driven off by the latent heat in the coke in the upper portion 99 of the stack, these volatiles then being consumed in the fire ball 116 described hereinbelow.

Returning now to the entry of the ignited preheated coal into coking oven 20, spreader gate 17 is adjusted to provide a relatively thick but uniformly distributed bed 19 of coal on travelling grate 18. One feature of the invention is that relatively small coal, even ¼" by 0, may be used to form coke agglomerate. The travelling grate is driven by a suitable source of power, not shown, it being understood that the grate, which may be of chain or perforate sections, moves the bed slowly from left to right, as seen in the drawing. In a typical embodiment, the upper run of the grate is from twenty to thirty feet long and from twenty to thirty feet wide. Spreader gate 17 is adjusted, by control mechanism 108, to provide a comparatively thick bed, in the range of four to twenty inches in depth. The maximum height of roof 22 should be about thirty-six inches above the grate. Preheating of the coal has been found desirable so as to avoid the necessity of extensive ignition, to provide for ready ignition of the entire bed from top to bottom, to eliminate moisture and so that only a small amount of primary air need be fed upwardly from zone 1 of air box 56 to firmly start and maintain carbonization through the bed. Without preheating of the coal, so much primary air must be fed up from zone 1 to ignite the bed that excessive combustion of the low-temperature volatiles takes place. This results in dilution of the low-temperature volatiles by the CO_2 combustion product and nitrogen.

In starting the process, enough primary air is fed upwardly from air box zones 1 to 8 to bring the oven up to its operating temperatures. Thereafter, the air valves 70 for air box zones 2 to 4, inclusive, are closed, or barely cracked, while the air valve 70 for zone 1 is opened so as to supply enough primary air to completely ignite bed 19 from top to bottom. However, the primary air supply is limited so that the bed temperature does not exceed 1060° F. as it passes above air box zones 1 to 4.

Fuel gas valves 58 are adjusted so as to feed fuel gas to zones 2, 3 and 4 of air box 56 so as to sweep off the low-temperature volatiles. It will be understood that bed 19 is initially partly ignited as it enters oven 20 and ignition is completed by forcing air upwardly through it as the bed passes over the first zone, and it remains ignited

as it passes over zones 2, 3 and 4. Assuming that the coal input to the oven had about 40% volatile content, approximately 58% of the original volatiles will have been driven off by the time the bed progresses beyond partition 110. Partition 110, is of course, adjusted by mechanism 112 so that the top of the bed scrapes along its lower edge. The low-temperature volatiles, including the tars, which are driven off the coal as the bed 19 passes over air box zones 1 to 4, inclusive, are exhausted through outlet 34 as previously outlined.

Air valve 70 leading to air box zone 5 is adjusted so that substantially more air is fed upwardly through bed 19 over zone 5 than was fed up from zone 1, and the air valves for zones 6, 7 and 8 are closed, or barely cracked. The rate of carbonization, when bed 19 passes above zone 5, is sharply increased so that the bed reaches temperatures in the range of 1800° F. to 1900° F. The stack gas feed to zones 6, 7 and 8 is adjusted so as to sweep off the high-temperature volatiles. However, over zones 5, 6, 7 and 8, the bed temperatures are not created solely by combustion within the bed. The unburned high-temperature volatiles, after being swept upwardly through the bed, combine with over-fire air fed in through ports 71 and ignite, thereby creating a fire ball in the region indicated generally at 116. The radiant heat from fire ball 116 progressively raises the temperature of the bed, from the top downwardly, as the bed progresses over air box zones 5, 6, 7 and 8.

The speed of movement of bed 19 from left to right, as seen in the drawing, is maintained so that by the time the bed passes beyond air box zone 8 and thence off the end of the travelling grate, most of the high-temperature volatiles will have been driven off. However, the bed is moved sufficiently fast so that the high temperatures developed by the radiant heat in passing over the last four air box zones will not have completely worked down to the surface of the grate. By leaving residual volatiles in the nearly completely carbonized bed, excessively high temperatures on the grate surface are avoided and thus longer grate life is achieved. In addition, considerably more tonnage can be handled on the grate by moving a thick bed through the coking oven at a rate faster than that which would achieve more complete carbonization, wherein the bed would be retained on the grate for a longer time, and higher temperatures would be developed on the grate surface. However, the bulk of the bed will, at the time it passes over the end of the travelling grate, have developed sufficiently high temperatures so that by co-mingling the nearly completely carbonized coke in the upper portion of retort 26, the residual volatiles will be driven off by the latent heat within the bed.

After preheating the oven, sufficient coke is run through to fill retort 26 nearly to its top, and thereafter feeder 30 is operated to discharge coke on the conveyor 32 at the same rate that the nearly completely carbonized coke is dumped off travelling grate 18 into the top of retort 26. For purposes of demonstrating the operation of the system, the stack gas has been considered as virtually inert. Actually, a small amount of oxygen remains in the gas as it is derived from the stack. If desired, the oxygen content may be removed by conventional apparatus. Sufficient stack gas is fed through line 78, valve 90 and line 92 so that, upon operation of pump 94, stack gas is circulated into retort 26 through manifold 96, ports 98 and thence upwardly through the lower portion 100 of the coke in retort 26, and thence out ports 102, manifold 104 and lines 106 and 106*a* through heat exchanger 50 and preheater 64. When the circuit through heat exchanger 50, air preheater 64 and the lower portion 100 of retort 26 is charged with stack gas, only enough additional stack gas need be introduced through valve 90 to make up the losses resulting from downwardly escaping gas through feeder 30, and the upward flow of stack gas through the upper portion 99 of retort 26, the last mentioned flow being sufficient only to sweep off the residual volatiles which are driven from the coke as a result of the latent heat remaining as the coke is dumped off the end of the travelling grate. The high-temperature volatiles swept off the coke in the upper portion 99 co-mingle with those swept upwardly from the portion of the bed travelling over air box zones 5, 6, 7 and 8 and are consumed in fire ball 116.

The heat extracted from the coke in the lower portion 100 of retort 26 by the up-flowing stack gases is transferred in heat exchanger 50 and air preheater 64 to the fuel gas flowing into manifold 52 and the primary air for manifold 68 and, in turn, the heat is fed back to bed 19. It is contemplated that the coke at the top of the upper portion 99 of retort 26 will be at approximately 1700° F.; the stack gases leaving retort 26 through ports 102 will be at approximately 1500° F.; and the stack gases entering the retort through ports 98 will be at approximately 200° F.

The relatively high coking temperatures achieved in the bed at the end of travelling grate 18 and at the top of retort 26 results in an extremely strong coke agglomerate, particularly adapted for metallurgical sintering and as a chemical agent in chemical processes, such as in the production of carbide and elemental phosphorus. The products derived from recovery system 38 have widespread use; and the heat output through outlet 24 is usable in an adjacent boiler or the like heat utilizing device.

Reference is now made to FIG. 2 of the drawings, wherein a second embodiment of the invention is diagrammatically illustrated. A horizontally elongate coke oven 103 is formed of ceramic or heat resistant material, and chain grate stoker 105 is conventionally mounted in the oven, with its upper or load-carrying run 107 moving horizontally through the oven from a hopper 109 adjacent the oven input end 111 to the oven output end denoted generally at 113. A zoned airbox 115 is disposed between the upper run 107 and the lower run 117 of the stoker, and between the sprockets 119 and 121 over which the runs turn at the end, the sprockets being conventionally driven by a suitable torque source. Airbox 115 is divided into separate zones, twelve being shown for the present examples, lettered *a* to *l*. The mechanical details of a zoned airbox operating in conjunction with a chain grate stoker are well known in the art, it being sufficient to note that the air or gas flowing to or from the material carried on any given part of the upper run of the grate is controlled primarily by the airbox zone disposed immediately below. Disposed below the output end 113 of oven 103 is a coker-quencher retort or cooker 123, into which the coke drops from the end of the upper grate run. After seasoning and cooling in cooker 123, the coke is removed from the lower end through a substantially airtight discharge mechanism, one of several types being illustrated at 125.

Returning to the input end of oven 103, coal is supplied through hopper 109 and spread to form a thick bed, in the range of 6" to 12" in depth, over grate run 107 by a spreader gate 127 whose height may be varied by conventional adjusting mechanism 129.

As it enters the input end of the oven, the coal passes through a preheating zone 131, overlying the first two zones *a* and *b* of airbox 115, wherein hot spent gases are downdrafted through the bed, as later detailed. Next to preheating zone 131 is a black furnace zone 133, so called because no appreciable combustion occurs therein, even though the temperature would be sufficiently high to ignite the coal if sufficient air were present. Black furnace zone 133 is discrete, i.e., is separated from the adjacent zones by a spaced pair of curtain walls 135 and 137, respectively, each having a sealing shoe 139 along its lower edge for riding on and sealing against

the top of the coal layer carried on the grate. The curtain walls are preferably vertically movable by adjusting mechanism diagrammatically shown at **141**. From black furnace zone **133**, the coal, having been stripped of its low-temperature volatile matter, passes into a carbonization zone **143**, wherein sufficient air is supplied to permit limited burning, and to raise the bed temperature from approximately 1000° F., which it attained in black furnace zone **133**, to 1800° F., thereby driving off and burning practically all of the high-temperature volatile matter remaining. It will be observed from the FIG. 2 diagram that the portion **145** of top of the oven over the preheating zone **131** is raised so as to provide ample volume for complete distribution of the incoming preheating gases; the oven top **147** over the black furnace zone **133** may be relatively low; and the oven to portion **149** over the carbonization zone **143** wherein burning occurs is relatively high so as to provide increased volume in the zone of extensive heat release.

The heat, gas and air systems for the FIG. 2 embodiment are as follows: associated with oven **103** is a product recovery system **151**, in which tar, the lighter fractions, and stripped gas are separated and recovered from the make gas fed to system **151** by conduit **153** leading from an outlet **155** from black furnace zone **133**. Part of the stripped gas derived from system **151** by a gas line **157** is fed through a branch line **159** for burning, as fuel, in a gas heater **161**, a valve **163** controlling the fuel gas input to the heater. The spent gas, virtually oxygen-free and at approximately 800° F., are exhausted from gas heater **161** through a line **165** and inlet **167** into the top of preheating zone, those hot spent gases then being drawn downwardly into airbox zones *a* and *b*, and thence through pipes **169** and **171**, control valves **173** and **175** and pump **177** to an exhaust line **179**. As the temperature of the coal passing through preheating zone **131** rises from room temperature (assuming no external preheating has occurred) to approximately 650° F., some of the low-temperature volatiles will be driven off and swept away, along with the original moisture, by the hot spent gases. However, the transit time of the coal bed through the preheating zone is sufficiently short so that the coal does not attain temperature sufficient to drive off any but a small portion of the low-temperature volatiles until about the time it passes beyond the preheating zone, and thus only a comparative few volatiles are sacrificed.

Part of the stripped gas at 100° F. output of recovery system **151** is fed via line **181**, controlled by valve **183**, through gas heater **161** wherein its temperature is raised to approximately 1200° F., the gas being forced through a supply line **185** by a pump **187** into stripped gas manifold **189**. Pipes **171**, controlled by valves **193** feed the hot stripped gas to airbox zones *c* and *f*, inclusive, beneath black furnace zone **133**. In passing upwardly through the coal bed on the grate, the hot gases maintain the coal at approximately 1000° F. and, during the transit time of the coal through zone **133**, most of the low-temperature volatiles are driven off by the heat and swept off by the flowing gases, and fed to recovery system **64** as previously detailed. By utilizing hot stripped gas devoid of oxygen, combustion within or above the bed is avoided as the coal passes through zone **133**, and the preheating zone **131**, being at below atmospheric pressure, serves as a sealing chamber to prevent escape of the hot stripped gas to the atmosphere.

For feeding hot air upwardly through the coal as it passes through carbonization zone **143**, there is a manifold **195** connected by pipes **197** to airbox zones *g* to *l*, inclusive. Control valves **199** in the pipes provide selective feed to the airbox zones, and a pipe **201** having a control valve **203** leads to ports **205** adjacent the lower end of a stack **207** for supplying over-fire air so that a fireball may be created over the bed in combustion zone **143** if desired. Heat for the air fed to manifold **195** is extracted from the hot coke as it passes downwardly through the lower end of cooker **123**, there being a circuit **209** for inert gas extracted by the ports, one of which is shown at **211**, intermediate the upper and lower ends of the cooker. The hot gas in circuit **209** is withdrawn from ports **211** by a pump **213**, forced through a heat exchanger **215** wherein it gives up heat, and back through ports **217** into the coke in the lower end of the cooker. Inert gas, such as spent flue gas issuing from a heat utilizing device (not shown) supplied by stack **207** may be used for supplying and making up the gas for circuit **209**. Air drawn from supply line **219** is forced by a pump **221** through the heat exchanger and fed, at approximately 900° F. through line **223** to manifold **195**. In a typical operation, Belleville coal, size ¼" x 0 is utilized as the starting material, the original constituents being approximately as follows:

Moisture	10.94%.	
Ash	9.71% . . .	10.90% dry basis.
Volatiles	35.79% . . .	40.19% dry basis.
Fixed carbon	43.56% . . .	48.91% dry basis.

After traversing preheating zone **131**, the moisture content is approximately zero, and it is estimated that the volatile content is between 39% and 40.19% of the dry coal, the temperature of all the coal in the bed, as it passes beneath shoe **139** on curtain wall **135** is approximately 650° F. The fixed carbon content is then the same quantity as at starting, but is now 48.91% of the dry coal, and the ash being 10.90%.

After traversing black furnace zone **133**, the volatile content of the char or coke in the bed is estimated at 12.05%, the fixed carbons remaining in the same quantity, but now comprising 71.92% of the char or coke, and the ash being 16.03%. The temperature of the bed, as it passes beneath curtain **50** is approximately 1000° F., the char or coke being ready as air is fed through it, to become more completely devolatilized as soon as the bed temperature reaches approximately 1800° F.

As the coal passes into carbonization zone **143**, the hot air fed through the bed from airbox zones *g* and *h* ignites the coke sufficiently to raise the bed temperature to approximately 1800° F., thereby driving off and partly burning some of the high-temperature volatiles, and firmly coking from bottom to top. By thus eliminating the low-temperature volatile matter, and by raising the entire width and thickness of the bed up to plasticizing temperature, hot spots of localized burning are avoided. Furthermore, by avoiding conditions under which a zone of plasticity extends diagonally downward through the bed, from the input end of the furnace nearly to the output end of the grate run, as prevailed in prior practices, piecemeal setting of the coke is avoided, and the entire vertical cross-section of the coke being formed in the bed sets almost simultaneously. The high-temperature volatiles which are driven off, but which do not burn in the bed, because of insufficient air fed through airbox zones *g* and *h*, pass upwardly towards stack **207**, and burn with the overfire air fed in through ports **205**, thereby creating a fireball. Air in decreasing amounts is fed upwardly through airbox zones *i*, *j*, *k* and *l*, sufficient only to permit burning of all but residual amounts estimated at 2% to 3%, of the remaining high-temperature volatiles and a small portion of the fixed carbon, the setting of the coke being further enhanced. By the time the coke drops off the end of the upper grate run, its temperature should then be approximately 1800° F., the fixed carbon content about 78.58%, ash about 19.42%, and residual volatiles about 2.0% to 3%.

In the upper portion of cooker **123**, the heat drives off virtually all of the residual volatiles, these passing upwardly and being consumed in the fireball. After quenching in the lower part of cooker **123**, the coke, then being in large strong lumps, consisting of approxi-

mately 78.58% fixed carbon, 19.42% ash and 2.0% residual volatiles, is discharged at approximately 200° F.

Referring now to FIGS. 3 and 4 of the drawings, the basic principle of the FIG. 1 embodiment is utilized in that the coal is treated in discrete low and high temperature zones of a coking oven as it passes horizontally through on a conveyer, and the improvement of the FIG. 2 embodiment is utilized in that the coal is first heated nearly to plasticizing temperature by downdrafting hot spent gases through it in one discrete oven zone and then raised to plasticizing temperature in an adjacent discrete oven zone. However, in the FIG. 3 and FIG. 4 embodiments, char is produced in the oven and the coal is finally devolatilized in the cooker by subjecting it to increased temperature and time.

In FIG. 3, the char producing oven **302** has a chain grate stoker **304** whose upper load carrying run carries coal from a hopper **308** adjacent the input end of the oven **310** to the output end **312**. An airbox **314** having zones *a* to *l*, inclusive, as disposed between the upper and lower grate runs **306**, **316**, and between the sprockets **318** and **320** over which the ends of the runs are driven by a suitable torque source. The treated coal, then charred, drops off the output end of the upper grate run into a cooker **322** through which it progresses downwardly to a suitable air-sealed discharge, such as screw conveyer **324**. As the char passes downwardly through the upper portions of cooker **322**, residual volatile matter is driven off and, as it passes through the lower part of the cooker, it is quenched sufficiently so that it may be handled in the open without catching fire.

Bunker coal at about 60° F. fed into hopper **308** is first spread evenly across upper grate run **306** by a spreader gate **326** whose height may be adjusted by conventional mechanism diagrammatically indicated at **328** to form a bed of uniform depth from 6″ to 12″. Next beyond spreader gate **326**, the coal passes through a preheating zone **330**, wherein hot spent gases are downdrafted through the bed. Next adjacent preheating zone **330** is a black furnace zone **332** separated from the preheating zone by a curtain wall **334** having a sealing shoe **336** along its lower edge which rides on the top of the bed so as to prevent significant gaseous intercourse between the adjacent zones, the height of curtain wall **334** being variable so as to accommodate it to the selected bed thickness by conventional adjusting mechanism **338**. As contrasted with the corresponding zone of the FIG. 2 embodiment, black furnace zone **332** is much longer, occupying the entire rear end of the oven, and the oven roof **339** may be relatively low, since no significant heat release occurs therein.

As the char drops off the end of the grate run into a final devolatilizing zone **340** in the upper portion of cooker **322**, it first passes through a throat **342** connecting the output end of oven **302** with the upper end of cooker **322**, the char stacked in the throat providing a choke which limits gaseous flow between the cooker and the oven. Laterally of throat **342**, and separated therefrom by a partition **345** is a combustion zone **346** in which burns the flame from a gas burner **382**, the heat from which drives off and burns with the high-temperature volatiles then remaining in the char.

The gas system for the FIG. 3 embodiment is as follows: leading from an outlet **348** is a gas line **350** through which the volatile matter driven and swept from the coal as it passes through black furnace zone **332** passes at about 1000° F. to a product recovery system **352**. The details of system **352** are not relevant here, it being sufficient to note that tar and lighter fractions are recovered from the volatile matter, and also fuel gas is stripped out and passed through a line **354** and propelled by a fan **356** through a line **358**, controlled by valve **360** to a manifold **362** which connects via ports **364** to the lower end of cooker **322**. The fuel gas entering ports **364** at about 100° F. passes upwardly through the lower end of cooker and exhausts through ports **366** and manifold **367** to an outlet line **368**. In transit through the lower end of the cooker, the fuel gas absorbs heat from the char, thereby cooling the latter down from about 1650° F. to 200° F., and thereby also raising the temperature of the gas to about 900° F. A fan **370** propels the heated fuel gas to a supply line **372**. Also leading to supply line **372** is a fuel gas bypass line **374** leading from the high-pressure side of fan **356**. A fuel gas take-off branch **376** controlled by valve **378** leads from a supply line **372** to a gas utilizing device, such as a gas fired rotary kiln.

Leading from fuel gas bypass line **374** is a burner supply line **380** which feeds cool fuel gas to burner **382**, a valve **384** controlling the burner gas supply, and air ports **386** provide the combustion air for the gas burner.

The hot spent gases, starting at about 2000° F. pass upwardly from combustion zone **346** through a stack **388** to a heat exchanger **390**. A heat-sensing device **392** in the throat **393** leading into heat exchanger **390** has a control **394** for a valve **396** in a branch line **398** leading from exhaust fan **404** into stack **388** for tempering the gas supplied to the heat exchanger. Gas at about 100° F. from bypass line **374** is blended in supply line **372** with the gas at about 900° F. from outlet line **368** so that the resultant mixture in supply line **372** is at about 282° F. The quantity of the spent gas entering heat exchanger is controlled by a damper **400** in a bleeder duct **402** which leads to an exhaust fan **404** and thence to an exhaust outlet **406**.

The somewhat cooled, spent, and substantially inert gas from heat exchanger **390** at about 800° F. passes through a heat exchanger outlet **408** and through an inlet **410** into pre-heating zone **330**, wherein they are downdrafted through the coal on grate run **306** and into airbox zones *a* and *b*, and thence through outlet pipes **412** controlled by valves **414** to an exhaust line **416** which leads to exhaust fan **404**. The amount of gas fed to preheating zone **330** may also be controlled by a damper **400***a* in bleeder branch **402***a* leading to bleeder duct **402**.

Airbox zones *c* through *l* are supplied with fuel gas as follows: connected to fuel gas supply line are heat exchanger coils **418**, in passing through which the fuel gas extracts sufficient heat from the 1800° F. spent gas to raise the fuel gas temperature to about 1200° F., the latter then flowing through line **420** into a manifold **422** and thence through pipes **424**, controlled by valves **426**, into airbox zones *c* through *l*.

The effect of the above treatments on the coal is as follows: in describing a typical operation of the FIG. 3 embodiment, it will be assumed that the starting material is Western Kentucky #11 Seam coal, ¼″ by 0 size approximately the following constituents:

	Percent
Moisture	8.73
Ash	5.47
Volatiles	39.12
Fixed carbon	46.68

The coal fed in through hopper **308** is spread evenly across upper grate run **306** to form a bed approximately 6″ to 12″ thick, and preheated while passing through zone **330** by downdrafting through it spent gas at approximately 800° F. By the time the coal passes beneath shoe **336** on curtain **334**, it should have attained a uniform temperature of approximately 650° F. At this point the estimated constituents are:

Ash	5.47% dry basis.
Volatiles	39.12% dry basis.
Fixed carbon	46.68% dry basis.

As the preheated coal passes through black furnace zone **332**, the hot fuel gas at approximately 1200° F. fed upwardly through the bed drives off most of the volatile matter which can be liberated at temperatures up to about 1000° F., and sweeps the liberated volatiles to and through outlet **348**. As the nearly carbonized coal reaches the

output end of the grate run at a temperature of about 1000° F., its constituents are estimated as follows:

	Percent
Ash	10.94
Volatiles	2.0
Fixed carbon	87.06

In devolatilizing zone **340** of cooker **322**, the heat from gas burner **382** raises the temperature of the exposed char to about 1650° F. thereby liberating and burning off virtually all of the residual volatiles so that the constituents of the resultant char quenched in the lower end of cooker **322** are primarily fixed carbons and ash.

The embodiment illustrated in FIG. 4 is similar in most major respects to that disclosed in FIG. 3, the elements corresponding directly to those previously detailed being designated with similar ordinary numerals, and those corresponding functionally being designated with prime numerals.

The main differences in the FIG. 4 embodiment relate to the preheating and drying of the coal. Across the outlet conduit **408'** of heat exchanger **390** is disposed a step louver **409**. Coal from a bunker **411**, controlled by a turnstile **413** in coal input throat **415** slides along louver **409** and in so doing is wiped by the hot gases issuing at about 800° F. from heat exchanger **390**. The hot gases, carrying off all moisture from the coal, are discharged via line **417** leading to exhaust fan **404** and the temperature of the coal is raised from an initial 60° F. to about 350° F. The dry and partly preheated coal then feeds to a closed hopper **308'** and thence on conveyor run **306** into preheating zone **330'**.

In passing through preheating zone **330'**, the temperature of the coal is raised to about 650° F. by heat supplied by an igniting hood **419** in which burns a gas burner **421** supplied with fuel gas from outlet **354** via line **423**. Only sufficient air is supplied to burner **421** through a valve controlled air line **425** to burn with the gas, and thus there is no appreciable oxidation of the coal as it passes through preheating zone **330'**.

The basic principle underlying all embodiments of the invention are: the stepwise temperature treatment of the coal as it passes through the ovens; the segregation of the ovens into discrete zones wherein the treatments of the coal under relatively low and high temperature conditions in the adjacent discrete zones do not interfere with one another; the elimination of the comparatively low-temperature volatiles before the coal is subjected to higher temperature treatment; the preheating of the coal to temperatures approaching those at which the bed starts to plasticize; and the subsequent quick raising of the coal temperature throughout the entire depth of the bed, either to coking or charring temperatures.

The invention is not limited to the details shown and described herein, but is intended to cover all substitutions, modifications and equivalents within the scope of the following claim.

I claim:

The method of producing coke and gas from carbonizable coal which contains low temperature volatiles capable of being driven off at temperatures of a certain degree and below and high temperature volatiles capable of being driven off at carbonizing temperatures above said certain degree, comprising: transporting a substantially uniformly thick horizontal bed progressively through a series of discrete contiguous regions of a confined horizontally elongate space, partly devolatilizing the coal by progressively raising the temperature of the coal to said certain degree as the coal progresses from region to region, extracting from at least one of said regions the low temperature volatiles driven from the coal as the latter progresses therethrough, stripping fuel gas from the extracted low temperature volaties, forming a stack of the partly devolatilized coal by dropping the latter off the end of the bed into a vertically elongate confined space contiguous at its top with the horizontally elongate confined space, burning part of the stripped fuel gas over the top of the stack and radiantly heating the coal to carbonizing temperature as the latter falls onto the top of the stack, and maintaining the coal in the stack until most of the high temperature volatiles are liberated therefrom while removing the carbonized coal from the bottom of the stack.

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