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Fernandes

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[54] **METHOD OF GASIFYING CARBONACEOUS MATERIAL**

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[52] **U.S. Cl.** .... **48/197 R;** 48/99; 48/71; 48/200; 48/202; 48/206; 48/211

[51] **Int. Cl.**[2] **C10J 3/08**

[58] **Field of Search** .... 48/63, 206, 203, 123, 71, 48/72, 73, 74, 64, 98, 99, 105, 107, 94, 95, 113, 202, 204, 207, 197 R, 200, 201, 210, 208, 209, 211

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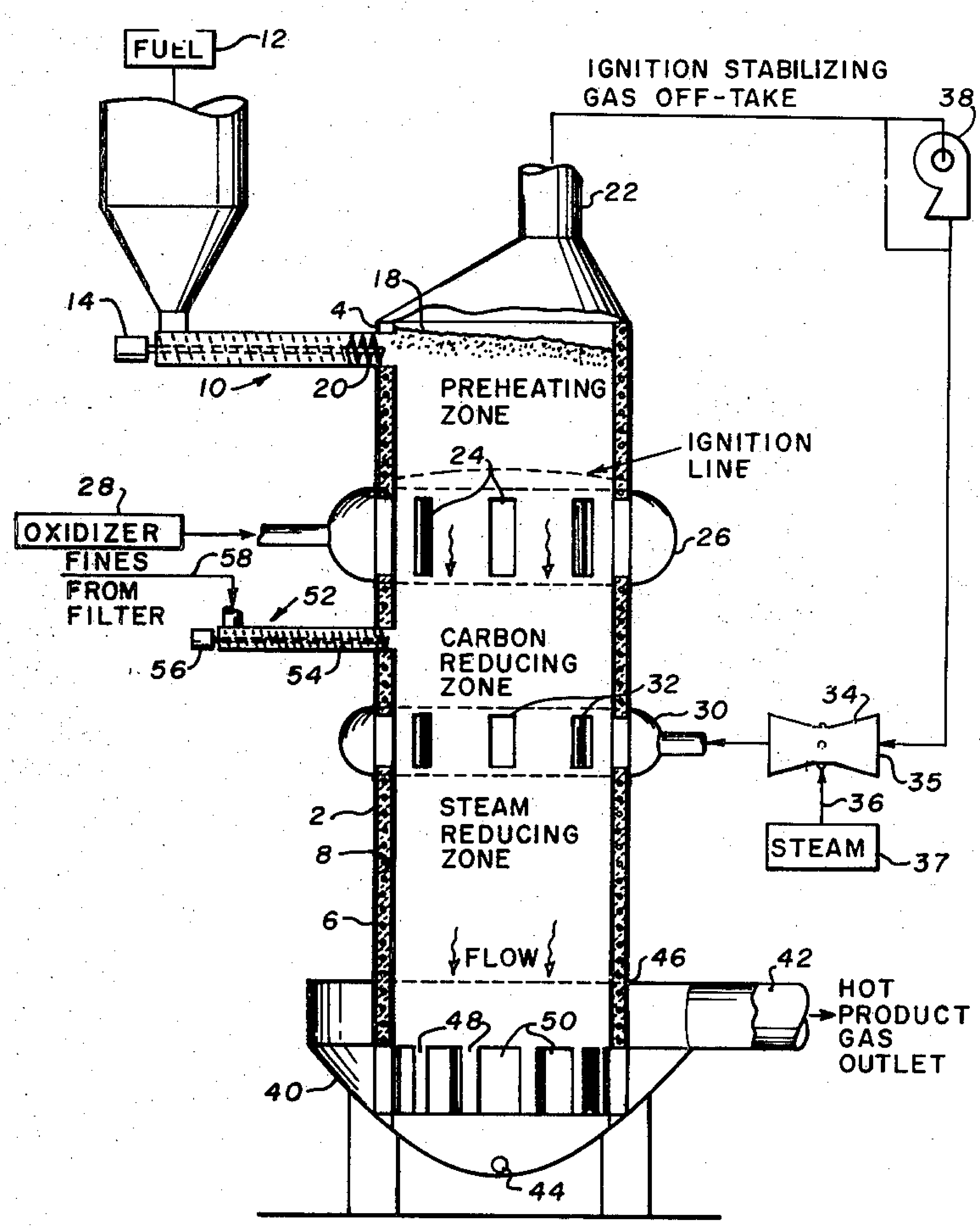
[57] **ABSTRACT**

A method and apparatus is disclosed for generating a clean, low Btu fuel gas by the reaction of a carbonaceous fuel limestone mixture with oxygen and steam in a downdraft fixed bed gasifier. The product gas and slag are discharged from the lower end of the gasifier after having passed through an incandescent char matrix in which contaminants such as sulfur are scrubbed from the gas. A portion of the hot product gas is withdrawn from the upper end of the gasifier to dry, preheat, and devolatilize freshly introduced fuel material. This gas which contains a heavy oily emulsion of tars and sulfur compounds is then reintroduced into the gasifier. The gasifier is capable of gasifying essentially any hydrocarbon material such as, refuse, lignite, anthracite, bituminous coal, coke, oil, liquid waste and many others, including manure and other farm waste.

8 Claims, 4 Drawing Figures



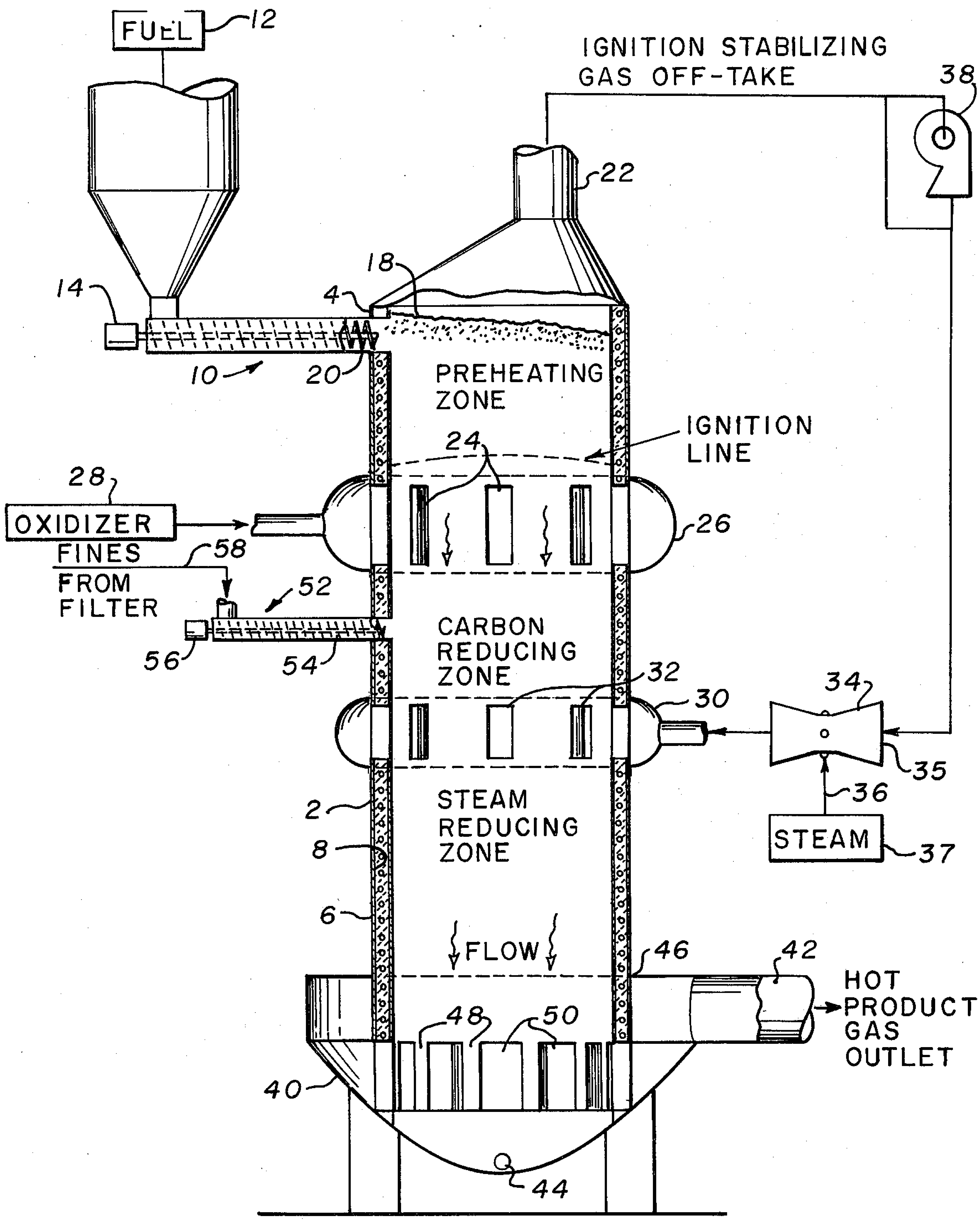

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FIG. 1

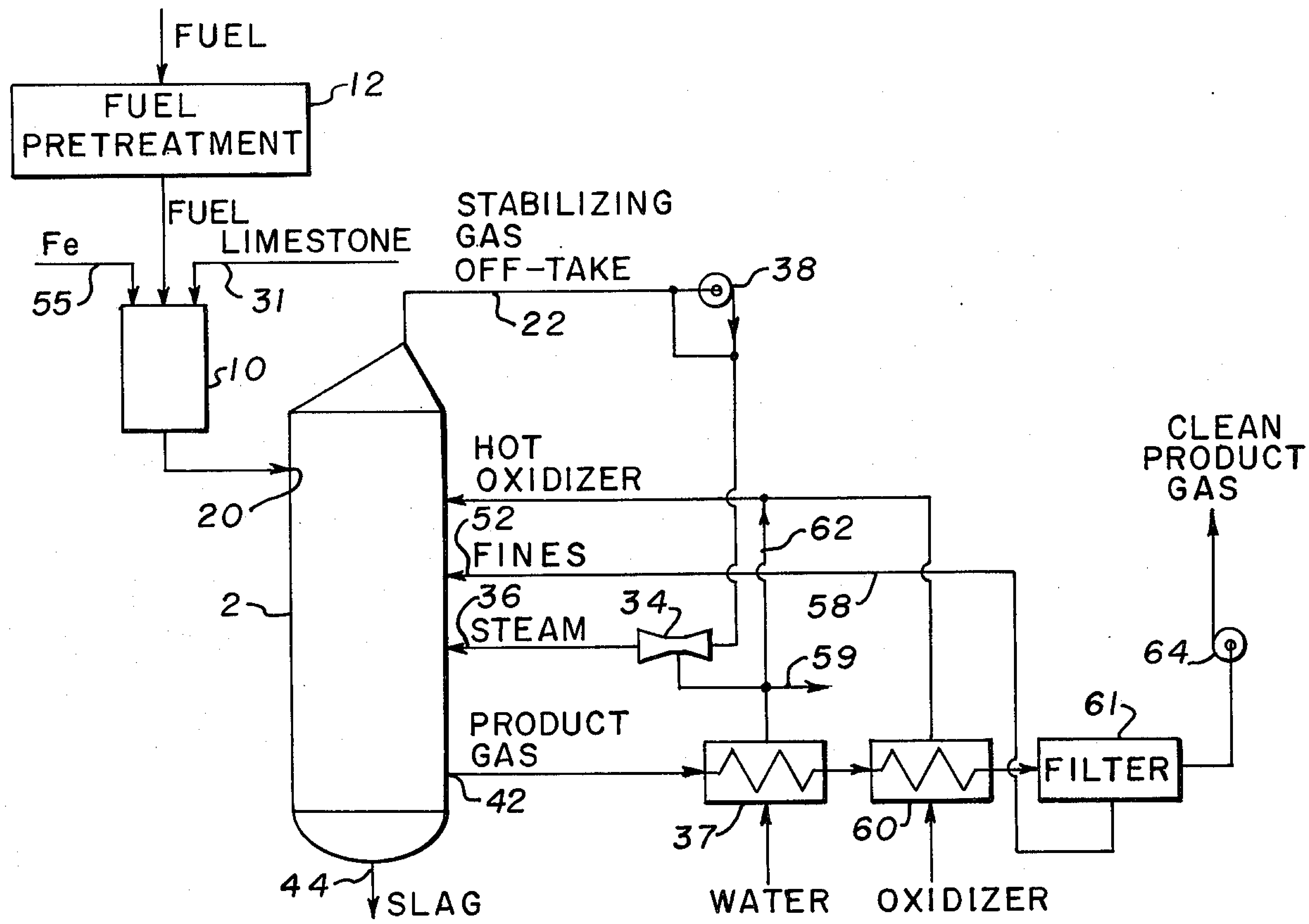

FIG. 2

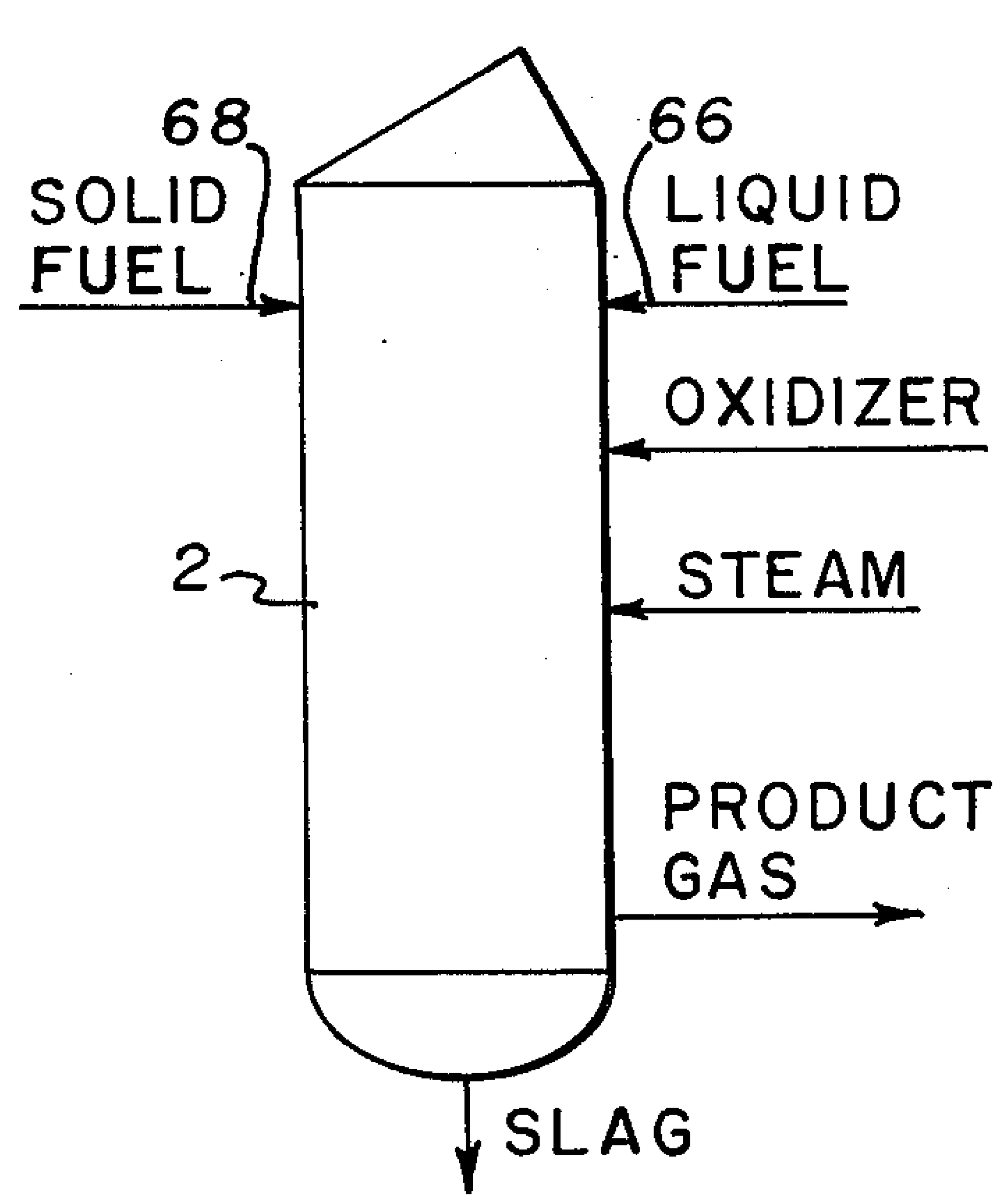

FIG. 3

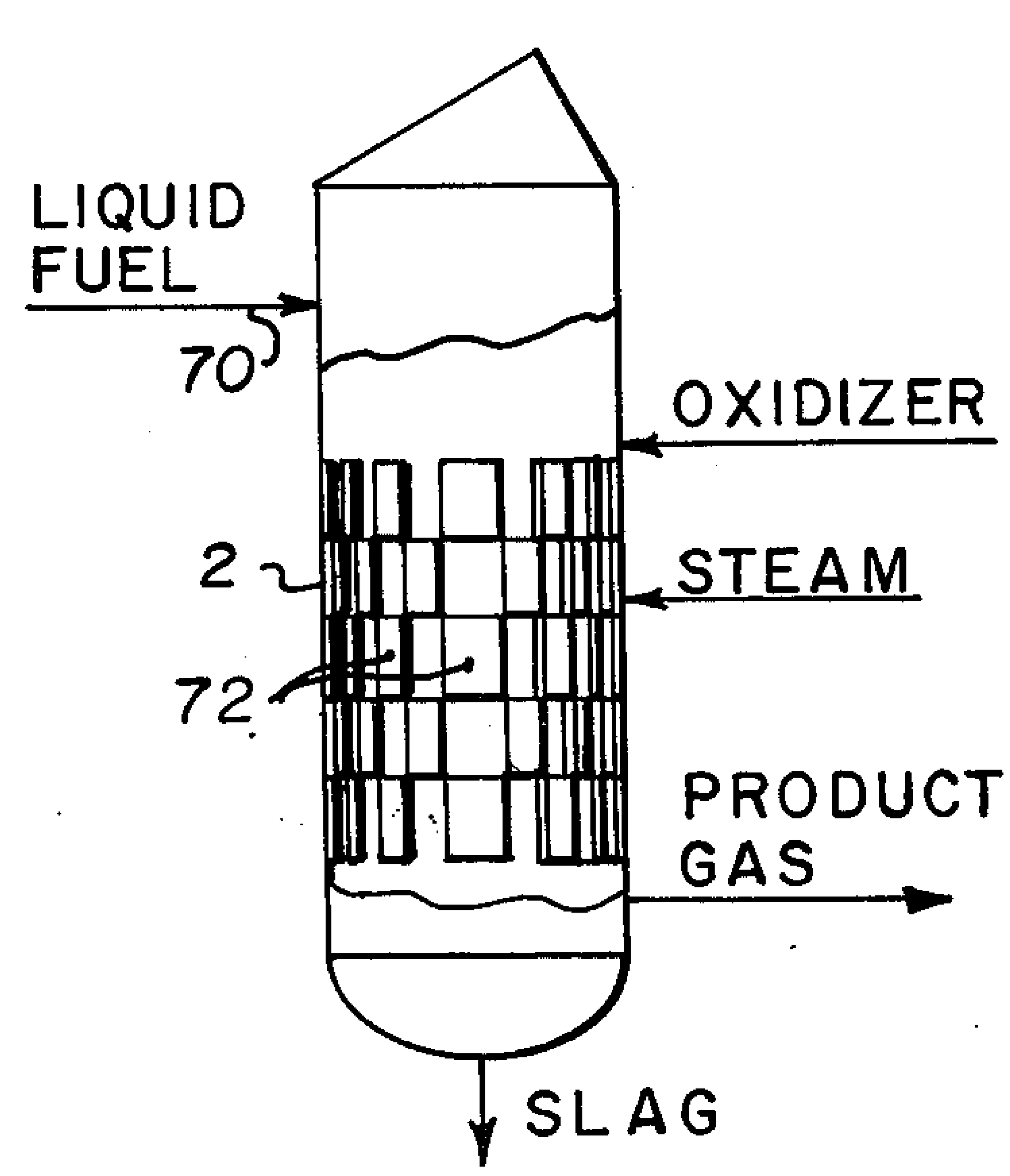

FIG. 4

METHOD OF GASIFYING CARBONACEOUS MATERIAL

BACKGROUND OF THE INVENTION

Description of the Prior Art

Current governmental air pollution standards limiting the level of emissions from the stacks of fossil fuel-fired power generation equipment have created an urgent need for clean burning fuels. An obvious solution to this problem is to burn fuels which are low in particulate matter and sulfur content. Such fuels, however, are in very short supply and also are very expensive.

One solution to the problem, particularly in the United States where the basic proven energy reserves are predominantly coal, is the gasification of coal to produce a low Btu fuel gas suitable for firing in a steam generator and similar devices. Generally speaking coal gasification involves the reaction of coal, at high temperatures, with a gas containing oxygen, and steam to produce a gas containing CO and H_2, which, as indicated, is suitable for use as a fuel. Processes for achieving coal gasification can be conveniently divided into three categories:

A. Fixed bed gasification where lump coal is supported on a grate or by other means and the flow of gas and coal may be countercurrent or concurrent.

B. Fluidized bed gasification where crushed or fine coal is fluidized by the gasifying medium, giving an expanded fuel bed that can be visualized as boiling liquid.

C. Suspension or entrainment gasification where fine coal is suspended in the gasifying medium. The particles moving with the gas either linearly or in a vortex pattern.

Fixed bed gasifiers are felt by many to be the most attractive from the standpoint of economics. Among the economically desirable features of fixed bed gasifiers are the following:

1. Their inherent high carbon conversion ratio.
2. The fact that a low producer volume is required per unit of gas production.
3. The minimum of fuel preparation required.

Most common of the fixed bed type gasifiers is the counter-current or updraft type where the coal moves downwardly within the gasifier and all of the gas produced passes upward and exits from the upper end. An undesirable feature of such an arrangement is that the product gas, as a result of passing over the freshly introduced coal, volatilizes the tars, sulfur compounds, and other contaminants within the coal and thus passes from the gasifier containing a heavy oily emulsion of tars, sulfur compounds, etc. Such gas obviously must be subsequently processed to remove these contaminants before it can be successfully fired in a power generating unit.

The present invention makes use of technology which has been developed in connection with vertical shaft furnaces. Such furnaces were initially developed for use in continuously producing cast iron from iron ore or scrap metals. A typical shaft furnace is shown and described in U.S. Pat. No. 3,186,830, entitled, "Melting Process" of W. H. Moore and H. H. Kessler.

In prior art gasification systems the means for removal of contaminating sulfur compounds from the product gas has primarily included processing the gas after it has exited from the gasifier and been considerably cooled. Typical of such desulfurization systems are those utilizing solvent extraction or dry extraction techniques. Regardless of the specific process used such systems require expensive equipment which in turn increases the cost per unit Btu content of the product gas, and accordingly makes the system competitvely less attractive.

Other prior art systems have suggested the introduction of limestone into the gasifier chamber along with the carbonaceous fuel, steam and oxidizer, in order to react the sulfur compounds found in the fuel with the calcium in the limestone to form calcium sulfur compounds. The calcium sulfur compounds are then passed from the gasifier in a molten state along with the slag passing from the bottom of the gasifier. The use of limestone to accomplish this is suggested in the disclosure of U.S. Pat. No. 2,830,883 to D. Eastman. Such an arrangement has not been used in conjunction with counter-current fixed bed gasifiers because of the aforementioned disadvantage in that the product gas would pick up contaminant just prior to exiting from the gasifier and thus insufficient temperature or time would be available for the contaminant to react with the limestone.

SUMMARY OF THE INVENTION

The present invention is directed to a method of producing a clean low Btu fuel gas by the reaction of a carbonaceous fuel with free oxygen and steam in a downdraft fixed bed gasifier. The material to be gasified is introduced at the upper end of the gasifier where it is preheated, dried and devolatilized by a stream of hot gas from the lower zones of the gasifier which has been drawn upward and is withdrawn from the gasifier at the upper end thereof. This upward flow of gas also serves to maintain the ignition level of the carbonaceous fuel material at a predetermined level within the oxidation zone of the gasifier. The portion of gas withdrawn from the upper end of the gasifier, which contains the volatiles released by the carbonaceous material, is re-introduced into the gasifier in the oxidation zone where the temperature is sufficiently high to effect thermal cracking of the volatile to valuable hydrocarbon compounds.

As the carbonaceous fuel material moves downward through the gasifier shaft it passes successively through oxidation and reduction zones where air or some other free oxygen containing gas, and steam, respectively are introduced into the gasifier. The resulting reactions convert the carbonaceous fuel material and other reactants to an incandescent char matrix extending to the bottom of the gasifier shaft, gaseous products (the makeup thereof depending upon the level of the gasifier) and a molten slag.

In a preferred embodiment limestone is introduced along with the carbonaceous fuel material and is converted to a molten state along with the slag. As the molten slag/limestone mixture and the product gas move downward through the incandescent char matrix the calcium in the limestone reacts with any sulfur contained in the gas to form sulfur compounds which are subsequently removed along with the molten slag from the bottom of the gasifier. The product gas, which also passes from the lower end of the gasifier, is comprised principally of hydrogen and carbon monoxide substantially free of any contaminating sulfur, NO_x and particulate matter, all of these contaminating substances having been removed either chemically or through scrubbing action as the product gas progressed down through the incandescent char matrix in the lower end of the gasifier.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially schematic, vertical cross sectional view of carbonaceous material gasifying apparatus according to the invention.

FIG. 2 is a schematic flow diagram illustrating the principles of operation of the process of the invention.

FIG. 3 is a simplified, vertical cross sectional view of another embodiment of the gasifier.

FIG. 4 is a view similar to FIG. 3 of still a further embodiment of the gasifier.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1 the gasifier comprises a vertical shaft 2 having upper and lower end portions 4 and 6 respectively and a water-cooled refractory lined inner wall 8. Communicating with the upper end 4 of the gasifier is a solid fuel introduction unit 10. This unit is adapted to receive properly sized suitably prepared solid fuel from a fuel source 12 and to feed same at a desired rate to the interior of the gasifier shaft. As shown schematically in the drawing, the fuel feeding unit 10 comprises a screw type feeding system driven by a suitable power source such as electric motor 14. In operation pressure in the upper end of the gasifier shaft is controlled to atmospheric pressure and thus a reasonably sealed fuel feeding unit is sufficient to preclude gas leaks from the gasifier through the fuel feeding unit. Solid fuel is fed into the gasifier through fuel inlet opening 20 at a rate sufficient to establish a bed of fuel extending from the bottom of the gasifier to a level 18 which lies above the fuel inlet opening 20.

Also communicating with the upper end 4 of the gasifier shaft 2 at a point above the bed level 18 is an offtake duct 22 for withdrawing from the gasifier a portion of the gases produced therein. This off flow of gases serves to preheat the newly introduced fuel and to stabilize the ignition line within the gasifier. These features of the gasifier will be more fully described below in connection with the operation of the gasifier.

A first series of tuyeres 24 for introducing into the gasifier a gas containing free oxygen is located at a position underlying the fuel inlet opening 20. As shown there is provided a plurality of such tuyeres 24 equally spaced about the outer periphery of the shaft 2. The tuyeres 24 are supplied with the free oxygen containing gas by means of oxidizer windbox or manifold 26 which extends circumferentialy around the shaft and is connected to a suitable supply 28 of such gas. This oxident gas is preferably preheated prior to introduction into the gasifier for reasons which, again, will be more fully set forth in the description of the operation of the gasifier.

Underlying the oxidizer windbox 26 is a second similar manifold arrangment 30 for introducing superheated steam into the gasifier through a second series of tuyeres 32. As shown in the drawings the portion of gas withdrawn from the upper end of the gasifier shaft through duct 22 is reintroduced into the gasifier along with the superheated steam through this second series of tuyeres 32. Preferably, a steam aspirator 34 positioned in the steam supply line 36 will act to draw the desired quantity of fuel gas from the upper gas off take duct 22. However, under certain operating conditions such as at startup it may be necessary to supplement the action of the aspirator 34 by use of a circulating fan 38 which is arranged in parallel with the gas off take duct 22. The aspirator is of conventional design and includes a suction port 35 to which the gas off take duct 22 is connected.

The lower end 6 of the gasifier shaft 2 extends downwardly into and is supported by a gas collector chamber 40 which includes a product gas outlet 42 at the side thereof and a slag tap 44 in its lower end. The attachment point 46 of the shaft 2 to the collector chamber 40 is such as to provide structural support for the shaft and to provide a gas tight seal therebetween. As is evident from the drawing the lower end of the shaft penetrates only partially into the gas collector 40; the space from the end of the shaft to the walls of the collector is partially occupied by a tier of refractory brick 50 or the like which are spaced so as to provide a plurality of openings 48 through which gas, generated in the shaft, may pass to enter the outer region of the collector chamber and from there exit from the gasifier. These bricks 50 also serve to provide lateral support to the extreme lower end of the bed of carbonaceous material which is maintained in the gasifier.

Referring still to FIG. 1, a fines injector 52 is located about midway between the series of tuyeres for introducing gas 24 and the second set of tuyeres 32 for introducing steam. This injector comprises a screw feed mechanism 54, a suitable drive unit 56, and is supplied with fines through conduit 58 which have been removed from the product gas by a filter 61. This arrangement is shown schematically in FIG. 2.

For the purpose of clarifying the description and thus the understanding of the operation of the gasifier of the present invention, the interior of the gasifier shaft will be separated into four generally distinct regions: The preheating zone adjacent to the upper end of the shaft; the oxidation zone underlying the preheating zone and adjacent the first set of tuyeres; the carbon reducing zone which lies between the two sets of tuyeres; and the steam reducing zone which extends from the second set of tuyeres downward to the bottom of the gasifier.

In operation, material to be gasified is introduced into the gasifier shaft 2 by means of the fuel feeding unit 10 to establish the fuel bed at a level 18 within the gasifier. The bed of fuel rests directly on the bottom of the gas collector 40. Once the gasifier is in operation the lower end of the fuel bed becomes essentially an incandescent char matrix through which the gas and liquid slag may pass. The material to be gasified may be essentially a hydrocarbon fuel of any type, such as, for example, refuse, lignite, anthracite, bituminous coal, coke, oil, liquid waste and many others, including manure and other farm waste. Many of the aforementioned fuels would of course require preparation prior to introduction into the gasifier. Generally, the fuel material should not contain a great deal of material below ⅛ inch in size and also it should not contain too many large lumps that would interfere with the speed of the gasification reactions. An upper size limit of around 6 inches with a preferred size of between ½ inch and 2 inches is considered to produce the best balance of conditions for speed of reactions and for establishing the char matrix within the gasifier shaft. A further important requirement is that the fuel be of such compressive strength as to support the carbon matrix. Also, the moisture content of the material feed should not exceed 10 to 12%. Moisture in excess of this range would interfere with temperature control within the gasifier. Such control being achieved by the introduction of steam as will be subsequently further expanded upon. Accordingly, some shredding, briquetting and drying of the fuel material may be required prior to introduction into the gasifier. In the case of liquid carbonceous materials it is necessary to simultaneously introduce sufficient solid material to establish the required char matrix, or alternatively, an artificial matrix of refractory brick or the like may be established within the gasifier shaft. Such arrangements are shown schematically in FIGS. **3** and **4**.

In the preferred embodiment a quantity of limestone (the term limestone as used herein is meant to include any CaO yielding material) is introduced along with the material to be gasified as shown at **31**. The limestone acts to increase the fluidity of the slag formed in the lower end of the reactor and also reacts with any sulfur contained in the fuel to form calcium-sulfur compounds which are then removed along with the molten slag.

Upon entry into the preheating zone of the gasifier the fuel and limestone mixture is dried, preheated and devolatilized by passing a portion of the hot gas formed in the lower zones of the gasifier upwardly through the newly introduced material. This upward flow of gas is withdrawn from the gasifier through the gas offtake duct **22** and preferably is recirculated back into the steam reducing zone of the gasifier in admixture with the superheated steam. The proportion of gas withdrawn from the gasifier at this point may vary from around 5 percent to up to 50 percent. Fifty percent of the gas might be withdrawn under startup conditions when the char matrix is still being established within the gasifier. Under normal conditions the amount of gas withdrawn through the offtake is around 15 to 25 percent. As previously indicated, the preferred arrangement for accomplishing this is to provide the suction required to remove this gas by means of a steam aspirator **34**. This arrangement is preferred for the reason that the gases withdrawn from the upper end of the gasifier contain tars and other contaminants such as sulphur compounds which form a heavy oily emulsion which would tend to clog or impede the operation of a fan. However, under some operating conditions such as at startup, the fan **38** is necessary to supplement the steam aspirator and thus is provided in a parallel arrangement in the gas offtake duct **22**.

The level of the fuel bed is maintained at a height **18** above the level of the oxidizing tuyeres **24** so that the upflow of hot gases is able to preheat the fuel to its ignition temperature. As a result, as the fuel moves downward and is exposed to the hot oxidizing gases which are injected through the first set of tuyeres **24**, ignition occurs immediately and the carbon and volatile matter of the fuel is oxidized to form water vapor and carbon dioxide. Also formed in this zone, by reaction of sulfur and nitrogen, with oxygen are sulfur oxide gases and minor amounts of nitrogen oxides, respectively.

The level at which ignition occurs, identified as the ignition line in FIG. **1**, is preferably maintained at a level above the oxidizing tuyeres **24**. The ignition level is stabilized at the desired point by control of the degree of preheating and drying of the fuel which in turn is achieved by the quantity of offtake flow from the upper end of the shaft through the duct **22**. Control of this flow is achieved by appropriate operations of the aspirator **34** or the fan **38**.

The oxidizer gas introduced through tuyeres **24** may be air, oxygen enriched air or pure oxygen. The use of oxygen in place of air or oxygen enriched air as the oxident will be predicated on the economics of the installation and the use being made of the product gas. Due to the absence of other gases when pure oxygen is used as the oxident, a higher Btu product gas will be produced under these circumstances. However, if oxygen or oxygen enriched air is used, it becomes necessary to add steam in the oxidation zone to dilute the reaction and prevent a violent reaction and local overheating of the system. Preferably the upper temperature limit in this zone is controlled to around 3,200°F. Such an arrangement is not difficult to accomplish if the economics of the system dictate the use of oxygen. Referring to FIG. **2** a quantity of steam from the steam supply **37** to the steam reducing zone may be diverted as needed through conduit **62** to the oxidation zone. Regulation of the quantity of the flow is dependent upon the temperature in the oxidation zone.

Passing from the oxidation zone the fuel, now converted to an incandescent char matrix, reacts with the gases (CO_2, H_2O, SO and NO_x) formed in the oxidation zone, reducing them to essentially carbon monoxide, hydrogen and some hydrocarbon gases. Also passing from the oxidation zone is a slag formed by the molten limestone and ash of the fuel material. This slag drips over the incandescent char matrix in the reducing zone removing the nitrogen oxides which may have formed in the oxidation zone and the sulfur oxide compounds. As pointed out above, the size of the fuel material used is important to ensure the formation of a porous char matrix bed in the gasifier shaft which will allow a free flow of gases so that the various reactions described can completely take place.

Passing downwardly from the carbon reducing zone the solid fuel and gases are reacted with steam introduced through the steam tuyeres **32**. In this zone any carbon dioxide remaining is reduced to carbon monoxide and the steam reacts with carbon to form hydrogen, carbon monoxide and small quantities of hydrocarbon gases. The temperature in this zone is reduced and controlled by control of the addition of steam to provide a gas exit temperature of around 2,100°F. This temperature may be higher or lower depending upon what is required to ensure that the slag remains molten in the lower part of the collector chamber **40** until it is removed through the slag tap **44**. This temperature of course will vary depending upon the type of fuel being gasified. The gasification reaction generally will continue down to about 1,650°F.

Referring to FIG. **1**, the product gas which contains principally hydrogen carbon monoxide, some hydrocarbon compounds, gas compounds such as methane and a few of the illuminants passes downwardly through the steam reducing zone, through the openings **48** in the brick tier **50** into the collector **40** and passes from the gasifier through gas outlet **42**. Referring now to FIG. **2**, the product gas which as indicated is at a temperature of around 2,000°F is first passed through a waste heat boiler **37** (steam supply of FIG. **1**) where the process steam utilized in the gasifier is formed. Any excess steam generated in this boiler **58** is passed via steam line **59** to a point external to the gasifier system, where it may be used. From the waste heat boiler **37** the gas passes to a second heat exchanger **60** where the oxidizer gas is preheated. From this heater and depending upon the use to which it is to be put, the gas may be cleaned by a gas filter as at **61**. The flow of gas in the circuit from the gas outlet **42** is maintained by an induced draft fan **64** which supplies the product gas to the receiving system. The fines removed from the product gas in the filter **61** may be recirculated to the gasifier through recirculating line **58** to the fines injector **52** where they are introduced into the gasifier in the carbon reducing zone by means of the feeder mechanism **54.**

With some fuels it may be desirable to add a quantity of iron or feldspar to the fuel mixture in order to lower the slag fusion temperature and keep the slag viscosity down. Iron also helps to absorb sulfur and acts as a catalyst in the gasification reactions. This material would be introduced into the fuel feed mechanism **10** along with the fuel and limestone, as shown at **55.**

Referring to FIGS. **3** and **4** two additional embodiments of the gasifier are shown. In FIG. **3** the gasifier is shown having both liquid **66** and solid **68** fuel introduction units. With such an arrangement the quantity of solid fuel introduced need only be sufficient to establish and maintain the required char matrix, the balance of the fuel could be a liquid such as a high sulfur fuel oil.

The FIG. **4** arrangement is adapted to burn all liquid fuel introduced through the fuel introduction means **70.** The porous char matrix is created upon an arrangement of refractory brick **72** within the gasifier. The liquid hydrocarbon carbonizes on the refractory brick to form the hot carbonaceous char. The operation and reactions which occur in these additional embodiments is substantially the same as with the solid fuel version described in detail above.

It should be noted that while the vertical gasifier has been described herein as being circular in cross section it should be understood that it is not meant to limit it to such a configuration. As a matter of fact it may be that for large scale gasification a shaft of rectangular cross section is preferred. It has been shown that a circular gasifier having an inside diameter of much more than 10 feet may experience problems with gas penetration. However if the short dimension of a rectangular vessel is kept well under ten feet, so that there is no gas penetration problem, the rectangular unit can be made as long as desired.

While these preferred embodiments of the invention have been shown and described, it will be understood that they are merely illustrative and that changes may be made without departing from the scope of the invention as claimed.

What is claimed is:

1. A method for producing a fuel gas from a carbonaceous material which comprises:

a. providing a substantially vertical shaft furnace having a preheating zone adjacent the upper end of the furnace, an oxidation zone underlying said preheating zone, and a reducing zone underlying said oxidation zone and adjacent the lower end of the furnace;

b. introducing a solid carbonaceous material having sufficient compressive strength to support a carbon matrix into said preheating zone;

c. oxidizing said carbonaceous material in said oxidation zone by reacting said carbonaceous material with free oxygen to form an intermediate gaseous product, a char matrix containing carbon, and molten slag;

d. reacting said intermediate gaseous products with steam and with carbon from said char matrix in said reducing zone to form a product gas comprising principally hydrogen and carbon monoxide;

e. flowing said molten slag downward through said char matrix;

f. removing said slag through the bottom of said furnace shaft;

g. maintaining an upward flow of a portion of the gases formed in said oxidation and reducing zones sufficient to maintain the level of ignition of said carbonaceous material in said oxidation zone at a predetermined level, said upward flow of gas passing through said preheating zone and contacting said carbonaceous material, whereby said material is dried, devolatilized and heated to a temperature just under its ignition temperature, the volatile matter driven from the carbonaceous material being carried from said furnace along with said portion of said gases and re-introducing said portion of the gases and volatile matter into said furnace in said reducing zone;

h. exhausting the balance of said product gas from the lower end of said furnace.

2. The method of claim **1** wherein said portion of the gases is introduced into said furnace along with said steam.

3. The method of claim **1** including introducing limestone into said preheating zone along with said carbonaceous material, melting said limestone and flowing said limestone downward along with said slag through said char matrix in said oxidation and reducing zones, reacting any sulfur contained in said product gas with the limestone in said slag to form molten calcium-sulfur compounds, said calcium-sulfur compounds passing from said furnace in admixture with said slag, the intimate contact between the limestone/slag mixture and said downward flowing gases as they pass concurrently through said char matrix assuring removal of substantially all sulfur contaminants from said product gas prior to exhausting the gas from the gasifier.

4. The method of claim **1** wherein the upward flow of the portion of the gases comprises between about 5 to 50 percent of the total gas produced in the gasifier.

5. The method of claim **4** wherein the upward flow of a portion of the gases comprises between about 15 to 25 percent of the total gas produced in the gasifier.

6. The method of claim **1** including introducing a liquid carbonaceous fuel into said preheating zone in addition to said solid carbonaceous material.

7. The method of claim **1** including controlling the temperature within said oxidation zone by admixing steam with said oxygen.

8. The method of claim **3** including introducing small quantities of iron along with said carbonaceous material and limestone.

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