Sept. 3, 1957 M. JOSENHANS 2,805,188

PROCESS FOR PRODUCING SYNTHESIS GAS AND COKE

Filed Oct. 23, 1952 3 Sheets-Sheet 1

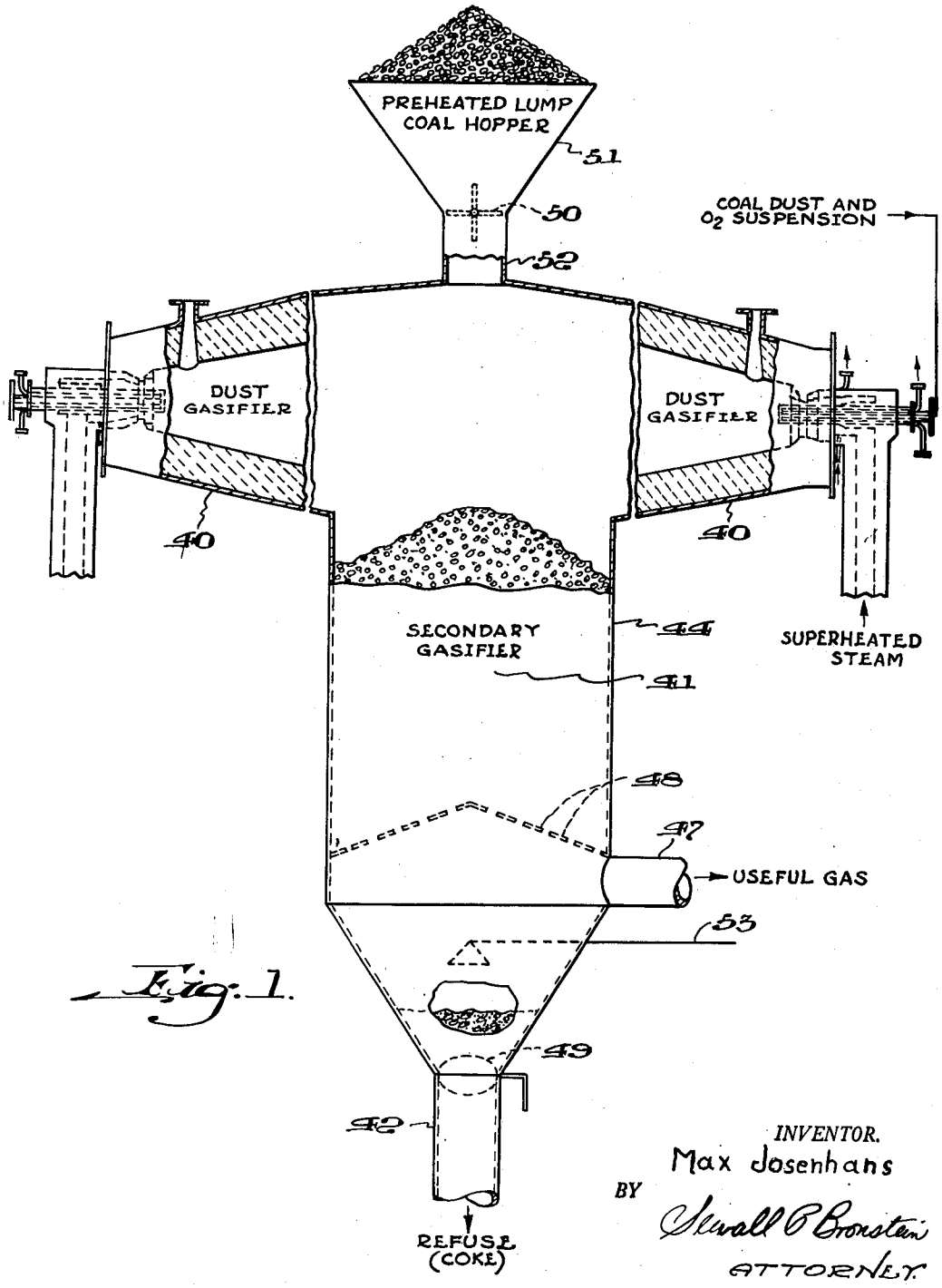


Fig. 1.

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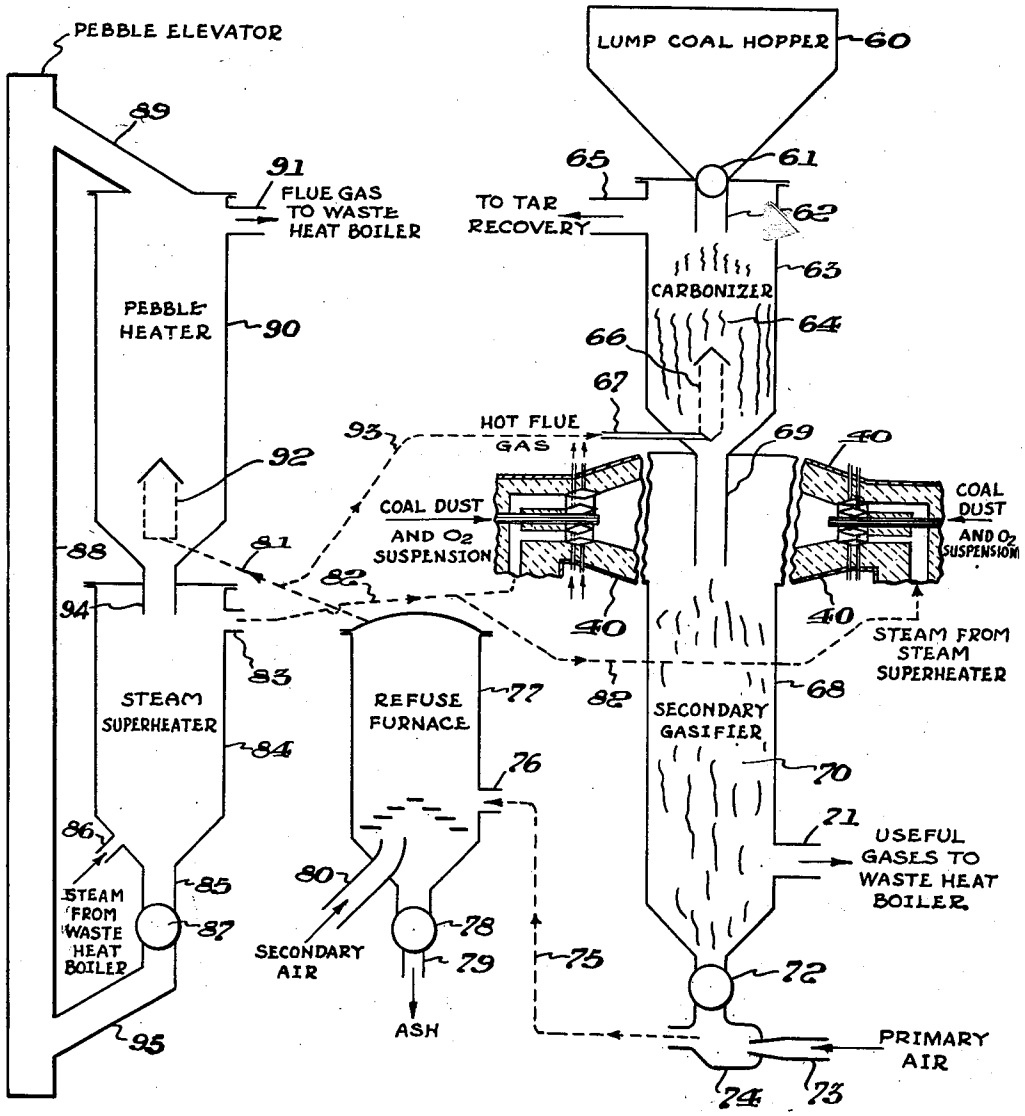


Fig. 2.

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Fig. 3.

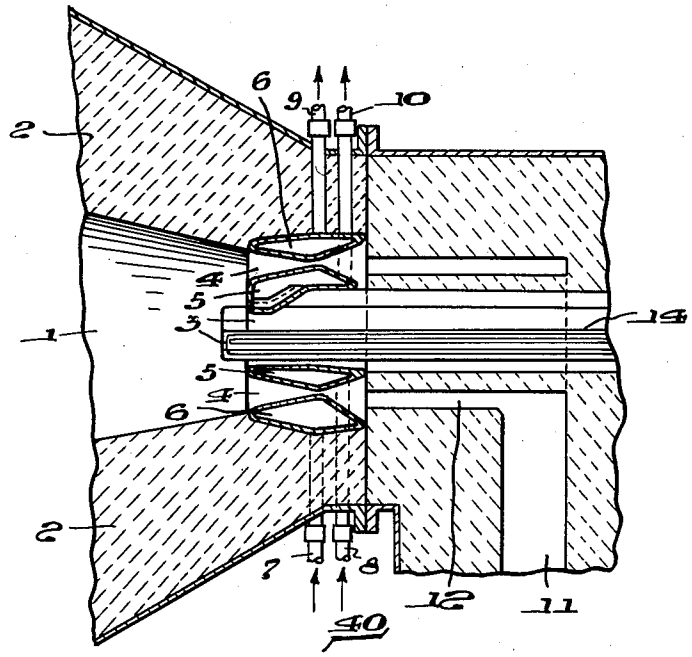
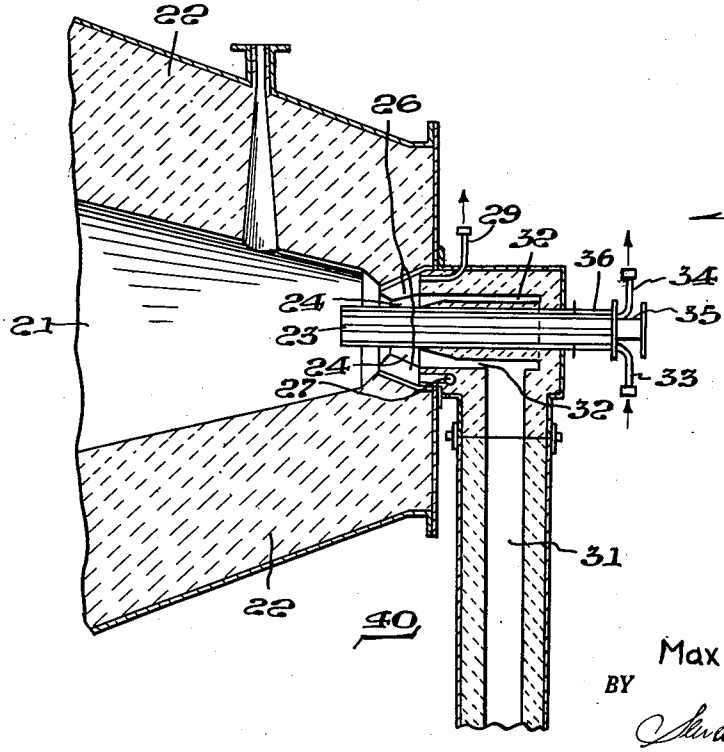


Fig. 4.



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United States Patent Office 2,805,188
Patented Sept. 3, 1957

2,805,188

PROCESS FOR PRODUCING SYNTHESIS GAS AND COKE

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Application October 23, 1952, Serial No. 316,451

3 Claims. (Cl. 202—9)

The present invention relates to improvements in processes and/or apparatus for the production of useful gases, such as fuel gases and synthesis gases for synthesis of chemical compounds, by the gasification of carbonaceous fuel. It further relates to such improvements and such processes and/or apparatus, whereby carbonized solid fuel, such as coke, which is suitable as a fuel or as feed material for standard fixed bed water gas machines is produced from coal simultaneously with the production of said useful gases.

Modern chemical industry calls for a process, which makes an inexpensive synthesis gas as a raw material for the manufacture of all kinds of synthetics, for example, synthetic fertilizers, fuels, plastics, hydrocarbons and the various other synthetics, such as are derived from acetylene or other basic hydrocarbons. Therefore, improvements in the production of synthesis gas are of the utmost importance in the chemical industry.

For the large amount of manufactured synthesis gas required by the chemical industry, coal and its derivatives are generally used. However, synthesis gas for use in many of the subsequent synthetic processes must be free from coal tar. The complete removal of tar vapors from the manufactured gas is difficult and costly. Therefore, provisions have been made to avoid tar formation during gas production. This has been done in two different ways as follows:

1. Use of fuels like coke or char, from which all tar has been driven out in a previous treatment.

2. If tar-containing fuels like run-of-the-mine coal are used, operating conditions of gasification are so selected that all tar which might be formed is completely decomposed as formed.

The standard water gas generator is a very well established and satisfactory means for producing synthesis gas. The process avoids tar formation by using coke or char as a raw material, from which all tar has been previously removed. However, this process is handicapped by the fact that the only fuels, which can be used, are relatively expensive. As soon as the coke or char price is above 1.5 times the coal price, the process cannot compete in cost with other gas generating methods, using coal or lignite as raw materials, with steam and/or oxygen of high purity as reactants for gasification. Such methods comprise what are known, and, hereafter referred to in the present specification and claims, as "dust gasification" methods, wherein very finely-divided pulverized fuel is intimately contacted with gasification media, such as a free oxygen-containing gas or a free oxygen-containing gas and steam, whereby the oxygen exothermically reacts with a portion of the fuel to raise the temperature of the remaining fuel and steam excessively high, at which excessively high temperature, the endothermic reaction of the remainder of the fuel with the steam to form carbon monoxide is favored. Among such "dust gasification" methods are included gasification of finely-divided fuels in "suspension type" gasifiers such as vortex type gasifiers, fluidized bed type gasifiers, and

gasifiers of the type described and claimed in copending U. S. applications Ser. Nos. 43,950, 43,592, now abandoned, and 43,953, now U. S. Patent No. 2,670,280, filed August 12, 1948, U. S. application Ser. No. 131,008, now abandoned, filed Dec. 3, 1949, U. S. application Ser. No. 226,792, filed May 17, 1951, and U. S. application Ser. No. 241,413, filed Aug. 11, 1951, now U. S. Patent No. 2,751,286, all wherein a jet of finely-divided fuel suspended in oxygen is burned in a primary combustion zone, which is peripherally enveloped in a continuously, cocurrently flowing annular stream of steam, the products from the combustion zone being commingled with the steam flowing from the envelope in a secondary endothermic reaction zone, where such steam endothermically reacts with hot unreacted fuel flowing from such combustion zone. In suspension type gasifiers, the very high temperatures, at which the reaction is carried out due to the intensive burning of the fuel-oxygen suspension, causes the tar contained in the fuel to be decomposed and gasified to form useful gases containing carbon monoxide and hydrogen.

However, such "dust gasification" or "suspension gasification" methods have certain disadvantages in that,

1. It is difficult, if not impossible, to force the endothermic steam-carbon reaction to the degree of completion required to consume substantially all the finely-divided fuel and to obtain sufficiently cooled exit gases, under conditions of gasification in presently known types of "dust gasification" equipment. Thus, the off-gases are exceedingly high in temperature and contains a considerable amount of unreacted steam (reactant steam and steam formed during the "dust gasification"), as well as dust, containing, in addition to ash, considerable amounts of unreacted carbon. However, such dust is too poor in carbon to be commercially utilizable as a fuel, and so the carbon contained therein is wasted, in addition to the unreacted steam, thus reducing the efficiency of the gasifier.

2. Pure oxygen or oxygen enriched air must be utilized for the gasification, which is very expensive. However, unless oxygen or oxygen enriched air is utilized, the required high temperatures cannot be obtained in the gasifier.

3. The reaction products emerge from the gasifier at extremely high temperatures, and thus contain large amounts of sensible heat, a good deal of which must be wasted. Such heat is produced by fuel and relatively expensive oxygen consumption, thereby increasing operation costs.

4. The efficient removal of liquid slag, produced at the high temperatures required during the gasification, is very difficult, especially, when the "dust gasification" is carried out at increased pressures.

Such liquid slag is very corrosive and causes rapid equipment deterioration if not efficiently removed.

The present invention provides an improved "dust gasification" process and/or apparatus of the type described above, whereby many of the above disadvantages are avoided or reduced, so that less fuel is required with less oxygen and less steam to produce more synthesis gases, containing less carbon-containing dust and less unreacted steam than any process or apparatus known heretofore.

The present invention further provides such an improved process and/or apparatus, wherein a useful, solid, carbonized fuel, suitable for use as a fuel or as a starting material for standard water gas generators, is produced from coal or coke simultaneously with and in cooperation with the above mentioned more efficient production of synthesis gas.

The present invention further involves such an improved process and/or apparatus, wherein lumps of tar-containing solid fuel of the size utilized in standard water

gas generators, are carbonized and/or gasified in a fixed bed simultaneously with an in cooperation with the above mentioned efficient production of synthesis gas, without caking of such bed with resulting prohibitive pressure drops through the bed, and, without contamination with tarry matter, of the useful gases produced in and passed through the bed.

In accordance with the present invention, it has been found that the above disadvantages of prior art "dust gasifiers" can be avoided and the above improved processes can be carried out by gasifying in a "dust gasifier," a finely-divided, carbonaceous fuel with a chemically combined oxygen-containing fluid capable of reacting endothermically with the finely-divided fuel, such as steam, and a free oxygen-containing gas, introducing the reaction products from such "dust gasifier," while still hot, into a fixed bed of moving solid, carbonaceous fuel, flowing such hot reaction products cocurrently with the flow of the moving, solid, carbonaceous fuel in the fixed bed, separating the refuse flowing from such fixed bed from useful gases admixed therewith.

The apparatus, in which the foregoing process of the present invention is carried out, comprises, "a dust gasifier" having means for flowing therein reactants, and means for flowing therefrom hot reaction products, a secondary gasification chamber connected at one of its ends with the dust gasifier outlet means, so that the hot reaction products from the dust gasifier can be introduced directly into such one end of the chamber, means for introducing solid carbonaceous fuel into the same one end of said chamber and for maintaining a fixed bed of moving said solid fuel in said chamber, means for cocurrently flowing the hot "dust gasification" reaction products and the carbonaceous fuel in said fixed bed together, from the above mentioned one end of such secondary gasification chamber, to the other end of such chamber, where refuse and useful gases are separated and then removed or removed and then separated.

According to applicant's present invention, hot reaction products, containing CO_2, H_2CO and unreacted carbon and steam issuing from known types of "dust gasifiers," are introduced into a moving bed of solid, carbonaceous fuel and are flowed cocurrently with such moving bed of fuel through a secondary gasifier, wherein gasification of the unreacted carbon in the "dust gasification" products as well as volatilization and gasification of the volatile matter in the fuel, if such fuel contains volatile matter, as well as gasification of at least a part of the non-volatile portion of the fuel in the bed occurs with the unreacted steam and carbon dioxide in the "dust gasification" reaction products, the high temperatures and large quantities of sensible heat in the "dust gasification" reaction products, providing the required endothermic heat of gasification in the secondary gasifier, the withdrawal of such heat by the endothermic volatilization and gasification in the secondary gasifier, resulting in comparatively cool refuse and gases issuing from the secondary gasifier.

The unreacted carbon and steam contained in the hot products issuing from the "dust gasifier" directly into the fixed bed of fuel commingle with the high carbon-containing fixed bed of carbonaceous fuel. The high carbon content of the resulting commingled mixture, as well as the increased surfaces presented by the fixed bed of fuel and the turbulence caused by the contact of the gases with the lumps of the fixed bed, increases reaction between carbon (the unreacted carbon from the "dust gasifier" plus the carbon contained in the fuel of the fixed bed) and unreacted steam as well as any carbon dioxide in the "dust gasifier" reaction products. The very high temperatures and, hence, large amounts of sensible heat in the "dust gasification" products, as they emerge from the "dust gasifier" raises the temperature of that portion of the fixed bed where such products are introduced, to very efficient gasification temperatures, high enough to decompose any tar or other volatile matter given off by the carbonaceous fuel due to the application of heat thereto, in such cases where such fuel contains such tar or volatile matter. As the moving fuel of the fixed bed and the "dust gasifier" reaction products flow cocurrently away from the point of introduction of such "dust gasification products" into such bed, they are cooled due to the endothermic reactions occurring in the fixed bed between the steam and carbon dioxide and the carbon, so that the solid refuse and gases finally removed from the fixed bed are relatively cool. In this way, the reaction products from the "dust gasifier" are cooled, resulting in less heat being discarded and therefore less oxygen and fuel being consumed to produce the same amount of synthesis gas, while at the same time the unreacted materials (carbon and steam) contained therein, are substantially completely reacted or rendered commercially utilizable. Thus, less oxygen, steam, and pulverized fuel are required, thereby reducing the cost of operation considerably. Furthermore, "dust gasification" capacity is increased considerably, thereby, requiring less "dust gasification" equipment for the same gas output. Furthermore, at the same time, H_2 and CO are produced in the solid bed reactor without the expense of additional oxygen or steam.

The carbon content of the refuse removed from the moving fixed bed depends upon the rate of flow of the carbonaceous fuel of the fixed bed, the length of said bed, the temperature and rate of flow of the hot "dust gasification" reaction products.

The contact or residence time of the hot reaction products with the solid fuel in the bed can be controlled by controlling the rates of flow of the fuel of the bed and the hot "dust gasification" reaction products, as well as the length of the bed, so that practically all of the carbon content of the carbonaceous fuel in the fixed bed as well as the unreacted carbon in the reaction products from the "dust gasifier" are consumed, leaving only liquid slag containing small amounts of carbon dissolved therein. However, it is much more preferred and efficient to control the rates of flow of the fuel of the fixed bed and the hot "dust gasification" reaction products, and the length of the bed, so that the solid refuse flowing from the bed contains a sufficient amount of carbon to be utilizable commercially as fuel. In such case, the molten slag produced in the dust gasifier, as well as any slag produced in a fixed bed, is adsorbed and solidified on the solid fuel of the fixed bed, and making its removal in solid form possible. This provides a novel way of slag removal during "dust gasification," especially, when carried out under pressure. Furthermore, the removal of slag in such a manner decreases refractory corrosion in the gasification apparatus due to slag, which is deposited thereon.

The solid residue, in such case, can be utilized as a fuel in producing and superheating steam for the "dust gasifier" and for drying and preheating fuel for the "dust gasification," as well as for preheating fuel for the fixed bed. Although the carbon in the reaction products from the usual "dust gasifier" is present in too small amounts to be utilized as a fuel, and thus must be wasted, the carbon contained in the solid refuse of the present invention can be utilized as a fuel. Hence, substantially none of the carbon is wasted.

If tar-containing coal is utilized as a fuel for the fixed bed, its rate of flow can be so controlled that substantially only the volatile matter of such coal is volatilized and gasified, the solid residue being suitable as a coke in slagging or non-slagging type gas generators at atmospheric or elevated pressures, or, in standard water gas machines, thereby increasing the efficiency of the "dust gasification" process, while at the same time carbonizing coal to produce coke for standard water gas machines. Undersized particles of this solid refuse can be recycled and used as a fuel for the "dust gasification" step while a part of the lump char may be recycled and introduced into the secondary gasifier. Furthermore, since, in such

cases, it is desirable to have high fixed bed fuel rates, capacity is increased. It is pointed out that it is the co-current flow of "dust gasification" reaction products and the fuel of the fixed bed, which makes possible the use of tar-containing fuels for the fixed bed, without caking occurring in the bed with resultant high pressure drops, and without contamination with tarry matter of the useful gases produced in and passed through such bed.

Fig. 1, diagrammatically discloses an embodiment of the present invention, applied to a dust gasifier of the type described in the above mentioned copending applications and more fully disclosed, in cross-section, in Figures 3 and 4.

Fig. 2, diagrammatically discloses yet another embodiment of the present invention applied to a dust gasifier of the type described in the above mentioned copending application and more fully disclosed in cross-section, in Figures 3 and 4.

Fig. 3 discloses in vertical cross-section the dust gasifier of Figures 1 and 2.

Fig. 4 discloses, in vertical cross-section, another type of dust gasifier, which can be utilized in Figures 1 and 2.

According to Fig. 1, a plurality of dust gasifiers **40**, are located circumferentially around the top of secondary gasifier **44**, so that hot reaction products flowing from such dust gasifiers, flow into a fixed bed of solid fuel **41**, such as lump coal, flowing downwardly through such secondary gasifier. A solid fuel hopper **51**, is located on top of the secondary gasifier and a conduit **52**, and feeding valve **50**, is provided for continuously feeding preheated solid fuel from hopper **51**, into the top of secondary gasifier **44**. The hot reaction products from reactors **40**, containing carbon monoxide, carbon dioxide, hydrogen, and unreacted carbon particles and steam, flow cocurrently with the flow of solid fuel of the fixed bed, in intimate contact therewith, downwardly, through secondary gasifier **44**, during which time, the coal is devolatilized and endothermic gasification of unreacted carbon in the reaction products from the dust gasifier **40**, the volatile matter from the coal, and, if desired, according to the rate of flow of solid fuel through the secondary gasifier, some of the devolatilized fuel in the fixed bed, occurs with the carbon dioxide and unreacted steam present in the "dust gasification" reaction products, to form useful gases containing carbon monoxide and hydrogen. The dust gasifier reaction products are simultaneously cooled by more than 1000° F. Make gas outlet **47**, is provided at the bottom of the secondary gasifier **44**, for removal of make gases containing carbon monoxide and hydrogen. Residue "coke" is removed from the fuel bed by means of cooled grate **48**, and leaves the gasifier by means of feeder **49**, and conduit **42**. If desired, the solid residue can be cooled by water spray **53**. "Dust gasifiers" **40**, are of the type described in copending U. S. application Ser. No. 241,413. With reference to Figures 3 and 4, each respectively of such gasifiers comprises a conically shaped gasification chamber **1** or **21**, having fuel dust-oxygen-suspension inlet nozzles **3** or **23**, connected with fuel dust-oxygen suspension supply pipes **14** or **35**, and annular steam inlet nozzle **4** or **24**, having a venturi shape and surrounding the fuel dust-oxygen inlet nozzles **3** or **23**, and being connected with steam passage **11** or **31** and steam distribution passage **12** or **32**. The outer walls of annular nozzle **4** are surrounded by an annular cooling jacket **6** or **26**, having a cool water inlet **7** or **27**, and a hot water outlet **9** or **29**. The inner walls of nozzle **4** or **24**, have a second cooling jacket **5** or **36**, cooperating therewith, having a cold water inlet **8** or **33**, and a hot water outlet **10** or **34**. The cooling jacket **5** or **36**, surrounds nozzles **3** or **23**, and acts as a cooling jacket therefor, as well as a cooling jacket for nozzle **4** or **24**. The dust gasification chamber **1** or **21** is bounded by refractory walls **2** or **22**.

Fig. 2 discloses yet another embodiment of the present

invention, wherein a plurality of dust gasifiers **40**, shown in cross-section, in Figures 3 and 4 and described above, are located circumferentially around the top of secondary gasifier **68**, so that hot reaction products flowing from such dust gasifiers flow into a fixed bed of coke **70**, flowing downwardly through such secondary gasifier. A carbonizer **63**, is located above the secondary gasifier, such carbonizer having a fresh coal hopper **60**, feeder **61**, and inlet **62**, a carbonized coal and coke outlet feeding into passage **69**, which leads into secondary gasifier **68**, an outlet **65**, for removal of volatile matter and a hot flue gas inlet **67**, and distributor **66**. Secondary gasifier **68**, has a useful gas outlet **71** and residue coke outlet and feeder **72**, through which hot residue coke is flowed into a blower **74**, having a primary air inlet **73**, for blowing such hot coke refuse through line **75**, and inlet **76**, to refuse furnace **77**, into which secondary air for completely burning such refuse is admitted through inlet **80**. Ash is removed from refuse furnace **77**, through feeder **78**, and line **79**. Hot flue gas lines **93** and **81**, connect refuse furnace **77**, with carbonizer **63**, through line **67**, and with pebble heater **90**, through hot flue gas inlet and distribution means **92**. Pebble heater **90**, has a cooled flue gas outlet pipe **91**, leading to a waste heat boiler, not shown, cold pebble bed inlet conduit **89**, and hot peddle outlet conduit **94**, leading into steam superheater **84**. Steam superheater **84**, has a superheated steam outlet pipe **83** and **82**, leading to the steam inlets of dust gasifier **40**, a cold pebble outlet **85**, and feeder **87**, leading to conduit **95**, and pebble elevator **88**, where pebbles are elevated to conduit **89**, and a steam inlet pipe **86**, leading from the waste heat boiler, not shown. Two suitable types of dust gasifiers **40**, leading into secondary gasifier **68**, are disclosed in Fgures 3 and 4, and have been described above.

Example

Utilizing the apparatus of Figures 1 and 4, high volatile, bituminous coal dried to 2.5% of water, ground so that 62% passes through a 200 mesh sieve is fed, together and in suspension with substantially pure oxygen in the ratio of 12.5 cu. ft. of oxygen per lb. of coal, into fuel-oxygen pipes **35**, and, thence, into nozzles **23**, from which such suspension of coal and oxygen are jetted into reaction chamber **21**, which has been previously heated to the ignition temperatures of the oxygen-coal suspension. The suspension of coal and oxygen, upon being jetted into reaction chamber **21**, ignites and burns while flowing through a primary combustion zone in reaction chamber **21**. The proportions of coal and oxygen are such that there is sufficient oxygen only to burn a portion, but not all of the coal to carbon monoxide. The heat generated by such burning heats the unburned remaining portion of coal to temperatures favoring reaction of the same with steam and oxygen to produce carbon monoxide and hydrogen.

Water is flowed continuously from pipes **27** and **33**, into cooling jackets **26** and **36** respectively, and thence out through pipes **29** and **34**, thus preventing the coal-oxygen suspension from becoming too hot before entering chamber **21**. Due to the partial combustion in the combustion zone, a reaction temperature of 3050° F. is obtained in reaction chamber **21**. Simultaneously with the injection of the coal/oxygen mixture into the reaction chamber 1.1 lbs. of steam superheated to 1500° F. are admitted through steam passages **31** and **32**, and steam nozzles **24**, per lb. of coal admitted through coal-oxygen nozzles **23**. The steam, due to the rate of flow of such steam compared to the rate of flow of the coal-oxygen suspension, as well as the design of chamber **21**, and nozzles **23** and **24**, issues into the chamber in the form of a cocurrently, contiuously flowing annular stream, completely enveloping the outer periphery of the jet of coal and oxygen as it issues into the reaction chamber

and ignites and the outer periphery of the combustion zone. The annular stream of steam, flowing in a direction along, around, and outside of the peripheries of such jet and combustion zone, forms a protective layer between the combustion zone, where a great deal of heat is generated, and where hot solid particles are produced and the walls of the reaction chamber. However, after the end of combustion in the combustion zone, the products of combustion as well as the hot unreacted carbon diffuse into the steam from the envelope and endothermic reactions occur in an endothermic reaction zone within the reaction chamber. Hot reaction products issue from the reaction chambers **21**, into the top of secondary gasifier **44**, which contains a solid bed of ¾ to 2 inch lumps of coal of the same type utilized in the coal-oxygen suspension, having about 900 lbs. of coal per lb. of finely-divided coal fed per second into the dust gasifier. Such solid bed of lump coal is moving constantly downward and the hot reaction product gases from the "dust gasifiers" move cocurrently and downwardly with such moving coal bed. Lump coal is fed from hopper **51**, feeder **50**, and conduit **52**, into the top of secondary gasifier **44**, at the rate of 0.43 lb. of coal per lb. of coal fed into the "dust gasifiers." This lump coal is rapidly carbonized on top of the fuel bed, where the hot gases from chambers **21**, at temperatures of from 2,200° F. to 2,600° F. and above, are first contacted therewith, and the volatile matter (tar, etc.) is practically completely converted into CO, H_2 and CO_2. In the coal bed, the unreacted carbon in the "dust gasification" reaction products from chambers **21**, is retained and reacts with carbon dioxide and unreacted steam contained in the reaction products. Furthermore, the coal is volatilized and the volatile matter is gasified by the carbon dioxide and unreacted steam in the reaction products. Furthermore, depending on the rate of flow of coal and reaction products, the length of the bed and, thus, the contact time of the hot product gases with the bed, a part of the carbon in the carbonized coal may or may not react with the carbon dioxide and unreacted steam. The high temperature of the product gases, as they contact the coal bed, heat the bed to sufficient temperatures for these reactions and volatilization to occur. Hot make gases are removed at **47**, and the solid residue is removed by water cooled grate **48**, feed **49**, and conduit **42**. The height of the bed and the rate of flow of solid fuel through the bed and, thus, the contact time of the hot reaction products with the solid fuel of the bed is regulated by feeder **49**, which may be a star valve or any other known type of solids feeder. The solid residue issuing from **42**, is a coke having a quality sufficient for use in typical water gas generators. The make gas is rich in carbon monoxide and hydrogen. The total gas production per 1 lb. of total fuel (finely-divided fuel and lump fuel) consumed, is 41 cu. ft., having the following analysis: CO_2—6.8%, CO—51.4%, H_2—39.1%, N_2+H_2S—2.7%. The reaction product gases from the "dust gasifier," while flowing from the top of the fixed bed to the bottom of the fixed bed, cocurrently with the coke, are cooled about 1,300° F. by the endothermic reactions occurring in the bed, which endothermic reactions produce additional carbon monoxide and hydrogen. The temperature of the gases in line **47** is about 1,300° F. The make gases are led from line **47** to a cyclone separator for dust removal and thence to a waste heat boiler and direct cooler.

If the apparatus of Figure 2 is utilized, lump coal is fed from hopper **60**, through feeder **61**, and conduit **62**, into carbonizer **63**, where it is carbonized by hot flue gases introduced through line **67** and distributor **66**. The volatile matter drawn off from the coal during carbonization escapes through line **65**, and is led to a tar recovery unit, not shown. Coke flows from carbonizer **63**, through line **69**, to secondary gasifier **68**, in which it forms a fixed bed **70**, of coke moving cocurrently with hot reaction product gases from "dust gasifiers" **40**, produced in the manner described above in discussing Figure 1. Useful gases are removed at **71**, and hot refuse flows through feeder **72**, to blower **74**, into which primary air is introduced from line **73**. The primary air blows the refuse along line **75** and inlet **76**, to refuse furnace **77**, where secondary air is introduced through line **80**, to completely burn such refuse to ash, which is removed through feeder **78**, and **79**. The hot flue gases formed in **77**, are flowed through line **81** and **93**, to pebble heater **90** and inlet **67** of carbonizer **63** respectively. The flue gas flowing to line **67**, through line **93**, is used to carbonize coal in carbonizer **63**, while the flue gas flowing to pebble heater **90**, through lines **81** and distributor **92** is used to heat pebbles introduced into pebble heater from line **89**. The spent flue gas is removed from pebble heater **90**, through line **91** from whence it is flowed to a waste heat boiler. The hot pebbles flow through conduit **93**, to steam superheater **84**, where they are contacted with steam from **86**, to superheat such steam. The superheated steam is flowed from steam superheater **84**, through lines **82**, to steam inlets **31**, (Figure 4) of the dust gasifiers **40**. Spent pebbles are removed from steam superheater **84**, through line **85**, feeder **87**, and line **93** and are recycled to pebble heater **90**, to be reheated by means of pebble elevator **88**, and line **89**. It may be seen that by utilizing the apparatus of Figure 2, all the heat for producing steam and carbonized fuel for the process, is obtained from the refuse removed from the secondary gasifier.

Coke or other solid fuels, such as anthracite, bituminous, and run-of-the-mine coal, as well as char and low temperature coke, can be used as solid fuel for the secondary gasifier.

Usually, the solids are fed into the top of the secondary gasifier and spent solids are removed at the bottom, so that the solid fuel and reaction products flow downwardly. However, so long as the flow of hot reaction gases and the fuel of the fixed bed is cocurrent, it is not necessary that the flow be from top ot bottom.

The residence time in the dust gasifier should be sufficient to permit essentially complete consumption of the oxygen introduced with the finely-divided coal or lignite. A residence time below 1.2 seconds, preferably below 0.5 to 0.8 second and above 0.05 to 0.1 second is sufficient. These residence times apply to gasification at atmospheric pressure. The process can be used advantageously at higher pressures up to about 40 atmospheres, preferably at 5 to 20 atmospheres. The residence time in this case has to be increased, roughly with the square root of the pressure.

The amount of oxygen used should permit gasification of at least 50 to 60% of the carbon of the coal, preferably between 70 to 85%. For this to occur, oxygen-coal ratios above 7 cu. ft. per lb. of coal, preferably between 8 and 11 cu. ft. of oxygen per lb. of coal, fed into the "dust gasifiers" are suitable.

The rate of steam flow into the "dust gasifiers" preferably ranges from 0.7 lb. to 1.1 lbs. of coal fed into the "dust gasifier."

For the production of carbon monoxide and hydrogen-containing synthesis gas, essentially pure oxygen is used. For ammonia synthesis gas, containing nitrogen, suitable mixtures of oxygen with air can be chosen.

The water content of the finely-divided coal should be below 5%.

Coal is ground, so that it can be fed in a suspension with oxygen. Particles below ⅛ in. are suitable. More finely ground coal, for example 50 to 70% passing through a 200 mesh sieve is preferred. It permits use of residence times in the "dust gasifiers" near the lower limit given above.

The residence or contact time of reaction gases in the secondary gasifier can be decreased with increase of average temperatures, the amount of carbon present and

cases, it is desirable to have high fixed bed fuel rates, capacity is increased. It is pointed out that it is the co-current flow of "dust gasification" reaction products and the fuel of the fixed bed, which makes possible the use of tar-containing fuels for the fixed bed, without caking occurring in the bed with resultant high pressure drops, and without contamination with tarry matter of the useful gases produced in and passed through such bed.

Fig. 1, diagrammatically discloses an embodiment of the present invention, applied to a dust gasifier of the type described in the above mentioned copending applications and more fully disclosed, in cross-section, in Figures 3 and 4.

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Fig. 3 discloses in vertical cross-section the dust gasifier of Figures 1 and 2.

Fig. 4 discloses, in vertical cross-section, another type of dust gasifier, which can be utilized in Figures 1 and 2.

According to Fig. 1, a plurality of dust gasifiers **40**, are located circumferentially around the top of secondary gasifier **44**, so that hot reaction products flowing from such dust gasifiers, flow into a fixed bed of solid fuel **41**, such as lump coal, flowing downwardly through such secondary gasifier. A solid fuel hopper **51**, is located on top of the secondary gasifier and a conduit **52**, and feeding valve **50**, is provided for continuously feeding preheated solid fuel from hopper **51**, into the top of secondary gasifier **44**. The hot reaction products from reactors **40**, containing carbon monoxide, carbon dioxide, hydrogen, and unreacted carbon particles and steam, flow cocurrently with the flow of solid fuel of the fixed bed, in intimate contact therewith, downwardly, through secondary gasifier **44**, during which time, the coal is devolatilized and endothermic gasification of unreacted carbon in the reaction products from the dust gasifier **40**, the volatile matter from the coal, and, if desired, according to the rate of flow of solid fuel through the secondary gasifier, some of the devolatilized fuel in the fixed bed, occurs with the carbon dioxide and unreacted steam present in the "dust gasification" reaction products, to form useful gases containing carbon monoxide and hydrogen. The dust gasifier reaction products are simultaneously cooled by more than 1000° F. Make gas outlet **47**, is provided at the bottom of the secondary gasifier **44**, for removal of make gases containing carbon monoxide and hydrogen. Residue "coke" is removed from the fuel bed by means of cooled grate **48**, and leaves the gasifier by means of feeder **49**, and conduit **42**. If desired, the solid residue can be cooled by water spray **53**. "Dust gasifiers" **40**, are of the type described in copending U. S. application Ser. No. 241,413. With reference to Figures 3 and 4, each respectively of such gasifiers comprises a conically shaped gasification chamber **1** or **21**, having fuel dust-oxygen-suspension inlet nozzles **3** or **23**, connected with fuel dust-oxygen suspension supply pipes **14** or **35**, and annular steam inlet nozzle **4** or **24**, having a venturi shape and surrounding the fuel dust-oxygen inlet nozzles **3** or **23**, and being connected with steam passage **11** or **31** and steam distribution passage **12** or **32**. The outer walls of annular nozzle **4** are surrounded by an annular cooling jacket **6** or **26**, having a cool water inlet **7** or **27**, and a hot water outlet **9** or **29**. The inner walls of nozzle **4** or **24**, have a second cooling jacket **5** or **36**, cooperating therewith, having a cold water inlet **8** or **33**, and a hot water outlet **10** or **34**. The cooling jacket **5** or **36**, surrounds nozzles **3** or **23**, and acts as a cooling jacket therefor, as well as a cooling jacket for nozzle **4** or **24**. The dust gasification chamber **1** or **21** is bounded by refractory walls **2** or **22**.

Fig. 2 discloses yet another embodiment of the present invention, wherein a plurality of dust gasifiers **40**, shown in cross-section, in Figures 3 and 4 and described above, are located circumferentially around the top of secondary gasifier **68**, so that hot reaction products flowing from such dust gasifiers flow into a fixed bed of coke **70**, flowing downwardly through such secondary gasifier. A carbonizer **63**, is located above the secondary gasifier, such carbonizer having a fresh coal hopper **60**, feeder **61**, and inlet **62**, a carbonized coal and coke outlet feeding into passage **69**, which leads into secondary gasifier **68**, an outlet **65**, for removal of volatile matter and a hot flue gas inlet **67**, and distributor **66**. Secondary gasifier **68**, has a useful gas outlet **71** and residue coke outlet and feeder **72**, through which hot residue coke is flowed into a blower **74**, having a primary air inlet **73**, for blowing such hot coke refuse through line **75**, and inlet **76**, to refuse furnace **77**, into which secondary air for completely burning such refuse is admitted through inlet **80**. Ash is removed from refuse furnace **77**, through feeder **78**, and line **79**. Hot flue gas lines **93** and **81**, connect refuse furnace **77**, with carbonizer **63**, through line **67**, and with pebble heater **90**, through hot flue gas inlet and distribution means **92**. Pebble heater **90**, has a cooled flue gas outlet pipe **91**, leading to a waste heat boiler, not shown, cold pebble bed inlet conduit **89**, and hot peddle outlet conduit **94**, leading into steam superheater **84**. Steam superheater **84**, has a superheated steam outlet pipe **83** and **82**, leading to the steam inlets of dust gasifier **40**, a cold pebble outlet **85**, and feeder **87**, leading to conduit **95**, and pebble elevator **88**, where pebbles are elevated to conduit **89**, and a steam inlet pipe **86**, leading from the waste heat boiler, not shown. Two suitable types of dust gasifiers **40**, leading into secondary gasifier **68**, are disclosed in Fgures 3 and 4, and have been described above.

Example

Utilizing the apparatus of Figures 1 and 4, high volatile, bituminous coal dried to 2.5% of water, ground so that 62% passes through a 200 mesh sieve is fed, together and in suspension with substantially pure oxygen in the ratio of 12.5 cu. ft. of oxygen per lb. of coal, into fuel-oxygen pipes **35**, and, thence, into nozzles **23**, from which such suspension of coal and oxygen are jetted into reaction chamber **21**, which has been previously heated to the ignition temperatures of the oxygen-coal suspension. The suspension of coal and oxygen, upon being jetted into reaction chamber **21**, ignites and burns while flowing through a primary combustion zone in reaction chamber **21**. The proportions of coal and oxygen are such that there is sufficient oxygen only to burn a portion, but not all of the coal to carbon monoxide. The heat generated by such burning heats the unburned remaining portion of coal to temperatures favoring reaction of the same with steam and oxygen to produce carbon monoxide and hydrogen.

Water is flowed continuously from pipes **27** and **33**, into cooling jackets **26** and **36** respectively, and thence out through pipes **29** and **34**, thus preventing the coal-oxygen suspension from becoming too hot before entering chamber **21**. Due to the partial combustion in the combustion zone, a reaction temperature of 3050° F. is obtained in reaction chamber **21**. Simultaneously with the injection of the coal/oxygen mixture into the reaction chamber 1.1 lbs. of steam superheated to 1500° F. are admitted through steam passages **31** and **32**, and steam nozzles **24**, per lb. of coal admitted through coal-oxygen nozzles **23**. The steam, due to the rate of flow of such steam compared to the rate of flow of the coal-oxygen suspension, as well as the design of chamber **21**, and nozzles **23** and **24**, issues into the chamber in the form of a cocurrently, contiuously flowing annular stream, completely enveloping the outer periphery of the jet of coal and oxygen as it issues into the reaction chamber

and ignites and the outer periphery of the combustion zone. The annular stream of steam, flowing in a direction along, around, and outside of the peripheries of such jet and combustion zone, forms a protective layer between the combustion zone, where a great deal of heat is generated, and where hot solid particles are produced and the walls of the reaction chamber. However, after the end of combustion in the combustion zone, the products of combustion as well as the hot unreacted carbon diffuse into the steam from the envelope and endothermic reactions occur in an endothermic reaction zone within the reaction chamber. Hot reaction products issue from the reaction chambers **21**, into the top of secondary gasifier **44**, which contains a solid bed of ¾ to 2 inch lumps of coal of the same type utilized in the coal-oxygen suspension, having about 900 lbs. of coal per lb. of finely-divided coal fed per second into the dust gasifier. Such solid bed of lump coal is moving constantly downward and the hot reaction product gases from the "dust gasifiers" move cocurrently and downwardly with such moving coal bed. Lump coal is fed from hopper **51**, feeder **50**, and conduit **52**, into the top of secondary gasifier **44**, at the rate of 0.43 lb. of coal per lb. of coal fed into the "dust gasifiers." This lump coal is rapidly carbonized on top of the fuel bed, where the hot gases from chambers **21**, at temperatures of from 2,200° F. to 2,600° F. and above, are first contacted therewith, and the volatile matter (tar, etc.) is practically completely converted into CO, H_2 and CO_2. In the coal bed, the unreacted carbon in the "dust gasification" reaction products from chambers **21**, is retained and reacts with carbon dioxide and unreacted steam contained in the reaction products. Furthermore, the coal is volatilized and the volatile matter is gasified by the carbon dioxide and unreacted steam in the reaction products. Furthermore, depending on the rate of flow of coal and reaction products, the length of the bed and, thus, the contact time of the hot product gases with the bed, a part of the carbon in the carbonized coal may or may not react with the carbon dioxide and unreacted steam. The high temperature of the product gases, as they contact the coal bed, heat the bed to sufficient temperatures for these reactions and volatilization to occur. Hot make gases are removed at **47**, and the solid residue is removed by water cooled grate **48**, feed **49**, and conduit **42**. The height of the bed and the rate of flow of solid fuel through the bed and, thus, the contact time of the hot reaction products with the solid fuel of the bed is regulated by feeder **49**, which may be a star valve or any other known type of solids feeder. The solid residue issuing from **42**, is a coke having a quality sufficient for use in typical water gas generators. The make gas is rich in carbon monoxide and hydrogen. The total gas production per 1 lb. of total fuel (finely-divided fuel and lump fuel) consumed, is 41 cu. ft., having the following analysis: CO_2—6.8%, CO—51.4%, H_2—39.1%, N_2+H_2S—2.7%. The reaction product gases from the "dust gasifier," while flowing from the top of the fixed bed to the bottom of the fixed bed, cocurrently with the coke, are cooled about 1,300° F. by the endothermic reactions occurring in the bed, which endothermic reactions produce additional carbon monoxide and hydrogen. The temperature of the gases in line **47** is about 1,300° F. The make gases are led from line **47** to a cyclone separator for dust removal and thence to a waste heat boiler and direct cooler.

If the apparatus of Figure 2 is utilized, lump coal is fed from hopper **60**, through feeder **61**, and conduit **62**, into carbonizer **63**, where it is carbonized by hot flue gases introduced through line **67** and distributor **66**. The volatile matter drawn off from the coal during carbonization escapes through line **65**, and is led to a tar recovery unit, not shown. Coke flows from carbonizer **63**, through line **69**, to secondary gasifier **68**, in which it forms a fixed bed **70**, of coke moving cocurrently with hot reaction product gases from "dust gasifiers" **40**, produced in the manner described above in discussing Figure 1. Useful gases are removed at **71**, and hot refuse flows through feeder **72**, to blower **74**, into which primary air is introduced from line **73**. The primary air blows the refuse along line **75** and inlet **76**, to refuse furnace **77**, where secondary air is introduced through line **80**, to completely burn such refuse to ash, which is removed through feeder **78**, and **79**. The hot flue gases formed in **77**, are flowed through line **81** and **93**, to pebble heater **90** and inlet **67** of carbonizer **63** respectively. The flue gas flowing to line **67**, through line **93**, is used to carbonize coal in carbonizer **63**, while the flue gas flowing to pebble heater **90**, through lines **81** and distributor **92** is used to heat pebbles introduced into pebble heater from line **89**. The spent flue gas is removed from pebble heater **90**, through line **91** from whence it is flowed to a waste heat boiler. The hot pebbles flow through conduit **93**, to steam superheater **84**, where they are contacted with steam from **86**, to superheat such steam. The superheated steam is flowed from steam superheater **84**, through lines **82**, to steam inlets **31**, (Figure 4) of the dust gasifiers **40**. Spent pebbles are removed from steam superheater **84**, through line **85**, feeder **87**, and line **93** and are recycled to pebble heater **90**, to be reheated by means of pebble elevator **88**, and line **89**. It may be seen that by utilizing the apparatus of Figure 2, all the heat for producing steam and carbonized fuel for the process, is obtained from the refuse removed from the secondary gasifier.

Coke or other solid fuels, such as anthracite, bituminous, and run-of-the-mine coal, as well as char and low temperature coke, can be used as solid fuel for the secondary gasifier.

Usually, the solids are fed into the top of the secondary gasifier and spent solids are removed at the bottom, so that the solid fuel and reaction products flow downwardly. However, so long as the flow of hot reaction gases and the fuel of the fixed bed is cocurrent, it is not necessary that the flow be from top ot bottom.

The residence time in the dust gasifier should be sufficient to permit essentially complete consumption of the oxygen introduced with the finely-divided coal or lignite. A residence time below 1.2 seconds, preferably below 0.5 to 0.8 second and above 0.05 to 0.1 second is sufficient. These residence times apply to gasification at atmospheric pressure. The process can be used advantageously at higher pressures up to about 40 atmospheres, preferably at 5 to 20 atmospheres. The residence time in this case has to be increased, roughly with the square root of the pressure.

The amount of oxygen used should permit gasification of at least 50 to 60% of the carbon of the coal, preferably between 70 to 85%. For this to occur, oxygen-coal ratios above 7 cu. ft. per lb. of coal, preferably between 8 and 11 cu. ft. of oxygen per lb. of coal, fed into the "dust gasifiers" are suitable.

The rate of steam flow into the "dust gasifiers" preferably ranges from 0.7 lb. to 1.1 lbs. of coal fed into the "dust gasifier."

For the production of carbon monoxide and hydrogen-containing synthesis gas, essentially pure oxygen is used. For ammonia synthesis gas, containing nitrogen, suitable mixtures of oxygen with air can be chosen.

The water content of the finely-divided coal should be below 5%.

Coal is ground, so that it can be fed in a suspension with oxygen. Particles below ⅛ in. are suitable. More finely ground coal, for example 50 to 70% passing through a 200 mesh sieve is preferred. It permits use of residence times in the "dust gasifiers" near the lower limit given above.

The residence or contact time of reaction gases in the secondary gasifier can be decreased with increase of average temperatures, the amount of carbon present and

the water and carbon dioxide content of the gases passing through this gasifier. Usually a retention time of gases in the secondary gasifier, depending on the total volume of the secondary gasifier may be from 0.2 to 3 seconds especially 0.4 to 1 second. The amount of carbon present in the secondary gasifier for 1 lb. of coal per second fed into the "dust gasifiers" should be above 50 lbs., preferably 200 to 1,500 lbs. or more.

The rate of flow of solid fuel into the secondary gasifier is preferably from 0.25 lb. to 0.5 lb. per pound of coal fed into the "dust gasifiers."

The steam utilized in the present invention should be superheated to a temperature ranging from 800° F. to 2,000° F., preferably 1,000° F. to 1,600° F.

Although the specific embodiment of the present invention described above discloses a particular preferred type of "dust gasifier," it is pointed out that the present invention includes within its purview the use of any type of "dust gasifier," utilizing carbon dioxide or steam and a free oxygen-containing gas or utilizing only a free oxygen-containing gas, or utilizing only steam or CO_2, as a gasification media, such as a fluidized bed gasifier, a vortex type gasifier, etc., as well as any other type of gasifier, wherein the exit gases are at high temperatures and/or substantial amounts of carbon-containing dust are present in the off-gases.

Instead of utilizing steam or carbon dioxide, any other chemically combined oxygen-containing fluid capable of reacting endothermically with carbon may be utilized.

Furthermore, instead of pure oxygen, oxygen-enriched air may be utilized.

Any type of pulverized carbonaceous fuel may be fed into the "dust gasifiers," such as lignite, high grade coals, low grade coals, high molecular weight hydrocarbon oils, heavy petroleum oils, pitch, tar, etc. Furthermore, hydrocarbon gases may be utilized as a fuel feed into the "dust gasifiers," although the present invention is not so suitably adapted to processes wherein such gases are utilized.

Any number of "dust gasifiers" can be connected with the secondary gasifier, although it is preferred to have more than one.

If desired, steam and/or oxygen may be flowed directly into the fixed bed of solid fuel to increase gasification and temperatures in such beds.

Although an attempt has been made to described the theory involved in the present invention, it is not limited to such theory.

It will be obvious to those skilled in the art that various modifications can be made in the several parts of the present apparatus and the several steps of the present process in addition to those enumerated hereinabove, without departing from the spirit of the present invention, and it is intended to cover in the claims such modifications as are included in the scope thereof.

I claim:

1. A process for producing synthesis gases, comprising, gasifying, in a dust gasifier, a finely-divided solid carbonaceous fuel with a chemically combined oxygen-containing fluid of the group consisting of the steam and CO_2 capable of reacting endothermically with said finely-divided fuel and a free oxygen-containing gas of the group consisting of oxygen and oxygen enriched air, in proportions to produce a hot mixture of synthesis gases, unreacted carbonaceous fuel dust and fluid, filtering said hot mixture through a fixed bed of moving solid carbonaceous fuel while flowing cocurrently with the flow of said moving carbonaceous fuel in said fixed bed, the rate of flow of said moving fuel being controlled, so that only a portion, but not all, of the total carbon contained therein and in said unreacted fuel dust, is consumed to produce synthesis gases during said cocurrent flow of said moving fuel and said mixture, and separating said gases from the ungasified residue.

2. A process as claimed in claim 1 and in which the fuel in said bed is coal, and in which the rate of flow of said moving coal in the bed is controlled, so that the volatile matter contained in the coal is utilized and consumed to produce useful gases during said cocurrent flow, sufficient carbon remaining in the coke resulting from the coal to permit its use commercially as a source of heat energy and separating said coke from the useful gases admixed therewith.

3. The process of claim 1, wherein said gasification step in said gasifier comprises burning a jet of said finely divided fuel suspended in said gas in a primary combustion zone, which is peripherally surrounded by a continuously, cocurrently flowing envelope of said fluid, said burning being controlled so that the constituents in said combustion zone are rapidly heated to temperatures favoring reaction of said fuel to form carbon monoxide, and so that only part of said fuel is consumed by said burning, the remainder of said fuel being rapidly heated in said combustion zone to temperatures favoring reaction of the same to produce carbon monoxide, commingling the products resulting from said burning and flowing from said combustion zone, including said heated remainder of said fuel, with the fluid flowing from said envelope in a secondary endothermic reaction zone to endothermically react said heated remainder of said fuel with said fluid.

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