

Feb. 3, 1953

C. H. O. BERG

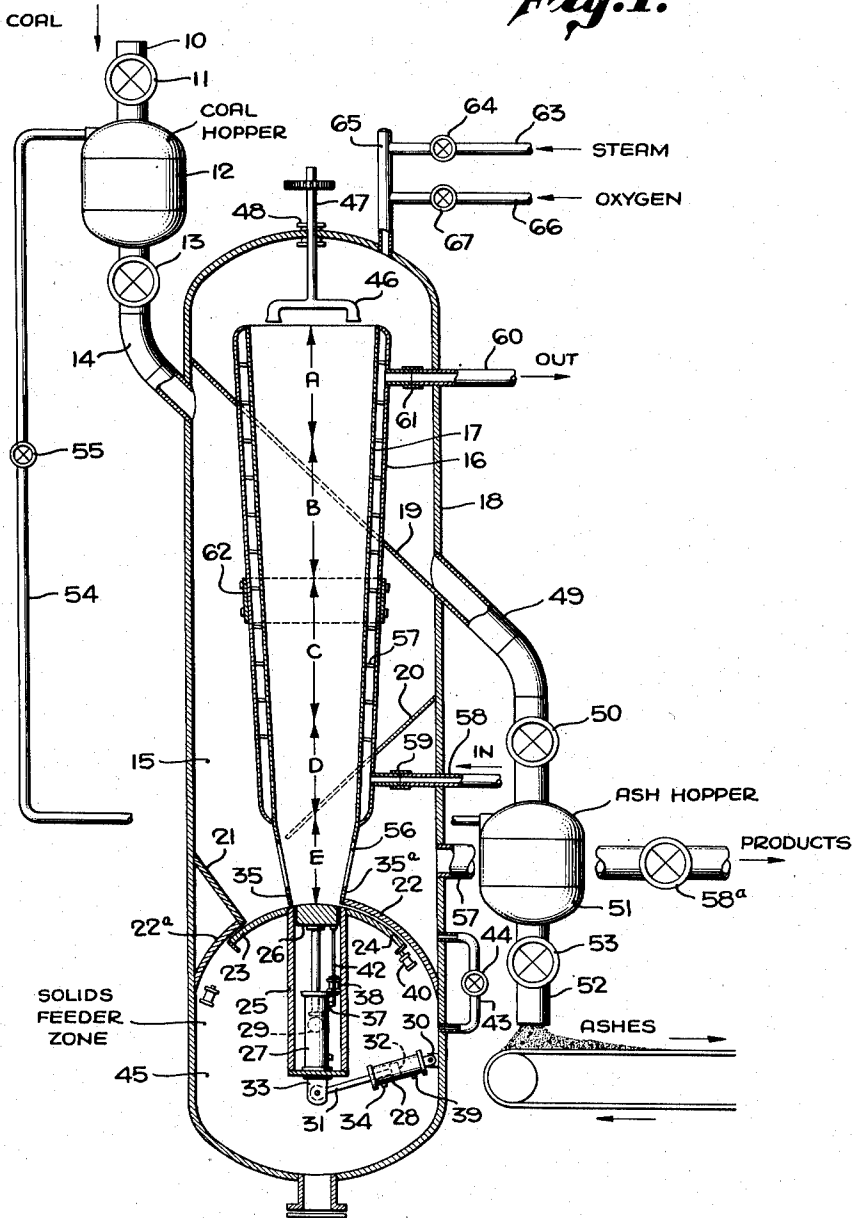
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GASIFICATION PROCESS AND APPARATUS

Filed June 5, 1947

2 SHEETS—SHEET 1

Fig. 1.



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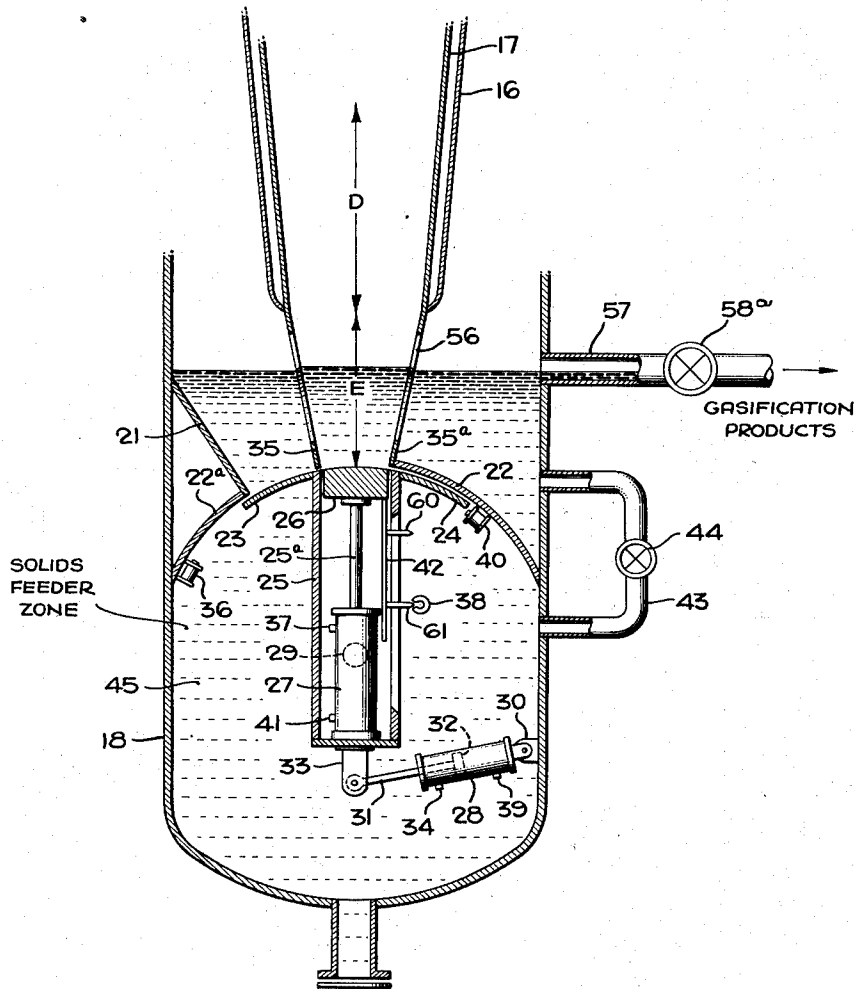
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GASIFICATION PROCESS AND APPARATUS

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2 SHEETS—SHEET 2

Fig. 2.



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GASIFICATION PROCESS AND APPARATUS

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Application June 5, 1947, Serial No. 752,757

11 Claims. (Cl. 48—86)

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This invention relates to a process and apparatus for the production of gases and is particularly directed to a process and apparatus for the gasification of solid carbonaceous materials and materials which are generally used as solid fuels so as to produce combustible gases suitable for use either as fuels or in the synthesis of liquid fuels or organic chemicals. My copending application Serial No. 723,311 is drawn to somewhat similar subject matter.

The production of gaseous fuels from carbonaceous materials generally employed as solid fuels is widely known in the art. Such production is carried out because of the fact that gaseous fuels have advantages over solid fuels in that they are clean, ash free, easily conveyed and handled, permit convenient firing of furnaces, and are applicable for use in internal combustion engines. In connection with steam generation or other application where furnaces are employed, gaseous fuels are adapted to extreme simplicity of control of temperature and heat supply. Combustible gases which are suitable for use as fuels may be manufactured from a wide variety of carbonaceous materials which are generally used as solid fuels. Such solid fuels include anthracite coal, bituminous coal, lignite, peat, petroleum coke, gas coke, charcoal, various types of woods and wood waste such as sawmill waste including sawdust and bark, tan bark, agricultural by-product such as straw, bagasse, and many other carbonaceous materials including materials which are basically cellulose.

One conventional manufactured gas, known as producer gas, is manufactured by the controlled primary combustion of coals, cokes, and other similar materials with primary air containing steam which yields a combustible gas containing carbon monoxide, hydrogen, methane, and a considerable amount of nitrogen. Water gas is manufactured by the reaction of incandescent carbon with steam to form carbon monoxide and hydrogen and the process is generally carried out alternately with air blowing to heat the bed of incandescent carbon to a temperature sufficiently high that steam will readily react. Coal gas, which has a higher heating value than either producer gas or water gas, is produced by the distillation of coal in the absence of air. Also produced simultaneously with the coal gas, are considerable quantities of benzene and other aromatic hydrocarbons together with tars and pitch.

The equipment which is employed in conventional gas producers, in general, comprises a vessel equipped with a grate near the bottom upon

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which the fuel bed is supported. Means are provided for introducing fresh fuel into the upper portion of the vessel and for removing ashes formed which fall through the grate. Reactant gases containing steam and oxygen are introduced below the grate and pass upwardly through the fuel bed and react therein with the carbonaceous material. The product gases are removed from above the fuel bed. During operation considerable quantities of heat are generated in the oxidation zone just above the grate due to carbon oxidation heating the fuel to temperatures in the range of from 1500° F. to 3000° F. The entire weight of the charge is transmitted through the fuel in the oxidation zone to be supported on the grate and therefore deformation and slagging of the ash occurs at temperatures where the ash becomes plastic, i. e., the softening point. The ash may flow under the resulting pressure and clog the grate halting the process.

The gasification rate increases with temperature and hence the highest possible temperature of operation is most desirable provided that this temperature is not so high as to exceed the softening point of either the solid fuel or the ash. Gasification rate of a given apparatus is, therefore, limited by the softening point of the solid fuel being gasified or that of the resulting ash. For example, in the gasification of a bituminous coal having an ash which fuses at about 2000° F., a maximum gasification rate of only about six pounds per square foot per hour is possible without exceeding the softening point. The rate of gasification of a coal which has an ash fusion temperature of around 3000° F. is more than double that at 2000° F. In the case of gas producers of modern design, maximum gasification rates in general are limited under most favorable conditions to about 40 pounds per square foot per hour while in most gas producers the maximum is between about 10 and 15 pounds per square foot per hour.

It is therefore an object of my invention as herein more fully described to provide a process for gasification of carbonaceous materials such as solid fuels which permits increased gasification temperatures and which is free from the conventional disadvantages which arise from slagging or fusion of the ash remaining following gasification of the carbonaceous materials.

A further object of my invention is to provide an improved gasification process which is adaptable to produce gases of widely variable composition and which gases are suitable for fuel, hydro-

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genation, synthesis, such as Fischer-Tropsch synthesis depending upon demand.

It is an additional object of my invention to provide a gasification process in which solid fuels may be gasified at maximum temperatures above the softening point at which ash fusion and slagging normally prevent continuance of operation in conventional gasification processes permitting thereby a higher gas production rate per unit of apparatus.

In addition, it is a still further object of my invention to provide a gasification process having an increased heat efficiency and adapted to produce gases from carbonaceous materials such as solid fuels which contain appreciable quantities of fines.

It is also an object of my invention to provide an improved gas production apparatus adapted to accomplish the above-mentioned objects.

Other objects and advantages of my invention will become apparent to those skilled in the art as the description thereof proceeds.

Briefly, my invention comprises an improved process and apparatus for the production of combustible or synthesis gases at atmospheric and superatmospheric pressures from carbonaceous solids such as conventional solid fuels by reaction at high temperature with water vapor and oxygen. The carbonaceous materials are introduced into the bottom of a vertical gasification zone and forced upwardly therethrough counter-currently to downwardly flowing reactant gases containing water vapor and oxygen. By employing an upflow of carbonaceous materials and a downflow of reactant gases, the high temperature oxidation zone wherein ash slagging generally occurs is maintained in the upper portion of the gasification kiln. The incandescent coal in the oxidation zone therefore is subjected to only a small fraction of the weight of solid materials subjected to incandescent coal present in the conventional gas producers previously employed. Thus, temperatures of gasification considerably above the ash softening point may be employed in the gasification process according to my invention without encountering difficulties inherent in conventional gasification processes. Solid fuels having abnormally low softening points or ash softening points such as between about 1500° F. and 2000° F. which are therefore not applicable to gasification in conventional processes because of the low maximum permissible operation temperature may be quite efficiently gasified in improved gasification process according to my invention because gasification may be performed at temperatures above the softening point of either the fuel or ash without usually encountered difficulties. In the apparatus according to my invention the temperature must approach the actual fluidity point of the ash before trouble is encountered due to slagging. This makes possible markedly increased gasification temperatures which permit a considerable increase in gasification rates over those obtained in the conventional gas producers previously described.

The process and apparatus of gas production according to my invention has further advantages over conventional gas production processes and apparatus procedure employed. It is possible to carry out gas production according to my invention over a wide range of pressure and it is therefore possible to vary the composition of the gas produced over extremely wide ranges. For example, it is possible to produce a gas contain-

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ing as high as about 80% by volume of hydrogen which is applicable in hydrogenation reactions, ammonia synthesis operations and for various other chemical uses. It is also possible to carry out the water gas reaction in the apparatus of my invention and to obtain a product gas having a mol ratio of hydrogen to carbon monoxide of about 1 to 1 if desired. By altering the operating conditions it is possible to produce gases having molar ratios of hydrogen to carbon monoxide which vary from about 1 to 1 to about 4 to 1 by introducing the proper quantity of steam into the gasification apparatus and by a judicious selection of operating pressure.

The reactant gases employed consist preferably of a mixture of steam and pure oxygen forming product gases which are virtually completely free of inert constituents which lower the heating value of the product gases when they are to be used as fuels. Such inert constituents also decrease the reactivity of the gases when they are to be used in synthesis reactions. It is possible to employ in the process of my invention reactant gases which comprise water vapor and air, water vapor and oxygen enriched air, or water vapor and fuel gas which contains excess oxygen. It is also possible to employ liquid water instead of water vapor which may be introduced directly into the upper portion of the gasification kiln. A dual purpose is thus served in that the hot ashes present are cooled before being discharged from the gasification kiln in generating steam required in the process. An increased thermal efficiency results in permitting an efficient recovery of most of the heat contained in ashes formed.

The process according to my invention provides, depending upon the solid carbonaceous materials being gasified, varying quantities of oils, tars, and other distillates including hydrocarbon liquids and gases which are not required to be burned in the process and which are valuable by-products. The process of my invention is also adaptable to production of fuel gases which have heating values sufficiently high to form excellent fuel gases. It is also possible to produce without further treatment synthesis gases applicable in the I. G.-Bergius or the Fischer-Tropsch synthesis processes. In these synthesis processes, a gas containing a molar ratio of hydrogen to carbon monoxide of around 2 to 1 is passed over an iron, nickel, or cobalt catalyst at temperatures between about 350° F. and 500° F., sometimes as high as 700° F. and pressures between atmospheric to as high as about 100 atmospheres to obtain hydrocarbons, alcohols, ketones, and a wide variety of synthetic organic compounds. By employing specially compounded catalysts, wax-like hydrocarbon substances may be produced from synthesis gases manufactured by the process of my invention.

The fact that the process according to my invention permits production of synthesis gases which as produced have the required hydrogen to carbon monoxide ratio gives the process a decided advantage over the conventional synthesis gas production by the water gas reaction wherein a gas containing an excess of carbon monoxide is obtained. A separate operation is required to generate sufficient hydrogen so that the water gas product may be graded to have the required hydrogen to carbon monoxide ratio.

My invention may be more readily understood by reference to the accompanying diagrammatic drawings in which,

Figure 1 illustrates a vertical cross section of

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one modification of the apparatus adapted to accomplish the process of gas production at pressures up to about 1,000 pounds per square inch or higher according to my invention, and

Figure 2 is a vertical cross section of the positive solids feeder employed to move solids upwardly through the apparatus. In order to facilitate a clear description of the apparatus, the solid carbonaceous material being gasified will be considered to be bituminous coal.

Referring to Figure 1, the coal to be gasified is introduced by means of line 10 into a pressure lock which comprises valve 11, coal hopper 12, and valve 13. The function of the pressure lock is to permit the introduction, by gravity, of coal into the gasification apparatus substantially without loss of pressure. Coal is introduced by means of line 10 through valve 11 which is open and falls into coal hopper 12 with valve 13 closed. Valve 11 is subsequently closed and valve 13 is opened causing coal hopper 12 to assume a pressure equal to that of the gasification apparatus. The coal contained within coal hopper 12 cascades therefrom through valve 13 by means of line 14 into feed bin 15 formed below baffle 19 in the annular space between cooling jacket 16 and gasification kiln 17 and gasification vessel 18. The thus introduced coal fills the space in bin 15 from baffle 19 down to baffle 20 and further extends down and rests against baffle 21.

The coal to be gasified is introduced into a vertical conical gasification kiln having the larger diameter at the upper end for upward passage therethrough by means of a positive solids feeder, as hereinafter more fully described, positioned within the lower parts of gasification vessel 18. The coal is thus forced upwardly through gasification kiln 17 through zones E, D, C, B, and A, respectively. During passage upwardly therethrough, the coal is gasified by reaction at elevated temperatures with steam and oxygen so that a substantially complete conversion of the carbonaceous material present in the coal to gases is effected. The solid material discharged from zone A in the upper portion of gasification kiln 17 comprises ashes of the coal being gasified and is substantially free of residual nongasified carbon.

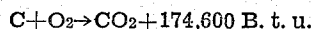
The temperatures employed in the gasification reaction, especially within oxidation zone B, are quite high and in many cases approach the fusion point of the ash. The incipient fusion of the ash usually contained in the coal forms clinkers which are removed from the upper portion of zone A. These clinkers are broken into smaller pieces by means of rotary scraper 46 attached to shaft 47 which is introduced through seal 48 in the top of gasification vessel 18. By suitable means, not shown, shaft 47 and scraper 46 are rotated about a vertical axis at an angular velocity of between about 5 and 50 revolutions per minute. The broken pieces of clinker fall downwardly from the upper edge of gasification kiln 17 and impinge against the upper side of baffle 19 and collect in the ash bin formed by the annular space between cooling jacket 16 of gasification kiln 17 and gasification vessel 18 above baffle 19. These pieces of clinker are continuously withdrawn by means of line 49 controlled by valve 50 and introduced into ash hopper 51. The clinkers are removed from ash hopper 51 by means of line 52 controlled by valve 53 and are disposed of in any suitable manner. Valves 50 and 53 together with ash hopper 51 comprise a pressure lock similar to that employed in intro-

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ducing fresh coal into bin 15 and the ashes, or pieces of clinker if incipient fusion occurs, are introduced into ash hopper 51 when valve 50 is open and valve 53 is closed. Valve 50 is subsequently closed and the ashes are removed from ash hopper 51 through open valve 53.

In one modification of my invention it is possible to control the operation of the coal lock and the ash lock so that a semicontinuous introduction of coal and removal of ashes is attained. When the pressure of operation of the gasification apparatus is quite high, for example, above about 250 pounds per square inch, it may be advantageous to extend a pressure line 54 controlled by valve 55 from ash hopper 51 to coal hopper 15 so as to let one hopper partially depressure into the other. For automatic operation of the gasification apparatus, valves 11, 13, 50, 53 and 55 may be controlled by a suitable timing mechanism so as to open and close at the proper times and for the proper intervals to attain a given coal throughput.

During the upward passage of the coal through gasification kiln 17, the coal is contacted by a reactant gas containing steam and oxygen passing downwardly therethrough. In zone A of gasification kiln 17 the ashes or clinkers are cooled by direct heat exchange with the downwardly flowing reactant gases effecting an efficient preheating thereof. The ashes removed from the upper portion of zone A and subsequently discharged from gasification vessel 18 are removed therefrom at a temperature between about 300° F. and about 400° F. The reactant gases, containing steam and oxygen, are introduced into the upper portion of gasification kiln 18. Steam, at a pressure somewhat greater than that of the gasification operation pressure is introduced by means of line 62 controlled by valve 64 into header 65. A gas containing oxygen, which is preferably pure oxygen but which may comprise oxygen enriched air, air, or flue gas, is introduced by means of line 66 controlled by valve 67 into header 65. The individual reactants are introduced at rates which are sufficient to give the required quantity and composition of steam and oxygen containing gases. The gases pass from zone A downwardly into oxidation zone B at a temperature of about 1000° F. to 1500° F. Within oxidation zone B all the heat generated in the process is formed by the reaction of the oxygen present in the reactant gas with unburned carbonaceous material present in the upwardly rising coal. This heat is formed principally by the following reaction:



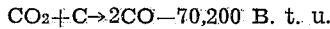
A substantially complete conversion of carbon to carbon dioxide is effected at temperatures as high as 2000° F. to 2500° F. or higher and the solids leaving oxidation zone B are substantially free from unconverted carbon. The gases leaving oxidation zone B to reduction zone C are also substantially free from oxygen.

Within reduction zone C an endothermic reaction takes place between the steam introduced with the reactant gases and the incandescent carbon present within zone C according to the following relationship:



Another endothermic reaction simultaneously occurs between the carbon dioxide formed in oxidation zone B with the hot carbon present in

reduction zone C according to the following relationship:



Both the reactions of steam and carbon dioxide with incandescent carbon consume heat and thus reduction zone C is considerably cooler than oxidation zone B, but hot enough so that the reducing reactions progress rapidly.

The hot gases thus formed in reduction zone C pass downwardly through preheating and distillation zone D wherein the incoming upwardly rising coal is preheated by the downwardly moving gases thus heating the coal to a temperature sufficient to effect the distillation of volatile matter present in the coal. Liquid oils, tars, and hydrocarbon gases are distilled from the coal in zone D at relatively low temperatures and travel downwardly countercurrent into disengaging zone E from which the distilled tars and oils together with the product gases containing carbon monoxide and hydrogen formed in oxidation zone B and reduction zone C are removed through perforations 53 present in grates 35 and 35a. These products of gasification are removed from gasification kiln 18 by means of line 57 controlled by valve 58a and are sent to subsequent apparatus, not shown, to effect purification if desired or to be used in a furnace, internal combustion engine or in a synthesis reaction.

In some cases of operation with particular types of coal it is necessary to provide means for cooling solids feeder zone 45. In order to accomplish this, that portion of gasification vessel 18 below line 57 may be maintained full of water, liquid gasification products, or any other suitable medium which circulates through or evaporates at a sufficient rate to prevent overheating of the individual parts positioned in solids feeder zone 45. It is preferred to maintain a circulation of liquid through feeder zone 45 and simultaneously allowing some of the circulated liquid to evaporate.

Referring now to Figure 2, the positive solids feeder comprises housing 22, guards 23 and 24, cylinder 25, piston 26, hydraulic cylinder 27 and hydraulic cylinder 28. Housing 22 comprises a curved member positioned within gasification vessel 18 and integrally attached thereto. Guards 23 and 24, which are integrally attached to cylinder 25, are constructed so as to have the same center of curvature as housing 22. Cylinder 25 is mounted on and free to rotate in an arc on vertical plane about trunnions 29. Hydraulic cylinder 28 is attached to the wall of gasification vessel 18 by means of attachment 39 and shaft 31 communicating with piston 32 is attached to the lower extremity of cylinder 25 by means of attachment 33. The introduction and removal of hydraulic fluid from hydraulic cylinder 28 causes, by the action imparted to piston 32 and shaft 31, the movement of cylinder 25 in an arc on a vertical plane about trunnions 29 positioned at the center of curvature of housing 22 and guards 23 and 24. Thus, when piston 32 is forced, by the introduction of hydraulic fluid through inlet 34 into hydraulic cylinder 28, to the right hand extremity of hydraulic cylinder 28, the upper end of cylinder 25, in which is positioned piston 26, moves in the aforementioned arc to a position below the open mouth of bin 15 between baffle 21 and grate 35. When cylinder 25 has moved to a position below bin 15, guard 23 comes into contact with pilot valve 38 which causes the introduction of hydraulic fluid into the hy-

draulic cylinder 27 by means of inlet 37. Piston 26 is pulled downwardly through cylinder 25 by shaft 25a creating an open volume in the upper portion of cylinder 25 into which cascades a portion of coal from bin 15. When piston 26 reaches the lower extremity of its travel through cylinder 25, lug 60 attached to connecting rod 42 comes into contact with pilot valve 38 which causes the introduction of hydraulic fluid into hydraulic cylinder 28 by means of inlet 39 thus causing cylinder 25 to rotate about trunnions 29 to a vertical position so that the upper open end of cylinder 25 is positioned directly below zone E of gasification kiln 17. When cylinder 25 reaches the vertical position, guard 24 comes into contact with pilot valve 40 which causes the introduction of hydraulic fluid into hydraulic cylinder 27 by means of inlet 41 causing piston 25 to move upwardly through cylinder 25 and forces the fresh coal feed upward into zone E and consequently displacing in an upward direction the column of solids present in zones A, B, C, and D of gasification kiln 17 not shown. When piston 26 reaches the uppermost extremity of its travel through cylinder 25, pilot valve 38 is again tripped by means of lug 61 attached to connecting rod 42 causing the introduction of hydraulic fluid into hydraulic cylinder 28 through inlet 34 which in turn causes cylinder 25 to rotate in an arc about trunnions 29 so that cylinder 25 is positioned below bin 15 in such a position as to receive a further quantity of fresh coal feed. The clearances between guards 23 and 24 attached to cylinder 25 and housing 22, the lower extremities of grates 35 and 35a, the lower extremity of baffle 21 and housing 22a are quite small, on the order of one-eighth of an inch or less. In order to equalize any pressure between zone E or bin 15 and solids feeder zone 45 due to the reciprocating action of piston 26, line 43, controlled by valve 44 is provided connecting solids feeder zone 45 with the remainder of the vessel above housing 22 and 22a.

In one modification of the apparatus of my invention no refractory brick or other material is utilized on the inside of gasification kiln 17. Insulation of the metal from the high temperatures of reaction generated in oxidation zone B is effected by a layer of cooled coal which exists adjacent to the wall of gasification kiln 17. This layer of coal is cooled by indirect heat exchange with a suitable cooling fluid such as for example water, oil or other, which is introduced into cooling jacket 16 by means of line 58 and circulated through cooling jacket 16 under a pressure substantially equal to that of the gasification operation. The cooling fluid is introduced by means of line 58 equipped with expansion joint 59 into lower portion of cooling jacket 15, moves upwardly therethrough and is removed from the upper portion thereof by means of line 60 which is also equipped with expansion joint 61. Suitable internal baffles 57 may be positioned within cooling jacket 16 so as to direct the cooling fluid evenly over the entire outside area of gasification kiln 17. Cooling jacket 16 is provided with expansion joint 62 which is required because of the high internal temperature as compared with the temperature of the fluid circulated through the cooling jacket.

The gasification process according to my invention is applicable to the production of producer gases which are suitable for furnace heating or for domestic use. The operation may be altered in such a manner as to produce gases

containing high concentration of carbon monoxide and hydrogen in the proper ratio which are suitable feed gases for Fischer-Tropsch or I. G.-Bergius synthesis operations. The apparatus of my invention may be modified to operate at pressures lower than atmospheric pressure in which case the construction of the apparatus may likewise be modified so as to eliminate gasification vessel 18 which is used at superatmospheric pressure as a fabrication expedient. Suitable refractories may be employed within the gasification kiln if desired.

The advantage offered by superatmospheric pressure operation in contrast to the conventional gas producers which operate at near atmospheric pressure is very marked. When synthesis gases are the desired products and a hydrogen to carbon monoxide molal ratio of about 2 to 1 is desired, it is possible to alter the pressure of gasification so as to reduce the quantity of carbon monoxide present in the product gases. Lower pressures displace the carbon dioxide-carbon monoxide equilibrium in favor of reduced quantities of carbon monoxide. Also the addition of an increased proportion of water vapor in the reactant gases reduces the temperature of the gasification operation which in turn reduces the reactivity of the incandescent coke so that smaller quantities of carbon dioxide are reduced in the reduction zone to carbon monoxide. This permits an effective means for the variation of the composition of the product gas by two factors; that is, by reduction of the pressure and the reduction of the gasification temperature. In general, the process and the apparatus is applicable to operation in virtually any pressure such as from about 10 pounds per square inch to as high as 1,000 pounds per square inch or even higher. In the production of synthesis gases having small quantities of carbon monoxide pressures in the range of from about 10 to 200 pounds per square inch absolute are applicable to advantage, and a pressure of operation which is representative as one of about 120 pounds per square inch.

In the production of manufactured gases which are employed as fuels in furnaces, internal combustion engines, or other uses, the use of pressures higher than those employed in the production of synthesis gases is of advantage. Increased pressures are of advantage because the formation of polyatomic gases such as methane and carbon dioxide is favored. The presence in such a gas of quantities of methane results in a marked increase in the heating value and the theoretical flame temperature of the product gas. In the reduction zone where the gas is contacted with incandescent carbon in the absence of free oxygen the carbon dioxide is reduced to carbon monoxide and the water vapor or steam present in the reactant gas decomposes to provide further quantities of carbon monoxide and also hydrogen. The formation of carbon dioxide and of methane is exothermic and therefore reduces the quantity of oxygen required to supply heat to the process to between about 50 and 75 volume per cent of the oxygen required to effect the same gasification at atmospheric pressure. The production of gases suitable as fuels may be carried out at pressures between about 10 and 1,000 pounds per square inch absolute or higher although pressures in the range of from about 100 to 400 pounds per square inch absolute are preferred. At these pressures the product gas may be cooled and scrubbed with water to effect an efficient removal of hydrogen sulfide or quanti-

ties of undecomposed carbon dioxide. Such high pressure gasification produces a good fuel gas.

Since the gasification rate directly determines the number of gas producers which are required to supply a given quantity of gas and since the gasification rate is primarily limited by the maximum possible temperature of operation below the ash softening point, it is obvious that the process and apparatus of the present invention is much superior to the conventional processes and apparatus previously used because of the fact that increased gasification temperatures may be employed because gasification temperatures considerably higher than the softening point are possible without the serious disadvantages normally encountered in the conventional gasification processes. The oxidation zone which is the zone of highest temperature and which frequently contains incandescent carbon heated to temperatures between 2,000° F. and as high as 3,500° F. carries very little weight of material above and does not rest on a grate thereby eliminating the conventional ash and fuel fusion and slagging problems.

Carbonaceous materials which may be gasified and which include the solid fuels previously mentioned are preferably ground and fed to the gasification apparatus according to my invention in the form of small chunks or pieces of from about 0.25 inch to about 1.25 inches major dimensions. The apparatus is also capable of handling and substantially completely gasifying solid fuels which are introduced as granules having diameters as small as about 0.1 or larger than about 1.5 inches.

I have further found that an apparatus containing a vertical kiln as a coking zone entirely analogous to that described for coal gasification may be employed under somewhat modified conditions in the coking of coals or other carbonaceous materials. When adapted to coking of coal, no steam is normally introduced into the apparatus with the oxygen-containing reactant gas. The coking operation comprising a partial oxidation, is conducted at temperatures ranging from about 1500° F. to about 3000° F. depending upon the nature of coal being coked or of the coke desired. The product gases leaving the apparatus are removed at a temperature between about 900° F. and about 1500° F. The coal is introduced into the kiln in a similar manner to that described heretofore through a reservoir containing liquids formed in the coking operation or of water and is circulated through the feeder zone to reduce temperatures of the feeder mechanism. The apparatus may likewise be operated under pressure as in the case of coal gasification. Coke formed is removed from the upper portion of the kiln similarly to the ash removal in gasification operations.

Having described and illustrated my invention and realizing that many modifications thereof may occur to those skilled in the art without departing from the spirit and scope of the following claims.

I claim:

1. An apparatus for the gasification of coal by reaction at elevated temperatures with oxygen and steam which comprises a vertical conical gasification kiln widening in an upward direction positioned within a gasification vessel adapted to withstand elevated internal pressures, a baffle separating the annular space between the gasification vessel and the gasification kiln into an

upper portion comprising an ash bin and a lower portion comprising a feed bin, pressure lock means for introducing said coal into said feed bin for subsequent introduction into said gasification kiln to be gasified, pressure lock means for removing ashes from said ash bin, means for introducing reactant gases into the upper part of said kiln, withdrawal means for removing product gases and liquids from the lower part of said kiln, and positive solids feeder means for passing said coal upwardly through said gasification kiln so as to maintain a bed of said coal at elevated temperatures in an oxidation zone in the upper portion of said gasification vessel where said coal is subjected to a small fraction of the weight of coal present within said kiln.

2. An apparatus for the gasification of coal which comprises an upwardly widening vertical gasification kiln open at the top, a jacket surrounding said gasification kiln, means for circulating a coolant through said jacket, a gasification vessel surrounding said kiln and jacket, a baffle separating the annular space between the gasification vessel and the gasification kiln into an upper portion comprising an ash bin and a lower portion comprising a feed bin, pressure lock means for introducing said coal into said feed bin while the latter is under superatmospheric pressure, solids feeder means within said vessel and below said gasification kiln adapted to receive coal from said feed bin and discharge it upwardly through said gasification kiln, pressure lock means for removing ashes from said ash bin, means for introducing reactant gases comprising water vapor and oxygen into the top of said gasification kiln, and means for removing product liquids and gases from the bottom of said gasification kiln.

3. An apparatus for the gasification of coal under superatmospheric pressures which comprises a vertical gasification vessel, an upwardly widening, open topped vertical metal gasification kiln supported within the upper portion of said gasification vessel, a cooling jacket surrounding said gasification kiln, means for circulating a coolant through said cooling jacket, a baffle separating the annular space between the gasification vessel and the cooling jacket into an upper portion comprising an ash bin and a lower portion comprising a feed bin, pressure lock means for introducing said coal into said feed bin, a solids feeder positioned within said gasification vessel and below said gasification kiln, adapted to receive coal from the feed bin and discharge it upwardly through said gasification kiln, means for breaking up clinkers and scraping ashes from the top of said gasification kiln into said ash bin, pressure lock means for withdrawing ashes from said ash bin, means for introducing reactant gases comprising water vapor and oxygen at controlled rates into the top of said gasification kiln, means for removing product gases and liquids from the bottom of said gasification kiln just above said solids feeder, and means for maintaining said solids feeder completely immersed in liquid comprising liquid products from the gasification kiln.

4. An apparatus according to claim 3 in which the solids feeder comprises a reciprocating piston adapted to be oscillated so that it is positioned alternately below the feed bin and the gasification kiln, means for lowering the piston when it is below the feed bin and raising it when it is positioned below the gasification kiln, and

guards oscillating with the piston and substantially sealing the lower end of the gasification kiln while the piston is positioned below the feed bin and substantially sealing the lower end of the feed bin when the piston is positioned below the gasification kiln.

5. A continuous process for the gasification of coal under pressure which comprises introducing said coal by gravity through a pressure locking zone into a feeding zone which is completely immersed in a liquid coolant, forcing said coal from said feeding zone upwardly through a gasification zone comprising successively a preheating and distillation zone, a reduction zone, an oxidation zone, and an ash zone, removing ashes from said ash zone through a pressure lock, introducing reactant gases comprising water vapor and oxygen at controlled rates into said ash zone so as to preheat said reactant gases and coal said ashes, reacting the preheated reacting gases with residual carbonaceous material at superatmospheric pressure and a temperature above 1500° F. and above the softening point of the ash in said oxidation zone so as to effect a substantially complete conversion of the oxygen in said reactant gases to carbon dioxide, contacting the thus formed gas containing water vapor and carbon dioxide with hot carbon at a lower temperature in said reduction zone so as to reduce carbon dioxide to carbon monoxide and convert water vapor to gases containing essentially hydrogen and carbon monoxide and form said residual carbonaceous material, countercurrently contacting the coal in said preheating and distillation zone with the gases containing hydrogen and carbon monoxide formed in said reduction zone so as to produce hydrocarbon gases and liquids from said coal and convert the coal to said hot carbon, withdrawing gases and liquid hydrocarbons from the lower portion of said preheating and distillation zone, retaining a portion of the liquids in said feeding zone to act as said coolant, and cooling said feeding zone by evaporation of a portion of the so-retained liquid.

6. A process according to claim 5 wherein the water added with said reactant gases is introduced at least in part as liquid water directly into said ash zone so as to cool said hot ashes by vaporization of the water.

7. A process according to claim 5 wherein the coal is gasified under a pressure of between about 100 and 400 pounds per square inch absolute.

8. A process for the gasification of coal at a superatmospheric pressure, which comprises establishing a vertical gasification zone, introducing said coal into a coal pressure locking zone at atmospheric pressure, raising the pressure in said zone to said superatmospheric pressure, passing the coal from said zone to the lower portion of said gasification zone and through a liquid seal in the lower portion thereof, maintaining said gasification zone at said superatmospheric pressure, passing the thus introduced coal upwardly through said gasification zone, introducing reactant gases comprising oxygen and steam into the upper portion of said gasification zone, passing said reactant gases downwardly through said gasification zone countercurrent to the upwardly rising coal therein, reacting said upwardly rising coal with said downwardly moving gases so as to produce product gases containing essentially carbon monoxide and hydrogen, and ashes, maintaining a maximum temperature in said gasification zone greater than the softening point of the material passing therethrough, passing said

ashes from the upper portion of said gasification zone into an ash discharge pressure locking zone at said superatmospheric pressure, reducing the pressure in said ash discharge pressure locking zone to atmospheric, discharging the ash therefrom, and removing said product gases substantially uncontaminated with air from the lower portion of said gasification zone just above said liquid seal.

9. A process for the gasification of coal at a superatmospheric pressure, which comprises establishing a vertical gasification zone containing a coal preheating and distillation zone, introducing said coal into a coal pressure locking zone at atmospheric pressure, raising the pressure in said zone to said superatmospheric pressure, passing the coal from said zone into said preheating and distillation zone and through a liquid seal in the lower portion thereof, maintaining said gasification zone at said superatmospheric pressure, introducing reactant gases comprising water vapor and oxygen into the upper portion of said gasification zone, passing said coal upwardly through said gasification zone, passing said reactant gases downwardly through said gasification zone countercurrent to said coal therein, reacting said coal with said reactant gases so as to produce hot product gases containing essentially carbon monoxide and hydrogen, and ashes, at a maximum temperature above the softening point of solids passing therethrough, passing said hot product gases downwardly through said preheating and distillation zone countercurrent to the coal so as to preheat said coal and distil volatile matter therefrom to form gaseous and liquid distillates and cooled product gases, retaining a portion of said liquid distillates in the lower portion of said preheating and distillation zone as said liquid seal, removing said gaseous and liquid distillates and said cool product gas substantially uncontaminated with air from the lower portion of said gasification zone, passing said ashes from the upper portion of said gasification zone into an ash discharge pressure locking zone at superatmospheric pressure, reducing the pressure in said ash discharge pressure locking zone to atmospheric and discharging the ash therefrom.

10. A process of coal gasification at superatmospheric pressure, which comprises establishing a vertical gasification zone provided with a feeding zone, introducing said coal into a coal pressure locking zone at atmospheric pressure, raising the pressure in said zone to said superatmospheric pressure, passing the coal from said zone into said feeding zone and through a liquid sealing medium therein, maintaining said gasification zone at said superatmospheric pressure, forcing said coal upwardly through said gasification zone, introducing reactant gases comprising oxygen and steam into the upper portion of said gasification zone, reacting said coal in said gasification zone with said downwardly passing reactant gases at a maximum temperature above the softening point of the resulting ashes, to form hot ashes and hot product gases containing essentially carbon monoxide and hydrogen, employing said hot ashes to preheat said reactant gases, employing said hot product gases to preheat and distil from said coal volatile matter comprising hydrocarbon gases and liquids, passing said ashes from the

upper portion of said gasification zone into an ash discharge pressure locking zone at said superatmospheric pressure, reducing the pressure in said ash discharge pressure locking zone to atmospheric, discharging the ash therefrom, removing said product gases together with said volatile matter from the lower portion of said gasification zone, removing said product gases, hydrocarbon gases and liquids substantially uncontaminated with air, from a point just above said feeding zone, cooling the solids in said feeding zone by submerging them in said liquid sealing medium and evaporating a portion of said liquid and circulating the remainder through a cooling circuit at a rate sufficient to prevent overheating thereof.

11. In a process of coal gasification according to claim 10, the improvement wherein said liquid submerging said feeder zone comprises liquids produced from said coal.

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