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Blaskowski

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[54] **METHOD AND APPARATUS FOR GASIFICATION OF PULVERIZED COAL**

[75] Inventor: **Henry John Blaskowski,** West Simsbury, Conn.

[73] Assignee: **Combustion Engineering Inc.,** Windsor, Conn.

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[52] **U.S. Cl.** .... **48/73,** 48/63, 48/197 R, 48/202

[51] **Int. Cl.** **G10j 3/20**

[58] **Field of Search** .... 48/73, 63, 77, 78, 197 R, 48/202, 206, 210, 62, 64, 67, 69, 76, 99, 101, 108, 111, 203, 208, 113; 23/277 C

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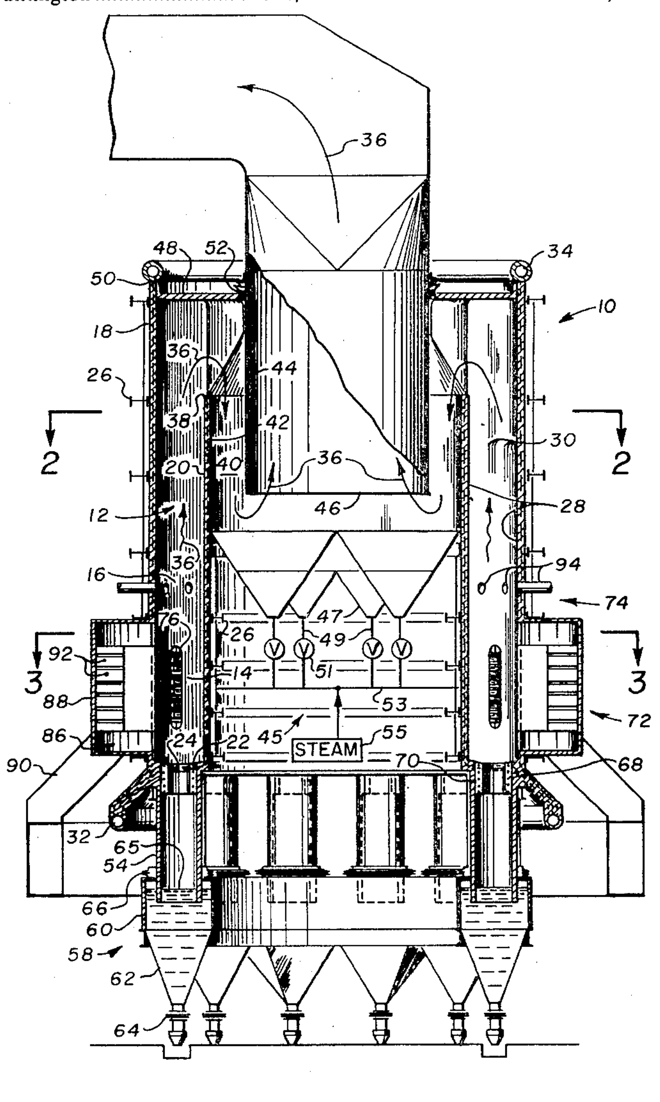
Primary Examiner—S. Leon Bashore
Assistant Examiner—Peter F. Kratz
Attorney, Agent, or Firm—Frederick A. Goettel, Jr.

[57] **ABSTRACT**

The gasification of coal is carried out in a gasifier having an annular reaction chamber. A two stage gasification process is used: the first stage involving the combustion of a first quantity of pulverized coal with stoichiometric air; and the second stage involving the reaction of a second quantity of coal, in suspension in steam, with the hot products of combustion from the first stage.

A cylindrical gas discharge duct is disposed coaxially within the inner cylindrical wall of the annular reaction chamber to define an annular gas passage therebetween. The gas and reactants from the reaction chamber thus flow upwardly through the reaction chamber, down through the gas passage and then up through the gas discharge duct in exiting from the gasifier. Waterwall construction is used to permit use of high reaction temperatures.

13 Claims, 5 Drawing Figures



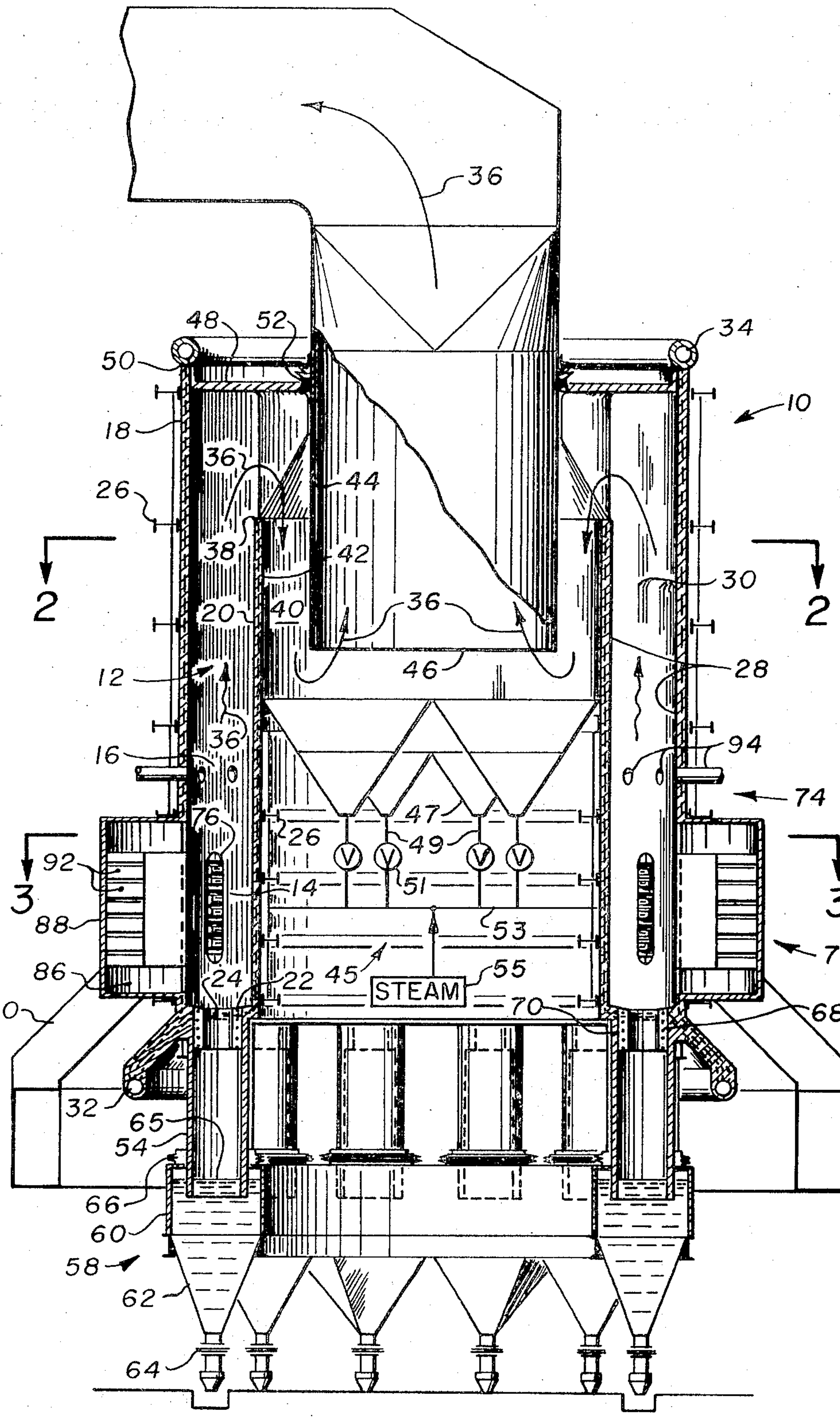

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FIG. 1

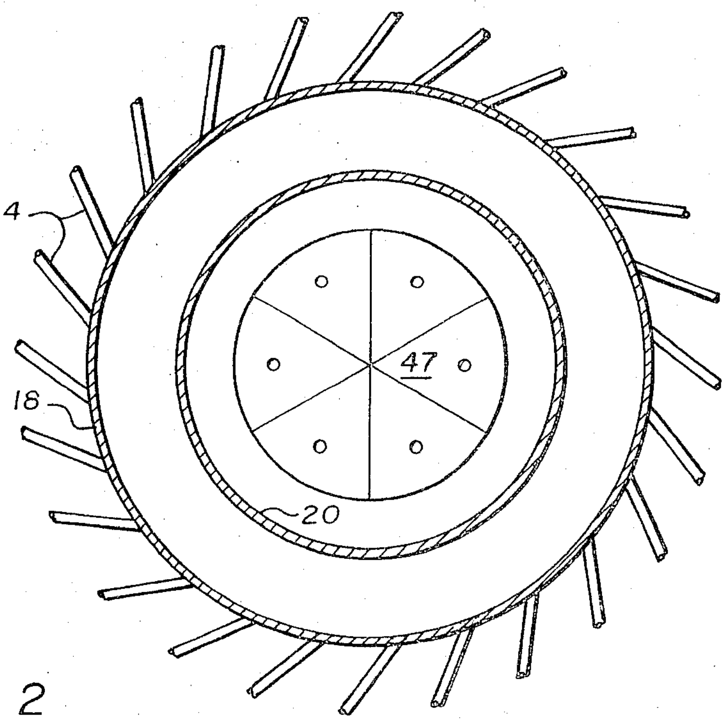

FIG. 2

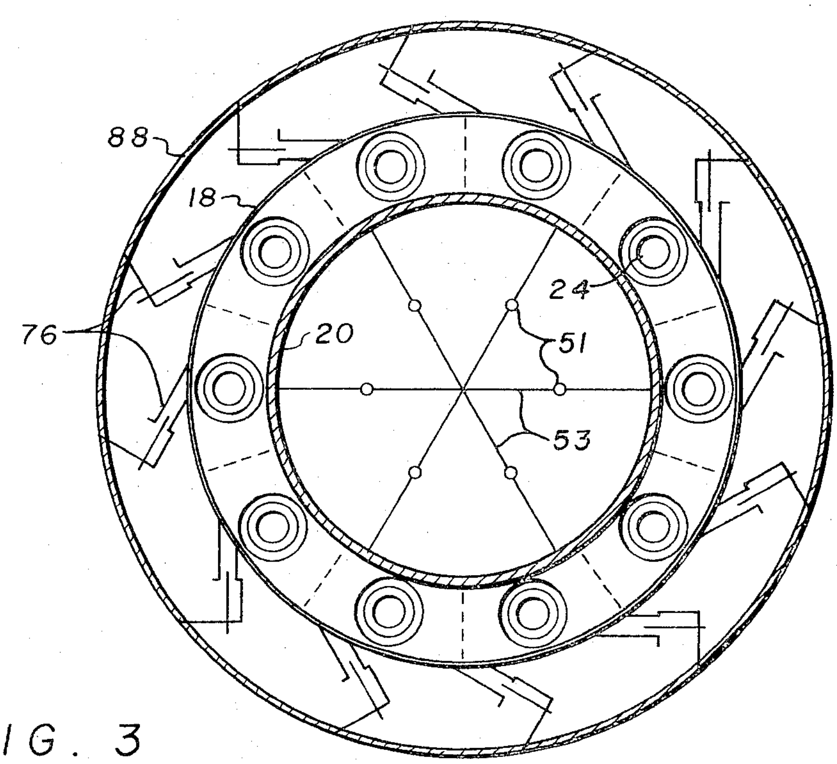

FIG. 3

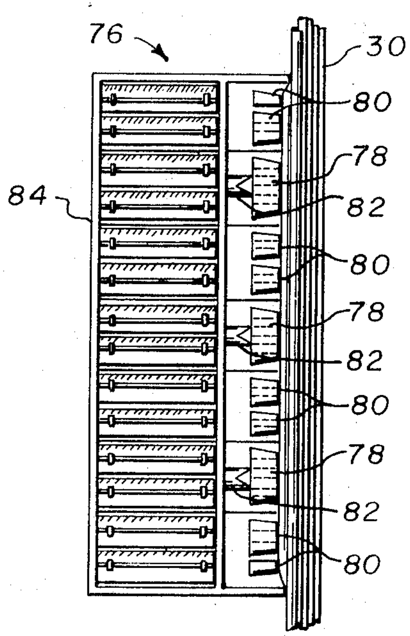
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FIG. 4

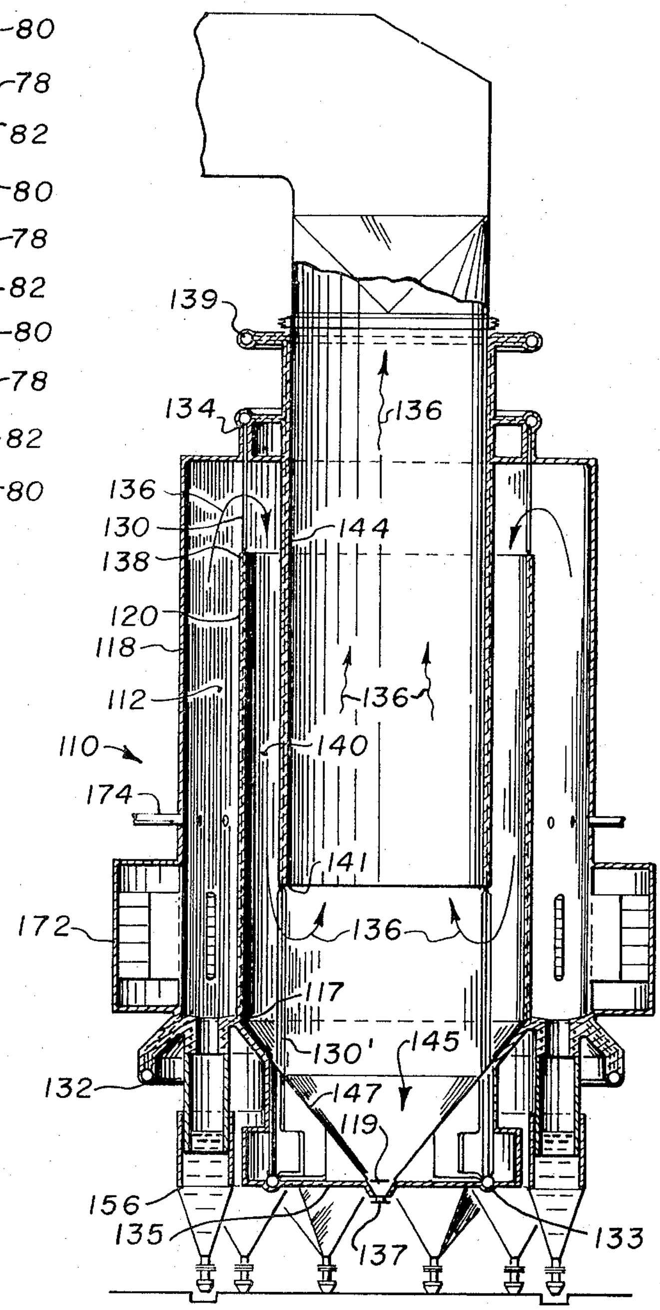
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FIG. 5

METHOD AND APPARATUS FOR GASIFICATION OF PULVERIZED COAL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method of and apparatus for reacting a solid carbonaceous fuel with oxygen and an endothermic gasifying agent such as steam in a manner to yield a gaseous product suitable for use as a source of energy.

2. 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. One solution to this problem is the gasification of coal by reacting it with oxygen and steam to produce a low heating value gas containing primarily hydrogen and carbon monoxide which may be desulfurized and then burned in a steam generator furnace.

Three basic processes have been developed for gasifying coal, they are: fixed bed gasification, fluidized bed gasification, and suspension or entrainment gasification. Fixed bed and fluidized bed systems cannot be operated with strongly caking coals without expensive pretreatment of the coal. On the other hand, entrained gasification systems may be used with any rank of coal, are capable of achieving high production rates per unit volume of reaction space, and may operate either non-slagging or slagging, all distinct advantages. One disadvantage of entrainment gasifiers is that they yield a relatively high temperature product gas, and, accordingly, in order to realize a high utilization of the Btu content of the coal, heat must be recovered from the product gas. Also in prior art systems the carbon conversion factor of entrainment gasifiers has been low in comparison with other gasification systems.

It has been recognized, however, that the carbon utilization factor and efficiency of an entrainment gasifier are particularly affected by the following factors: (1) the temperature at which the endothermic gasification reactions takes place, (2) the residence time of the reactants in the reaction zone, i.e., there must be sufficient time for each particle of coal to react before it is swept away with the produced gas, and (3) the degree of mixing or diffusion of reactants in the reaction zone. Accordingly, it has been the goal of current entrainment gasifier research to come up with designs which will achieve an optimum combination of these very important factors.

Another problem which has been encountered with entrainment gasifiers is the recycling of some of the hot product gases from the top of the gasifier back into the reaction zone where oxygen is present. This recycling, a comon problem in any open vessel combustor using buoyant ingredients, is particularly troublesome in a gasifier where the gases passing out the top, due to the endothermic nature of the gasification reaction, are considerably cooler than the lower gases. The result of this recycling is that some of the oxygen in the lower region of the gasifier is claimed by the recycling fuel gas. Since the proportions of the ingredients are carefully controlled the loss of this oxygen to the recycling gas results in an excess of unburned carbon and a high char content in the product gas or "make gas" as it is commonly referred to.

SUMMARY OF THE INVENTION

The present invention is directed to an entrainment type coal gasifier having a vertically extending annular reaction chamber. The coal to be gasified is introduced into the reaction chamber in two streams. In the first stream a mixture of coal and preheated air is injected, at near stoichiometric proportions, into the lower end of the reaction chamber where it is burned to produce a high temperature product of combustion gas. This stream of coal and air is directed into the annular chamber in a manner similar to the tangential firing systems used in many steam generators. This injection causes circular flow about the annulus and promotes complete, high temperature combustion. The high temperature in this region encourages slagging of the ash in the coal, which is removed through slag taps in the lower end of the reactor, and also provides a high temperature heat source for the endothermic gasification reaction which takes place above it in the reduction zone.

The second stream of reactants includes the balance of the coal to be gasified in suspension with steam. This stream, also injected substantially tangentially, impinges upon the rising, whirling hot gases from the combustion zone and reduces its temperature by a combination of the following reactions: (1) $C + H_2O \rightarrow H_2 + CO$; (2) $C + 2H_2 \rightarrow CH_4$; and (3) $CO_2 + C \rightarrow 2CO$. Additional small quantities of CH_4 are cracked from the volatile of the coal in the second stream immediately upon entering the high temperature zone. The first reaction, i.e. $C + H_2O$, is highly endothermic and causes the temperature to drop to a temperature level which is determined by the degree of mixing and the residence time in the gasifier. The gas produced contains mostly CO and H_2 with small quantities of CH_4.

A gas outlet duct or cylinder disposed coaxially within the inner cylinder of the annular reaction chamber forms, with the chamber inner cylinder, a second annular flow path through which the gas produced must pass in the downward direction before exiting from the gasifier at the upper end of the duct. This arrangement provides additional residence time within the gasifier while maintaining overall gasifier height within manageable limits.

The disclosed apparatus for, and method of, gasification results in optimum temperature, residence, and mixing conditions and as a result a very high efficiency is achieved. Furthermore, the use of an annular reaction chamber and tangential type firing virtually precludes the recycling of the product gas back into the reaction zone.

Other objects and advantages of the invention will become apparent upon reading the following detailed description of an illustrative embodiment and upon reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially schematic vertical cross sectional view of coal gasification apparatus embodying the invention.

FIG. 2 is a simplified sectional view taken on the line 2–2 of FIG. 1.

FIG. 3 is a simplified sectional view taken on the line 3–3 of FIG. 1.

FIG. 4 is an enlarged sectional view of a typical combustor nozzle system which would be used in practicing the invention.

FIG. 5 is a simplified view, similar to FIG. 1, of another gasifier embodying the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

General Arrangement of the Gasifier

Referring to FIG. 1 there is shown a coal gasifier **10** having an annular reaction chamber **12**. For purposes of clarifying the description and thus the understanding of the invention the reaction chamber **12** will be divided into two generally distinct regions; the combustion zone **14**, near the lower end thereof, and the reduction zone overlying the combustion zone and identified by the numeral **16**. The annular reaction chamber is defined by the gasifier cylindrical outer wall **18** and an inner wall **20**, which is also cylindrical and disposed coaxially with the outer wall. These walls cooperate to form at their lower ends an annular bottom portion **22** which contains openings **24** for slag disposal, as will be subsequently further described.

The gasifier **10** is supported by means of structural members (not shown) attached to buckstays **26** attached to the inner and outer walls of the gasifier. A typical arrangement would be to provide overhead support beams carried by columns extending from the ground level. The structural members attached to the buckstays **26** would extend downwardly from these support beams and effectively suspend the gasifier. Such support systems are common and well known in the gasification and steam generation fields.

Both the inner **20** and outer **18** walls of the gasifier **10** are water cooled and are lined on the sides facing the interior of the reaction chamber with a suitable high temperature refractory material **28**. The water cooling is accomplished by fabricating the walls from panels made up of a plurality of parallel vertically extending tubes through which water is continuously circulated, such tubes are represented typically at **30**. Similar panels are conventionally used in forming the water cooled walls of steam generating boilers. When installed, the lower ends of each of the water tubes **30** is flow coupled to an annular inlet header **32** located at the lower end of the gasifier and connected to a supply of cooling water (not shown). The upper ends of the water tubes are flow coupled to an outlet header **34** positioned atop the outer wall **18** and connected to a suitable disposal point. Ideally the heat recovered from the gasifier by the water circulating through the walls will be utilized to increase the efficiency of the system. Such uses may include preheating the air passed into the gasifier, or the hot water may be fed directly to a steam generator to supplement the boiler feedwater. The later arrangement is disclosed in a patent application entitled "Method of Operating a Combined Gasification-Steam Generating Plant", of H. J. Blaskowski, filed on the same day as the present application and assigned to the same assignee now U.S. Pat. No 3,818,869.

The exit path for the gas produced in the gasifier **10** is indicated in the drawing by a series of arrows **36**. As is shown the gas flows upwardly within the annular reaction chamber **12** and over the upper end **38** of the inner wall **20**. The gas then changes direction and flows down through an annular passageway **40** defined by the

inner surface **42** of the inner wall and the gas outlet duct **44**. The gas outlet duct **44** is suitably supported and positioned coaxially with the reactor walls **18, 20** and extends down through the upper end of the gasifier **10** with its open, lower end **46** terminating at a level below the upper end **38** of the inner wall **20** to form the annular passageway **40** previously referred to. The upper end of the reaction chamber **12** is closed off by means of an annular plate **48** which is attached to the upper end **50** of the outer wall **18**, just below the cooling water outlet header **34**, and to the outer circumference of the gas outlet duct **44** by means of a bellows seal or the like **52**.

Slag Disposal System

Attached to and extending downwardly from each slag discharge opening **24** is a cylindrical sleeve **54** for conducting molten slag from the interior of the gasifier **10** to the slag disposal system which comprises a plurality of slag hoppers **58** into which the sleeves **54** extend, there being a separate hopper for each of the sleeves. Each slag hopper **58** includes an upper cylindrical portion **60** and a lower portion **62** of an inverted pyramidal shape terminating in a discharge nozzle **64**. The hoppers **58** are filled with water to a level **65** to immerse the lower ends of the cylindrical sleeves **54**. The upper end of each slag hopper **58** is connected to the outside circumference of its associated sleeve **54** by means of a bellows seal **66**. In order to prevent heat damage to the inner surface of the sleeves **54** there is provided at the upper end of the interior of each sleeve **54** a coil of water conducting tubing **68** covered with a suitable refractory material **70**. These coils are flow coupled to the water circulation system for the gasifier walls.

When the gasifier is operating molten ash formed in the combustion zone will settle to the bottom of the gasifier **22**, pass through the slag openings **24**, down the sleeves **54** and into the water in the hoppers **58** where rapid quenching will shatter the ash into a granular form. The drain nozzles **64** provided at the lower end of each hopper **58** permit periodic draining of accumulated slag and water from the hoppers. In the configuration shown in the drawings there are 10 slag tap/hopper combinations. As best shown in FIG. 3 these taps are equally spaced about the lower end of the reaction chamber.

Char Recycling System

Located in the interior of the gasifier **10**, below the lower end **46** of the gas outlet duct **44** is the char recycling system **45**. This system includes a series of 6 char hoppers **47** and a network of recycling lines **49** for mixing char collected in the hoppers **47** with steam and introducing the resulting char/steam mixture into the combustion zone **14**.

The upper ends of the six hoppers **47** are shaped in the form of a segment of a circle so that when assembled together and attached to the inside of the inner wall **20** they cooperate to form a gas tight barrier across the inside of the gasifier **10**. The body of each hopper tapers uniformly to its lower end where a recycling line **49** having a valve **51** for controlling the flow therethrough, communicates therewith. Each of the recycling lines in turn communicates with a horizontally disposed line **53** which is supplied with steam from a suitable source **55** and passes through the gasifier inner wall **20** to the combustion zone **14**. When the valves **51** are opened, char colledted in the hoppers passes down through the recycling lines **49** to the horizontal lines **53** where it is mixed with steam and injected into the gasifier **10.**

Combustion Zone Nozzles

Referring back to FIG. **1** there are shown two completely independent nozzle systems for introducing reactants into the gasifier, one generally indicated at **72** for the combustion zone **14** and the other **74** for the reduction zone **16.** The system associated with the combustion zone **72** is adapted to inject a portion of the pulverized coal to be gasified, in suspension with a gas containing free oxygen, typically air, into the annular combustion zone **14** in a manner to achieve complete, highly efficient combustion of the coal. This system **72** comprises a plurality of burner assemblies **76** spaced around the circumference of the gasifier **10** adjacent to the combustion zone **14** and extending through the gasifier outer wall **18.** A typical construction of burner **76** is illustrated in FIG. **4** as including a plurality of fuel nozzles **78** and a plurality of air nozzles **80.**

Each of the fuel nozzles **78** is connected through conduit **82** to a supply (not shown) of a pulverized coal/air suspension. The air nozzles **80,** positioned alterriately with the fuel nozzles communicate via duct means **84** with an air plenum **86** which extends around the full circumference of the gasifier and is defined by a belt type enclosure **88.** The enclosure **88** is attached directly to the outer wall **18** at its upper and lower ends and is supplied with preheated air through suitable duct arrangements **90.** Flow of air from the plenum to the air nozzles **80,** through air ducts **84,** is regulated by a series of air dampers **92** which are controlled to maintain the desired air/fuel ratio entering the combustion zone **14.**

The combustion of the fuel and air introduced by this system into the gasifier results in the generation of a high temperature, 3100°+F, product of combustion gas which tends to rise upward in the gasifier. These rising hot gases provide the high temperature heat source needed to sustain the endothermic gasification reactions which occur in the overlying reduction zone **16.** The temperature in the combustion zone **14** also must be maintained above the fusion temperature of the fuel ash to assure slagging of the ash in the fuel.

The preferred arrangement of the burner assemblies **76,** about the gasifier, is best shown in FIG. **3.** This arrangement may be generally described as similar to that which is employed in a tangentially fired furnace used for steam generation. In such arrangements, the burners, which are usually located in the four corners of an open center four-sided furnace, are aimed tangent to a small imaginary circle in the center. The result of such an arrangement being an intensive, turbulent, rotative motion where the flames impinge and spread out to fill the furnace area thus promoting rapid, complete combustion and efficient heat exchange.

While in the present arrangement each set of nozzles is directed tangent to the same imaginary circle, it is not imperative that they be so arranged. All that is really required is that the air and fuel streams from each of the burner nozzles be directed so as to impinge upon the streams originating from the adjacent nozzle, all being directed in either a clockwise or counterclockwise direction. While the drawing shows twelve burner assemblies **76** equally spaced about the gasifier **10,** the number of burners is not critical as long as the desired result, complete, high temperature combustion, is achieved.

Reduction Zone Nozzles

The reduction zone reactant injection system **74** is designed to introduce pulverized coal in suspension in steam into the annular reaction chamber **12.** The conditions under which, and the manner in which, this injection takes place are closely related to the overall efficiency of the gasifier. As has been pointed out the efficiency of a gasifier is strongly influenced by the following factors: the temperature at which the endothermic gasification reaction takes place; the residence time of the reactants in the high temperature reaction zone; and the mixing of the reactants in the reaction zone. The high temperature required is provided by the hot product gases from the combustion zone, while the optimum residence time and reactant mixing are achieved through a combination of the reactor structural configuration, and the proper pre-injection treatment of the coal particles. The pre-injection treatment of the coal will be discussed subsequently in connection with the operation of the gasifier.

Referring to FIG. **2,** the reduction zone nozzle system **74** comprises a plurality of individual nozzles **94** disposed about and extending through the outer wall **18** of the gasifier adjacent the reduction zone. These nozzles are connected to a source of a pulverized coal/-steam suspension by means of a suitable manifold and supply piping arrangement (not shown). As is evident from FIG. **2** these nozzles **94,** as were the combustion nozzles or burners **76,** are directed substantially tangentially to the inner wall **18** of the gasifier. The reasons for this arrangement being, as before, to achieve intimate, turbulent mixing of the reactants. It should be noted that the drawings show a counter-current arrangement of combustor and reductor nozzles to enhance the turbulence in the reduction zone, a co-current arrangement may prove equally effective.

The disclosed embodiment shows 24 reductor nozzles **94** equally spaced about the gasifier **10.** This large number of small nozzles is preferred to a lesser number of larger nozzles in order to insure that no portion of the reactants from any nozzle need travel any appreciable distance prior to initiation of the gasification reaction, and accordingly reducing the residence time required for completion of the reaction. The relatively narrow depth of the annular chamber **12** also contributes to reducing the residence time.

Operation of Gasifier

In operation a mixture of pulverized coal and preheated air, preferably in stoichiometric proportions, is injected into the combustion zone **14** through the combustion zone reactant injection system **72.** As stated previously, a portion of the air entering the combustion zone is used as a vehicle to transport the pulverized coal and accordingly enters with it through the fuel nozzles **78.** The balance of the air is brought in through the air supply ducts **90,** into the belt enclosure **88,** where the volume of air passing to the combustion zone **14** is controlled by the dampers **92.** In a typical example the air is preheated to between about 500°–650°F, preferably about 620°F, and about one-third of the coal to be gasified is injected into the combustion zone.

The mixture is ignited in any suitable manner and the pulverized coal is burned rapidly while swirling about the annular chamber **12**. The temperature in the combustion zone, particularly at the lower end near the slag taps **24**, is maintained above the slag fusion temperature of the fuel so that the molten slag will drain from the chamber **12** through the slag taps **24** to the hoppers **58** below. The combustion zone temperature must also be maintained at a level sufficiently high to ensure that the product of combustion gases are hot enough to maintain the overlying reduction zone **16** at an optimum temperature for the gasification reaction to take place. While theoretically the higher this temperature is the better the conditions for gasification, a temperature of around 3100°F is felt to provide a balance between feasibility, due to materials limitations etc., and high gas yield.

The hot stream of gaseous products of combustion and any unburned fuel from the combustion zone rises through the annular chamber **12** to the reduction zone **16** where the reductor nozzle system **74** injects the second stream of reactants into the chamber so that they impinge upon the hot rising combustion gases. The second stream contains the balance of the pulverized coal in suspension in steam. The temperature of this steam is such that it brings the coal to a temperature just below that at which the volatile matter in the coal will be volatilized. This temperature, of course, varies depending upon the type of coal being used, and is a readily available parameter. When the coal/steam mixture is injected into the reactor the 3000°+F atmosphere, created by the rising combustion gases, immediately raises the temperature of the coal to drive off the volatile to leave a porous char made up of primarily carbon. The porosity of this char offers a considerable increase of carbon surface to be contacted by the hot gaseous reactants, thus resulting in a maximum amount of carbon available for the desirable $C + H_2O \rightarrow CO + H_2$ reaction which takes place in the reduction zone.

As has been previously indicated, other fuel gas producing reactions taking place in the reduction zone include: $C + 2H_2 \rightarrow CH_4$ and $CO_2 + C \rightarrow 2CO$. The volatile driven off from the coal in the second stream is also partially cracked to yield additional H_2 and some methane. The make gas produced rises from the reduction zone **16**, passes over the upper end **38** of the inner wall **20**, down through the annular passageway **40** and up through the gas outlet duct **44**. The temperature of the gas at this point will ideally be as low as can possibly be achieved while still maintaining a high efficiency reaction, typical temperatures at this point would be in the range of 1500°–1700°F.

While a large percentage of the gasification takes place in the reduction zone **16** the gas passing from this zone still contains quantities of char which have not yet completely reacted. Thus, in order to realize a high gas production rate, with a resulting low char rate, it is desirable to extend the residence time of these particles within the reactor. This is accomplished by the provision of the long exit path identified by arrows **36** leading from the reduction zone out through the gas outlet duct **44**. This path defined by the gasifier inner and outer walls **18, 20** and the cylindrical outlet duct **44** not only provides extended residence time within the gasifier but also encourages any large char particles which are unlikely to completely react to drop into the char hoppers **47** as the gas changes direction from annular passageway **40** to pass upward through the outlet duct **44**. The char collected in these hoppers is periodically removed through the lower end of the hoppers and mixed with a small quantity of steam and injected through lines **53** into the combustion zone **14** of the gasifier. The char is then fluidized by exposure to the high temperatures existing in the combustion zone and removed along with the other slag through the slag disposal system **56**. The small amount of steam introduced into the combustion zone will result in some gasification in the combustion zone, however, this will not be enough to significantly lower the temperature which must be maintained there.

Referring now to FIG. **5**, another preferred embodiment of the invention is shown therein in a somewhat simplified form. The operation and general arrangement of this gasifier **110** is essentially the same as the previously described embodiment. In particular, the combustion zone nozzle system **172**, the reduction zone nozzle system **174** and the slag disposal system **156** are identical to the FIG. **1** embodiment and thus are not shown in detail here, nor will they be described in any detail.

The present design includes water cooled inner and outer cylindrical walls **120** and **118**, respectively, which cooperate to form an annular reaction chamber **112**. The water cooling arrangement and construction of these walls is basically the same as the previously described embodiment. The inlet header **132** to the cooling tubes in the inner and outer walls is located in the same position at the lower end of the gasifier, while the outlet header **134** is located directly above the inner wall **120**. The location of this header **134** is dictated by the arrangement used for structurally supporting the gasifier and will not be described in great detail here. What happens is that the header **134** is hung from an overhead support (not shown) and the inner wall **120** is in turn supported by water tubes **130** which extend from the header to the upper end **138** of the inner wall **120**.

The main differences between the two embodiments lie in the construction of the inner gas uptake cylinder **144**, and the char disposal system **145**. In the present design the char disposal system **145** comprises a single large conical hopper **147** extending from the lower end **117** of the inner wall **120** and terminating in a discharge opening **119**. Accumulated char may be removed from the hopper **147** through this opening and recycled to the gasifier as previously described or disposed of as waste. The hopper walls are constructed from a plurality of water cooled tubes attached together by suitable flanges or fins to form solid walls. These tubes are supplied with cooling water by a second annular cooling water inlet header **133** located underneath the hopper **147** and positioned coaxially therewith. An insulating enclosure **135** also extending from the lower end **117** of the inner wall **120** fully encloses the hopper **147** and header **133** and includes a nozzle type opening **137** just below the opening **119** in the char hopper **147**.

Extending upwardly from the annular header **133** are a plurality of water tubes **130'** which extend through the wall of the hopper **147** through the full height of the gasifier **110** where they terminate in a second annular outlet header **139**. From the point where these tubes **130'** pass into the interior of the gasifier to the elevation **141**, which represents the lower end of the gas uptake cylinder **144**, these tubes are arranged so as to permit gas flow from the annular passageway **140** to the interior of the cylinder **144**. From this elevation **141** up to the header **139**, these tubes cooperate by way of conventional finned construction and refractory coating to form the solid walls of the cylinder **144**.

It is important to note that in this construction the lower end **141** of the cylinder **144** extends axially into the gasifier **110** significantly deeper than the corresponding duct **44** of the previously described embodiment. As a result of this arrangement, the exit path of gases from the gasifier, represented by arrows **136**, is considerably longer than the previous embodiment. All other conditions being equal, the net result is increased residence time within the gasifier. Furthermore, because the gas uptake cylinder **144** and the char hopper **147** are both water cooled the gasifier may operate at higher temperatures.

It thus should now be apparent that the disclosed apparatus for, and method of, gasification is such as to provide near optimum temperature, residence, and mixing conditions for the gasification reaction. Also as a further benefit of the annular reaction chamber construction, little or no recycling of gases back to the reaction zone will occur.

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. Apparatus for continuously generating a make gas by the reaction at high temperatures of oxygen and steam with a solid fuel containing carbon and ash comprising:

- a first vertically extending cylindrical wall;
- a second vertically extending cylindrical wall smaller in diameter than and coaxially disposed within said first wall to define an annular reaction chamber therebetween, the lower ends of said first and second walls cooperating to define a bottom for said annular reaction chamber;
- means for discharging molten slag through said bottom of said reaction chamber;
- means cooperating with the upper edge of said first wall forming a top for said reaction chamber and extending radially inward of said second wall, said second wall being shorter than said first wall to define a first horizontal flow passageway between the upper edge of said second wall and said top means;
- means for discharging make gas from said apparatus comprising a cylindrical duct extending downward through said top means, said duct being smaller in diameter than said second wall and terminating at a level below the upper edge of said second wall to define a vertical flow passageway therebetween;
- means extending across the interior of said second wall below the level of termination of said gas discharge duct for preventing the downward flow of gas therebeyond, said means defining a second horizontal passageway with the lower end of said duct;
- first nozzle means for introducing into the lower end of said reaction chamber a first quantity of solid fuel in a pulverized state in suspension in a stream of gas containing free oxygen in near stoichiometric proportions, so that combustion of said fuel and gas results in the production of hot products of combustion at a temperature above the fuel ash fusion temperature which rise within said reaction chamber;
- second nozzle means for introducing into said reaction chamber, at a location adjacent and above said first nozzle means, a second quantity of solid fuel in a pulverized state in suspension in steam;
- whereby said fuel and steam suspension impinges upon said rising hot products of combustion and reacts therewith to form said make gas, said reacting gases rising upward through said reaction chamber, through said first horizontal flow passageway, downward through said vertical flow passageway, through said second horizontal flow passageway and thereafter upward through said discharge duct.

2. The apparatus of claim **1** wherein said first nozzle means is constructed and arranged to direct said suspension of fuel and gas tangentially to said second wall of said annular reaction chamber.

3. The apparatus of claim **1** wherein said second nozzle means is constructed and arranged to direct said suspension of fuel and steam tangentially to said second wall of said annular reaction chamber.

4. The apparatus of claim **2** wherein said second nozzle means is constructed and arranged to direct said suspension of fuel and steam tangentially to said second wall of said annular reaction chamber.

5. The apparatus of claim **4** wherein said first nozzle means comprises a plurality of nozzle assemblies spaced around the circumference of and extending through said first vertically extending wall, said nozzle assemblies being angularly directed such that the stream from each nozzle assembly impinges upon the stream emanating from an adjacent nozzle assembly, and wherein said second nozzle means comprises a plurality of nozzles spaced around the circumference of and extending through said vertically extending wall.

6. The apparatus of claim **1** wherein said means extending across the interior of said second wall comprises at least one hopper means for collecting particulate ash falling from the make gas and including means for introducing said collected particulate ash in suspension in steam into said reaction chamber adjacent to said bottom.

7. The apparatus of claim **1** wherein said means for discharging molten slag comprises a plurality of cylindrical sleeves communicating at their upper ends with a corresponding number of slag discharge openings in said bottom of said reaction chamber, each of said sleeves extending downward from said bottom and terminating in a corresponding number of slag hoppers, said hoppers being filled with water to a level to immerse the lower ends of said cylindrical sleeves; and drain means associated with each of said hoppers for periodically removing accumulated slag from the hoppers.

8. A process for continuously generating a low Btu make gas by the reaction at high temperatures of oxygen and steam with a solid fuel containing carbon and ash, which comprises:

- introducing into the lower end of a vertical annular reaction zone, a stream of solid fuel in a pulverized state in suspension in a stream of gas containing free oxygen at near stoichiometric proportions;
- burning said stream of fuel and gas in said annular reaction zone to produce gaseous products of combustion at a temperature above the fuel ash fusion

temperature, said products of combustion rising upwardly within said zone;

introducing into said reaction zone at a level above the point of introduction of said stream of fuel and gas, a stream of solid fuel in a pulverized state in suspension in a stream of steam, said stream of fuel and steam impinging upon said rising hot products of combustion;

endothermically reacting said stream of fuel and steam with said hot products of combustion; and

simultaneously conducting said endothermically reacting gases upwardly to the top of said reaction zone and from thence inward and downward through a vertical coaxially disposed annular gas passage zone and then inward and upwardly through a central circular gas exit passage, said path through which said reacting gases pass being sufficiently long to provide a residence time of said reacting gases therewithin sufficient for substantially complete gasification of said solid fuel to take place.

9. The process of claim **8** wherein said solid fuel and gas suspension is introduced into said annular reaction zone in a plurality of streams emanating from spaced points about the periphery of said annular reaction zone each of said plurality of streams being directed such that it impinges upon an adjacent stream.

10. The process of claim **9** wherein said solid fuel and steam suspension is introduced into said annular reaction zone in a plurality of streams emanating from spaced points about the periphery of said annular reaction zone each of said plurality of streams being directed such that it impinges upon an adjacent stream.

11. The process of claim **8** wherein said gas containing free oxygen is heated to a temperature between about 500°–650°F prior to introduction into said reaction zone.

12. The process of claim **8** wherein the temperature of said stream of fuel and steam prior to introduction into said reaction zone is slightly below the temperature at which the volatile matter in said fuel will be volatilized.

13. The process of claim **8** wherein the ratio by weight of solid fuel contained in said stream of fuel and gas to that contained in said stream of fuel and steam is about 1:2.

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