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(54) METHOD AND APPARATUS FOR THE PRODUCTION OF SYNTHESIS GAS

(54) METHODE ET APPAREIL POUR LA PRODUCTION DE GAZ SYNTHETIQUE

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This invention relates to the generation of synthesis gas and more particularly to method and apparatus for producing a synthesis gas by the combustion of solid fuels.

In the production of synthesis gas, the desired amounts of hydrogen and carbon monoxide in the product gas determines the proper proportions of steam, oxidizing fluid and solid fuel which are fed to a reactor or furnace where combustion takes place to produce the product gas. The temperature and pressure within the combustion chamber of the reactor are generally high, with the temperature reaching 3000°F. or more. Accordingly, precautions must be taken to protect the reactor casing from high temperatures and hydrogen embrittlement. Prior arrangements have utilized insulating refractory linings to protect the reactor casing but such insulation unduly adds to the size of the casing. Furthermore, complex telemetering arrangements have been devised for the reactor casing to indicate the wall temperature at different parts of the casing to thereby warn the operator when a dangerous condition occurs.

The present invention contemplates novel process and apparatus for producing a synthesis gas and in which the heat contained in the product gas is used to heat the feed to a reactor. Novel means also are provided to protect the reactor casing and the heat exchangers in the present arrangement from the extreme conditions generally arising in the operation of a system for the generation of synthesis gas.

In accordance with the present invention the proper proportions of an oxidizing fluid, steam and solid fuel are conducted to a reactor wherein combustion takes place to produce a product gas having the desired amounts of hydrogen

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and carbon monoxide. The product gas is delivered to a boiler and thence to a superheater where heat is given up by the product gas to provide the system with superheated steam. The steam is mixed with solid fuel and then passed to a reheater where the steam and fuel pass in heat exchange relationship with the product gas from the superheater. The reheated mixture of fuel and steam is then fed to the reactor where it is combined and reacted with the oxidizing fluid and the cycle is repeated.

The invention will be understood from the following description when considered in connection with the accompanying drawings wherein one embodiment of the invention is illustrated.

In the drawings wherein like reference numerals refer to like parts throughout the several views:

Fig. 1 is a schematic illustration of a gasification system constituting one embodiment of the present invention;

Fig. 2 is an elevational view, in section, of the reactor and quench chamber of Fig. 1;

Fig. 3 is a section taken on the line 3-3 of Fig. 2;

Fig. 4 is a section taken on the line 4-4 of Fig. 2;

Fig. 5 is a section taken on the line 5-5 of Fig. 2 and shows in particular the slag crusher arrangement;

Fig. 6 is an elevational view, in section of the ash storage chamber of Fig. 1;

Fig. 7 is a section taken on the line 7-7 of Fig. 6;

Fig. 8 is a section taken on the line 8-8 of Fig. 6;

Fig. 9 is an elevational view, in section, of the superheater of Fig. 1;

Fig. 10 is a section taken on the line 10-10 of Fig. 9;

Fig. 11 is an elevational view, in section, of the boiler of Fig.1;

Fig. 12 is a section taken on the line 12-12 of Fig. 11;

Fig. 13 is an elevational view, in section, of the reheater of Fig. 1; and

Fig. 14 is a section taken on the line 14-14 of Fig. 13.

Referring now to the drawings for a more detailed description of the present invention and more particularly to Fig. 1 thereof, a substantially cylindrical shaped reactor or furnace 20 is provided with a mixture of steam and solid fuel, as for example pulverized coal, by a pair of conduits 21, and with an oxidizing fluid, as for example oxygen, by a conduit 22. The conduits 21 are connected to a heat exchanger or reheater 23 to be more fully described hereinafter, and the conduit 22 is connected to a source of compressed oxygen. The coal and steam are fired in the presence of the oxygen in the reactor to gasify the coal and produce a product gas containing hydrogen, carbon monoxide, carbon dioxide and some water vapor. The proportion of coal, steam and oxygen depend upon the desired amounts of effluents in the product gas. Reactor 20 comprises an inner shell 24 (Fig. 2) of suitable metal which is lined internally with refractory material 25. Refractory 25 defines a combustion chamber 26 in the upper portion of reactor 20 and a gas and slag outlet of reduced cross-sectional area in the lower portion; the configuration of the outlet being such as to limit the loss of heat by radiation from chamber 26 through the outlet. The size of the outlet is a function of the quantity of molten material and its fluidity so that the size of the outlet necessary to prevent entrapment of the slag and plugging of the outlet can be readily determined. The product gas formed in combustion chamber 26 flows to a quenching chamber 27 of a quenching vessel 27A which is partly lined with refractory 25. The gas in chamber 27 is sprayed with jets of water from spray nozzles 28 to reduce the temperature of the gas to a level below the fusion temperature of the ash. Most of the solidified ash drops out of the gas stream and is collected in a water bath in chamber 27. The water is introduced into chamber 27 by a water inlet conduit 29 and the level of the bath is maintained at a predetermined height below the slag outlet; it being understood that since evaporation from the quench bath occurs it is necessary to replenish the supply of water. A blowdown connection 29A is also provided for the purpose of regulating the concentration of dissolved solids in the bath. The product gas leaves quenching chamber 27 through a gas discharge conduit 30 connected to the latter.

Reactor 20 includes an outer pressure shell or jacket 31 which surrounds inner shell 24 and is spaced therefrom to define a space 32. A boiler or steam drum 33 is disposed at the top of outer shell 31 and the interior of the drum communicates with the space 32 through an opening 34 in shell 31. A conduit 35 is connected to steam drum 33 and conducts feed water to the latter which passes through opening 34 to space 32. A steam offtake pipe 36 is connected at one end to drum 32 and at its other end to gas discharge conduit 30.

A sight level guage 37 is provided to effect indications of the level of water in drums 33, which water level is maintained at a predetermined level by automatic means not shown. A manway 38 is provided to allow access to the interior of reactor 20.

The heat generated by the combustion of reactants in chamber 26 causes steam to be generated in space 32, which steam flows upwardly into the upper portion of drum 33 whence the steam passes to steam offtake pipe 36 thence into product gas conduit 30. Pipe 36 serves as a pressure equalizing line to bring the pressure within combustion chamber 26 to a value substantially equal to the pressure in space 32 so that the pressure difference across inner shell 24 is small. For this reason, inner shell 24 can be made relatively thin. It will be understood that the refractory 25 and water space 32 protect the pressure shell 31 from high temperatures and hydrogen embrittlement, which embrittlement occurs when the inner shell reaches a temperature in a predetermined range. Refractory 25 protects inner shell 24 from slag corrosion and also limits the rate of heat loss to the water in space 32 to a low value. The water jacket for reactor 20 also functions to warn against the loss of refractory lining and flame impingement on inner shell 24. An equal increase in the steam production in space 32 and water demand will indicate a condition of refractory loss while a disproportionate demand for water over and above the steam production will indicate a rupture of the inner shell.

Quenching chamber 27 gradually tapers in cross-sectional area to define an ash discharge opening 39 at the bottom of the chamber. Arranged immediately below opening 39 and carried by walls of chamber 27 adjacent the opening is a slag crusher arrangement 40 which comprises a pair of crushing rollers 41 and 42. Roller 41 is drivably connected to a shaft 43 which is driven by a motor (not shown) and the roller 42 is maintained in constant engagement with roller 41 by biasing springs 44. The water jets from spray nozzles 28 contact the slag from combustion chamber 26 to produce thermal shocks of a great magnitude to cause part of the slag to break up into small particles of more or less spherical shape, and the remainder to form a fibrous mass. The quench bath cools the solidified slag to a temperature which can be tolerated by slag crusher 40. Slag and water from quenching chamber 27 thus pass through rollers 41 and 42 which break up the slag to a size suitable for handling.

An ash storage vessel 45 (Figs. 1 and 6) is arranged below quenching vessel 27A and communicates with quenching chamber 27 by way of a guard valve 46 and a lock valve 47, both of which valves may be conventional gate valves. Ash storage vessel 45 is of generally uniform cross-sectional area but tapers toward the bottom thereof to form two reduced portions 48 and 49. A relief valve 50 and a vent valve 51 are disposed at the top of vessel 45 and a third valve 52 is provided which is connected to a pressure equalizing pipe 53 (Figs. 1 and 6) communicating with the annular space 32 of reactor 20. Vessel 45 is also provided with a manway 54 to allow access to the interior of the vessel. A rib member 55 (Fig. 7) extends transversely of and substantially within reduced portion 48 of vessel 45 and carries a housing 56. A member 57 is arranged for sliding movement in housing 56 and has connected thereto an arm 58 which is secured to a shaft 59 in an elongated housing 60. Housing 60 and shaft 59 project outside of vessel 45 where shaft 59 is secured to an arm 61 which is movable by an actuating lever 62 (Fig. 6). A packing 63 is provided in elongated housing 60 outside vessel 45 to prevent leakage through the housing and along shaft 59. It may be readily understood that movement of actuating lever 62 will cause vertical movement of member 57 and housing 56 through the linkage just described.

A vertically extending valve stem 64 is secured at its upper end to slidable member 57 and at the lower end to the bottom 65 of a closed cylindrical shaped valve member 66 in reduced portion 49 of vessel 45; the member 66 having an inclined top portion 67. A substantially cylindrical guide member 68 of larger diameter than valve member 66 is arranged concentric with the latter and has a flange portion 69 secured to a frusto-conical shaped cap 70. The diameter of guide member 68 is such as to allow for axial movement of valve member 66 therein. A bearing insert 71 is secured to cap 70 and provides a guide for movement of stem 64 through cap 70. Cylindrical guide member 68 is seated upon a plurality of radially extending vanes or ribs 72 which are arcuately spaced to communicate the reduced portions 48 and 49 of vessel 45 with each other. A member 73 is arranged at the bottom of reduced portion 49 and is fastened to the latter by a plurality of bolts 73A (one shown in Fig. 6). Member 73 has a contoured surface 74 which extends inside of reduced portion 49 and carries a sealing or seating ring 75 which makes knife-edge contact with a ring 75A in bottom 65 of valve member 66. Surface 74 is contoured in the manner shown to cooperate with bottom 65 of member 66 to thereby provide a variable size outlet opening. It may be seen that as valve member 66 is moved with respect to contoured surface 74, the area of the outlet opening changes to vary the velocity of flow of liquid through the outlet, which liquid flows from the upper portion of vessel 45 and through spaced ribs 72. A central aperture is provided in member 73 and is adapted to be covered and uncovered by a closure plate 76 pivoted as at 76A and 76B by a counter-balanced lever 77. A gasket 78 of suitable material is provided in closure plate 76 and engages a projecting rim portion 73B of member 73 to seal the aperture in the latter with respect to the atmosphere. A vent valve 79 is provided in closure plate 76 and the latter is detachably secured to member 73 by fastening means 79A.

A conduit 80 is provided at reduced portion 49 and conducts a cooling medium, as for example water, into the portion 49 to obviate warpage and buckling of the elements therein, which warpage and buckling prevents satisfactory operation of the cylindrical valve member 66. A pair of adjacent conduits 81 and 82 (Fig. 6) are connected to reduced portion 49 and each conduit is provided with a pair of spaced hand-operated valves, 81A and 81B respectively, and 82A and 82B, respectively. A sediment separator (not shown) is provided in conduits 81 and 82 between each pair of hand-operated valves to collect and separate solid particles from water flowing through the conduits. Conduits 81 and 82 are joined beyond valves 81A and 82A to a discharge conduit 83. Generally, the valves of one conduit are open while the valves of the other conduit are closed, in order that flow be present in only one conduit at any given time. For example, if flow is assumed in conduit 81, valves 81A and 81B are open in the conduit and valves 82A and 82B in conduit 82 are closed. Accordingly, water from reduced portion 49 flows only through conduit 81 and is discharged through conduit 83 without entering conduit 82. When the sediment separator in conduit 81 collects a predetermined amount of sediment or solid particles, valves 81A and 81B are closed and valves 82A and 82B are opened to cause the water to flow through conduit 82. The sediment separator in conduit 81 may then be removed and cleaned without interrupting the flow of liquid from reduced portion 49. In like manner, when the sediment separator in conduit 82 becomes clogged then the valves 81A and 81B are opened and the valves 82A and 82B are closed to allow removal of and cleaning of the clogged sediment separator.

In operation, water and ash flow through valves 46 and 47 from quenching chamber 27 to ash storage vessel 45. When the vessel 45 is nearly full of ash, guard valve 46 is closed to stop the flow of solid material between the vessels 27A and 45; then lock valve 47 is closed to provide a pressure tight seal between chamber 27 and vessel 45. The time interval between the closing of valves 46 and 47 is sufficient to cause all the solid material or ash to clear the seating surface of valve 47. Pressure equalizing pipe 53 is provided so that a very slight differential pressure is present across the valves 46 and 47, which slight difference in pressure enables an operator to easily operate the valves without much effort. After vessel 27A and vessel 45 are isolated, valve 52 is closed and valve 51 is opened to reduce the pressure in vessel 45 to atmospheric. Vent valve 79 in closure plate 76 is opened to discharge any liquid in the space between plate 76 and bottom 65. Closure plate 76 is then unfastened from member 73 and pivoted downwardly by lever 77. Lever 62 is actuated to raise valve stem 64 and bottom 65 of cylindrical valve 66, through the intermediate linkage, an amount in accordance with the desired rate of flow of liquid and solid material through the outlet opening defined by the edge of bottom 65 and contoured surface 74. It may be understood that the arrangement of cap 70 and valve 66 in the manner disclosed provides for easy movement of the latter because the only forces acting on valve 66 to restrict upward movement thereof are those presented by the water along the valve 66 and within the space between contoured surface 74 and ribs 72. Since such forces are negligible, the weight of water above the valve presents no problem in the movement of the valve. Furthermore, no difficulties are confronted in seating valve 65 because of ashes which may be on sealing ring 75 and insert 75A, by reason of the knife-edge contact of such elements. When the desired amount of ashes and water has been dumped from storage vessel 45, lever 62 is actuated to seat valve 66 on sealing ring 75. Vent valve 79 on closure plate 76 is closed and the latter is pivoted to a position where it is again fastened to member 73. Vent valve 51 is closed and valve 52 is opened to communicate vessel 45 with annular space 32 of reactor 20. When the pressure in vessel 45 attains the pressure in reactor 20, valves 46 and 47 are opened to allow water and ashes to flow again into storage vessel 45.

Product gas conduit 30 is connected at its other end to the lower portion of an inner cylindrical shell 85 (Figs. 11 and 12) which constitutes the shell of a heat exchanger or boiler 86. An outer pressure shell 87 is arranged concentric and in fluid tight relationship with shell 85 to define an annular space 88 and a water jacket which is supplied with water through a water inlet conduit 89 connected to a portion of the water jacket arranged around conduit 30. A plurality of vapor generating tubes 90 are arranged in pressure shell 85 and have opposite ends mounted in upper and lower tube sheets 91 and 92, respectively. The lower ends of tubes 90 communicate with a water chamber 93 and the upper ends of the tubes communicate with an elongated head or steam drum 94 at the top of the heat exchanger 86. A downcomer conduit 95 is connected at one end to drum 94 and at its other end to a conduit 96 which communicates with water chamber 93; the other end of conduit 96 being sealed. Water is fed into drum 94 from annular space 88 by a pipe 97 which is connected to an extending portion 98 of shell 87; extending portion 98 being arranged around a gas outlet conduit 99. A steam offtake conduit 100 is connected to the top of drum 94 to conduct steam from the latter.

In the foregoing arrangement, the product gas enters shell 85 at the bottom thereof and flows upwardly and over the vapor generating tubes 90 and thence out of the shell through gas outlet conduit 99. The water flowing into space 88 through water inlet conduit 89, passes upwardly and out of the space through pipe 97 and into steam drum 94.

Downcomer conduit 95 conducts the water from drum 94 into water chamber 93 whence the water flows upwardly through vapor generating tubes 90. The water in space 88 and tubes 90 is heated by the product gas whereby the water becomes saturated and part of the latter changes to steam which flows into drum 94 where the steam is discharged through offtake conduit 100. The water jacket provided for heat exchanger 86 serves the dual purpose of protecting shell 85 from the high temperature product gas which, aside from its temperature effect, may cause hydrogen embrittlement; the water jacket also permits a reduction of the diameter of pressure shell 87. It will be understood that the diameter of shell 87 can be made relatively small in the present invention because the water jacket eliminates the need for larger thicknesses of ordinary high temperature insulation which would be required for the equivalent temperature reduction to protect pressure shell 87. It may be seen, in addition, that all metal parts of the exchanger are substantially the same temperature by reason of the water jacket so that the latter obviates the necessity of an expansion joint between shell 87 and the tube sheets. Furthermore, the differential pressure between shell 87 and the gas side of shell 85 is slight inasmuch as the product gas and steam are substantially equal in pressure.

A second heat exchanger or superheater 101 (Figs. 1, 9 and 10) of substantially the same construction as boiler 86, has a conduit 102 connected to steam offtake conduit 100. The lower portion of superheater 101 is provided with a chamber 103 which communicates the lower ends of a plurality of vapor conducting tubes 104 mounted in a tube sheet 105 with conduit 100. Tubes 104 are arranged in a cylindrical-shaped inner shell 106 which has an outer shell 107 arranged concentric therewith and in spaced fluid-tight relationship. The upper ends of tubes 104 are mounted in a tube sheet 108 which is spaced from the upper ends of inner and outer shells 106 and 107 and the tubes communicate with a chamber 109 at the top of the superheater. An annular member 110 is secured to tube sheet 108 in any suitable manner, as for example by welding. Disposed below and spaced from annular member 110 is a second annular member 111 which is secured by means, as for example bolts 112 (only one shown in Fig. 9) to a third annular member 113 secured to outer shell 107. An expansible and contractible member 114 is secured to annular members 110 and 111 to allow for relative movement of tube sheet 108 and outer shell 107. A water inlet conduit 115 is connected to steam drum 33 of reactor 20 and conducts water to a space between the inner and outer shells 106 and 107. An outlet conduit or steam riser 116 communicates with the mentioned space and with steam drum 33 at the top of reactor 20 (Fig. 1). The other end of gas outlet conduit 99 (Fig. 9) is connected to the interior of the inner shell 106 at the upper portion of superheater 101 to provide the latter with product gas from boiler 86. One end of a gas conduit 117 is connected to the lower portion of shell 106 and serves to conduct the product gas from the latter.

In the operation of superheater 101, the steam from drum 94 of boiler 86 flows through conduit 102 into chamber 103. The steam then passed upwardly through tubes 104 where the steam is superheated by passing in heat exchange relationship with the product gas which flows downwardly in inner shell 106; the gas being discharged through gas conduit 117. The superheated steam flows into chamber 109 where it is discharged through a conduit 118 connected to the chamber. The product gas heats the water in the space between the inner and outer shells to provide saturated water and steam, the latter passing out of said space through steam riser 116 and into steam drum 33 of reactor 20. The water jacket of superheater 101 serves the same purpose as the water jacket of boiler 86. An expansion seal is required in the superheater because the temperatures encountered are much higher than those in the boiler.

The solid fuel or pulverized coal for introduction in the system and for admixture with the steam flowing into the reactor 20 is collected and stored in a coal bunker 120 (Fig. 1). A pair of conduits 121 are connected to bunker 120 and each is provided with a slide gate valve 122. The coal from bunker 120 flows by gravity through conduits 121 and the flow is regulated by slide gate valves 122. Conduits 121 are connected to a single conduit 123 which is connected to a lock hopper 124. A lock valve 125 (diagrammatically shown in broken lines) is arranged to move in conduit 123 and serves to seal the lock hopper 124 to the atmosphere. The lock hopper 124 may be pressurized by means (not shown) to the system operating pressure. A connecting conduit 126 communicates lock hopper 124 with a pressure hopper 127 and a lock valve (not shown) in conduit 126 is operable for isolating hopper 127 from hopper 124. Lock hopper 124 is alternately at operating pressure and atmospheric pressure while pressure hopper 127 remains constantly at operating or system pressure. When the lock hopper is to be filled with coal, the lock valve in connecting conduit 126 is operated to isolate hopper 127 from hopper 124 and lock valve 125 is opened to return the lock hopper 124 to atmospheric pressure. Slide valves 122 are then opened to cause flow of coal through conduit 123 into the lock hopper. When the lock hopper is full, slide valves 122 and lock valve 125 are closed and the pressure in the hopper is brought up to the operating or system pressure. The lock valve in conduit 126 is then operated to connect the two hoppers together. A conventional coal feeder 128 is disposed at the bottom of pressure hopper 127 and is connected to a conduit 129 which in turn is connected to steam conduit 118 wherein the superheated steam from superheater 101 flows. Feeder 128 is operable for controlling the flow rate of coal from pressure hopper 127 so that the proper proportions of coal and steam are mixed in steam conduit 118.

The heat exchanger or reheater 23 (Figs. 1, 13 and 14) mentioned hereinbefore comprises a cylindrical-shaped casing 131 which is lined internally with insulation 132, as for example thermal or air setting material. A plurality of tubes 133 are disposed in casing 131 and the upper portions of the tubes extend through a tube sheet 134 while the lower portion of the tubes extend through a lower tube sheet 135. The portions of tubes 133 extending beyond the tube sheets 134 and 135 are shown in the drawing integral with the portions of the tubes between the tube sheets, but from a manufacturing standpoint it may be advisable to terminate the tubes at the tube sheets, weld the tube ends to the sheets, and add extensions to the tube ends. The tube portions extending beyond the tube sheets are bent in a convergent manner to form smaller groupings; the lower ends of the tubes terminate adjacent an inlet head nozzle opening 136 in a plate 137 and the upper ends of the tubes terminate adjacent an outlet head nozzle 138. A dome shaped member 139 encloses the upper extending portions of tubes 133 and is filed with insulation 132, while a cylindrical-shaped member 140 encloses the lower extending portions of the tubes and is similarly filled with insulation 132. A pair of adjoining annular members 141 and 142 are disposed at the lower end of casing 131, the annular member 141 being secured to casing 131 as by welding and annular member 142 being fastened to member 141 as by bolts 143 (only one shown in Fig. 13). An expansible and contractible bellows type seal 144 encloses cylindrical member 140 and is secured at its upper end to annular member 142 and at its lower end to plate 137. Seal 144 provides for relative movement of casing 131 and plate 137 with changes in temperature. An annular plate 145 is secured to plate 137 by bolts 146 (one shown in the drawing) and has an opening which accommodates the other end of steam conduit 118 which carries the steam and coal mixture. Casing 131 is provided with a lower side tubular extension 147 which accommodates the other end of gas conduit 117 carrying the product gas from superheater 101, and an upper side tubular extension 148 which accommodates one end of a discharge conduit 149. Outlet nozzle 138 communicates with the upper ends of tubes 133 and is connected to conduits 21 leading to reactor 20.

The product gas from superheater 101 flows through conduit 117 into reheater 130 where the gas passes over and in heat exchange relationship with tubes 133 and then passes out of the reheater through discharge conduit 149. The product gas in conduit 149 may be fed to other apparatus for further chemical reactions, if desired, or the product gas may be utilized as is. The steam in conduit 118 is mixed with coal from conduit 129 to provide a mixture wherein the coal is suspended in the steam. In mixing with the coal, the steam is reduced in temperature while the coal temperature is elevated. The mixture then flows through inlet nozzle 136 of reheater 23 and into tubes 133 where the mixture passes in heat exchange relationship with the product gas in casing 131, and the temperature of the mixture is elevated to a predetermined level. The mixture then flows through nozzle 138 and into conduits 21 where the mixture is discharged into furnace 20 and reacted with oxygen from conduit 22.

Due to the erosive nature of the coal and steam mixture, the velocity of the latter must be limited to a value which prevents erosion but yet to a value high enough to avoid settling out of coal particles; it being understood that the settling action produces unsteady flow of the coal. The velocity requirement of the mixture determines the number and size of tubes 133 while the heat transfer and tube temperature requirements determine the tube length and gas area on the shell side. The velocity of the coal particles in the steam at the inlet and outlet of reheater 23 is generally high. Consequently, to avoid erosion of the tube sheets 134 and 135 and members 139 and 140, tubes 133 are provided with extensions, as described hereinabove, so as to cause the coal particles to flow out of contact with the tube sheets and mentioned elements.

In operation, the proper proportions of steam, coal and oxygen are reacted in reactor 20 to produce a product gas having the desired porportions of hydrogen and carbon monoxide. The product gas is quenched in quenching chamber 27 to remove ash from the gas which then flows out of the chamber through gas conduit 30. The product gas in conduit 30 is fed to boiler 86 where it is passed in heat exchange relationship with water in tubes 90 to provide steam for the system. The product gas and steam in boiler 86 are then conducted to superheater 101 where the gas is passed in heat exchange relationship with the steam to superheat the latter. Conduit 118 carries the superheated steam away from superheater 101 and is connected to conduit 129 through which pulverized coal flows. The superheated steam and coal are mixed in conduit 118 and in mixing, the steam is reduced in temperature while the coal temperature is elevated. The coal and steam mixture and the product gas from superheater 101 are then conducted to reheater 23 where they are passed in heat exchange relationship with each other to elevate the temperature of the steam and coal mixture. The product gas in reheater 23 is then conducted from the latter by conduit 149 to other apparatus for further chemical reaction, if desired. The coal and steam mixture is fed through conduits 21 to reactor 20 and the cycle is repeated.

It may now be apparent that the present invention provides novel process and apparatus for the generation of synthesis gas and wherein the heat contained in the product is utilized to heat the feed to a furnace. By providing water jackets for the furnace and certain of the heat exchangers, the walls of such units are protected from hydrogen embrittlement and the effects of high temperature. Furthermore, the size of the units are maintained relatively small by substantially balancing the pressures within and outside the pressure shells. This is accomplished by the relatively small pressure drop of the product gas as it flows through each unit and by the maintenance of steam pressure in the water jackets substantially equal to the pressure of the product gas.

Although one embodiment of the present invention has been illustrated and described in detail, it is to be expressly understood that the invention is not limited thereto. Various changes may be made in the design and arrangement of the parts and in the steps of the process without departing from the spirit and scope of the invention as will now be understood by those skilled in the art.

WHAT IS CLAIMED IS:

1. In a system of the class described, means including oxidizing fluid inlet means and solid fuel and vapor mixture inlet means for receiving and causing reaction of an oxidizing fluid and a mixture of solid fuel and vapor and to provide a product fluid, means connected to receive liquid therein and connected to receive said product fluid in heat exchange relationship with the liquid to change the latter to a vapor, means for admixing the last-mentioned vapor with a solid fuel, reheater means for receiving said admixture of vapor and solid fuel and said product fluid from the second-mentioned means and causing said vapor and solid fuel mixture and the product fluid to pass in indirect heat exchange relationship with each other, and means communicating with the reheater means and the first-mentioned means to conduct the reheated vapor and solid fuel to the latter.

2. In a system of the class described, means including oxidizing fluid inlet means and solid fuel and superheated vapor mixture inlet means for receiving and causing reaction of an oxidizing fluid and a mixture of solid fuel and superheated vapor to provide a product fluid, means connected to receive a liquid therein and connected to receive said product fluid in heat exchange relationship with the liquid to change the latter to a vapor, superheater means connected to receive the second-mentioned vapor in heat exchange relationship with the product fluid from the second-mentioned means to superheat said second-mentioned vapor, means for admixing the superheated vapor with a solid fuel, reheater means for receiving said admixture of superheated vapor and solid fuel and said product fluid from said superheater means and causing said mixture of superheated vapor

and solid fuel and the product fluid to pass in indirect heat exchange relationship with each other, and means communicating with the reheater means and with the first-mentioned means for conducting the reheated superheated vapor and solid fuel to the latter.

3. In a system of the class described, a reactor having a combustion chamber connected to receive oxygen and connected to receive a mixture of pulverized solid fuel and superheated steam, said oxygen and said mixture being reacted in said combustion chamber to produce a product gas, a heat exchanger connected to receive water and connected to receive said product gas from the reactor to cause said product gas to pass in heat exchange relationship with said water to produce steam, a second heat exchanger connected to receive the steam and product gas from the first-mentioned heat exchanger and to pass said steam and product gas in heat exchange relationship with each other to provide superheated steam, conduit means for conducting the superheated steam from said second heat exchanger, means carrying pulverized solid fuel and communicating with the conduit means for causing admixture of said solid fuel and said superheated steam in said conduit means, a third heat exchanger communicating with said conduit means to receive said mixture of solid fuel and superheated steam and communicating with said second heat exchanger to receive the product gas therefrom, said third heat exchanger being constructed and arranged to cause said product gas and mixture of solid fuel and superheated steam to pass in indirect heat exchange relationship with each other to reheat said mixture, and means communicating with said third heat exchanger and with said reactor for

conducting the mixture of superheated vapor and solid fuel to the combustion chamber of the latter.

4. The system of claim 3 wherein the reactor and the first and second heat exchangers each include a pressure-tight shell through which the product gas flows, and means are provided for maintaining the pressure differential across said shells substantially zero.

5. The system of claim 3 wherein the reactor and first and second heat exchangers each include a pressure-tight casing through which the product gas flows, and means are provided for cooling said shells to prevent overheating thereof.

6. The system of claim 3 wherein the reactor and first and second heat exchangers each are provided with an inner shell which contains the product gas and an outer shell spaced from and substantially enclosing the inner shell, the space between the inner and outer shells containing a cooling medium.

7. The system of claim 6 wherein means communicate the combustion chamber within the inner shell of the reactor with the space between the inner and outer shells of the reactor, and wherein means communicate the mentioned space with the space between the inner and outer shells of the second heat exchanger, and means communicate the space between the inner and outer shells of the first-mentioned heat exchanger with the steam flowing to the second heat exchanger from the first heat exchanger.

8. In a system of the class described, a reactor having a casing and a combustion chamber therein connected to receive oxygen and connected to receive a mixture of pulverized solid fuel and superheated steam, said oxygen and said mixture being reacted in said combustion chamber to

produce a product gas, spray nozzles connected to a source of liquid and arranged in said reactor and outside said combustion chamber for spraying said product gas to reduce the temperature of the latter below the fusion of ash therein to thereby cause solidified ash to drop out of the product gas, a water jacket for the casing connected to receive water therein in heat exchange relationship with the product gas for changing the water to steam, conduit means communicating the water jacket with the interior of the casing to cause the pressure of the water in the jacket to be substantially equal to the pressure within the reactor casing, a conduit connected to receive the product gas from said reactor, a heat exchanger comprising a casing connected to said conduit for receiving the product gas therein, a water jacket for said last-mentioned casing connected to receive water therein in heat exchange relationship with said product gas, a plurality of tubular members disposed in the casing of said heat exchanger and communicating with the last-mentioned water jacket to receive water therefrom, said tubular members being in heat exchange and fluid-tight relationship with the product gas for changing the water to steam, a second heat exchanger having a casing and a water jacket, said water jacket being connected to a source of water to receive water therein, said casing being arranged to receive and pass in heat exchange relationship the steam and product gas from the first-mentioned heat exchanger to superheat the steam, means communicating the water jacket of said second heat exchanger with the water jacket of the reactor, a conduit for carrying away the superheated steam from the second heat exchanger, means carrying pulverized solid fuel and communicating with the last-mentioned conduit for causing admixture of the solid fuel and superheated steam, a third heat exchanger communicating with the last-mentioned means and with said second heat exchanger for causing the mixture of superheated steam and solid fuel to pass in indirect heat exchange relationship with the product gas from the second heat exchanger, and means communicating the third heat exchanger with the combustion chamber of said reactor to deliver the mixture of solid fuel and superheated steam to the combustion chamber.

9. In a system of the class described, a reactor having a combustion chamber connected to receive oxygen and a mixture of pulverized solid fuel and superheated steam, said oxygen and said mixture being reacted in said combustion chamber to produce a product gas, a heat exchanger connected to receive water therein and connected to receive said product gas from the reactor to cause said product gas to pass in heat exchange relationship with said water to produce steam, a second heat exchanger connected to receive the steam and product gas from the first-mentioned heat exchanger and to pass said steam and product gas in heat exchange relationship with each other to provide superheated steam, conduit means for conducting superheated steam from said second heat exchanger, a storage vessel connected to a supply of pulverized solid fuel and adapted to be subjected alternately to atmospheric pressure and to the pressure of the system, a second vessel subjected to the system pressure at all times, means communicating said storage vessel with said second vessel to provide the latter with pulverized solid fuel from the storage vessel, means for isolating both said vessels with respect to each other, said storage vessel being isolated from said second vessel and subjected to at-

mospheric pressure when the storage vessel is replenished with solid fuel and said storage vessel being subjected to system pressure and communicating with said second vessel when the latter is provided with solid fuel from said storage vessel, means communicating the second vessel with the conduit means for causing admixture of said solid fuel and the superheated steam from said second heat exchanger, a third heat exchanger communicating with said conduit means to receive said mixture of solid fuel and superheated steam and communicating with said second heat exchanger to receive the product gas therefrom, said third heat exchanger being construction and arranged to cause the product gas and mixture of solid fuel and superheated vapor to pass in indirect heat exchange relationship with each other to reheat said admixture, and means communicating with said third heat exchanger and with said reactor for conducting the admixture of superheated vapor and solid fuel to the combustion chamber of the reactor.

10. In a system of the class described, a reactor having a casing with a combustion chamber connected to receive an oxidizing fluid and a mixture of pulverized solid fuel and superheated steam for reaction therein to produce a product gas, a water jacket for said reactor containing water in heat exchange relationship with the product gas, means communicating the water jacket with the combustion chamber of said reactor, a first heat exchanger connected to receive said product gas in heat exchange relationship with water in said first heat exchanger to produce steam,a water jacket for said first heat exchanger, a second heat exchanger connected to receive the steam and product gas

from said first heat exchanger and arranged to pass the steam and product gas in heat exchange relationship with each other to superheat the steam, a water jacket for said second heat exchanger communicating with the water jacket of said reactor, means carrying pulverized solid fuel, and conduit means communicating with said last-mentioned means and with the second heat exchanger and the reactor for admixing the superheated steam with the solid fuel and for delivering the latter to the combustion chamber of the reactor.

11. A process for the production of synthesis gas, comprising the steps of reacting oxygen and a mixture of coal particles and superheated steam in a reaction zone to produce a product gas, passing the product gas in heat exchange relationship with water in a heat exchange zone to change the water to steam, flowing the product gas and steam from said first heat exchange zone in heat exchange relationship with each other in a second heat exchange zone to superheat the steam, flowing the superheated steam from the second heat exchange zone in admixture with relatively small coal particles, passing the product gas from the second heat exchange zone and the mixture of superheated steam and coal particles in heat exchange relationship with each other in a reheat zone to reheat the mixture, and flowing the mixture from the reheat zone to the reaction zone for reaction with oxygen therein.

A.

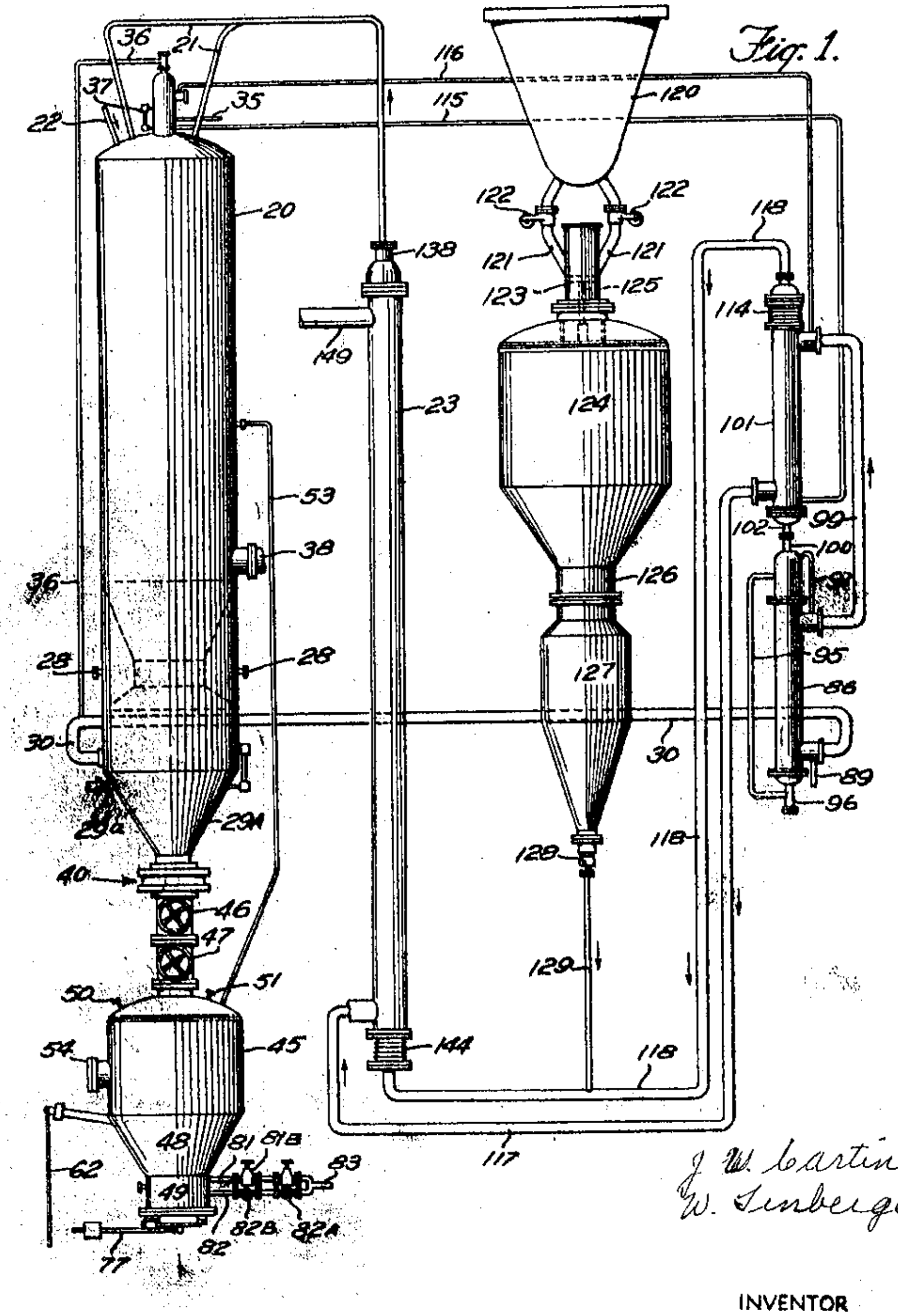

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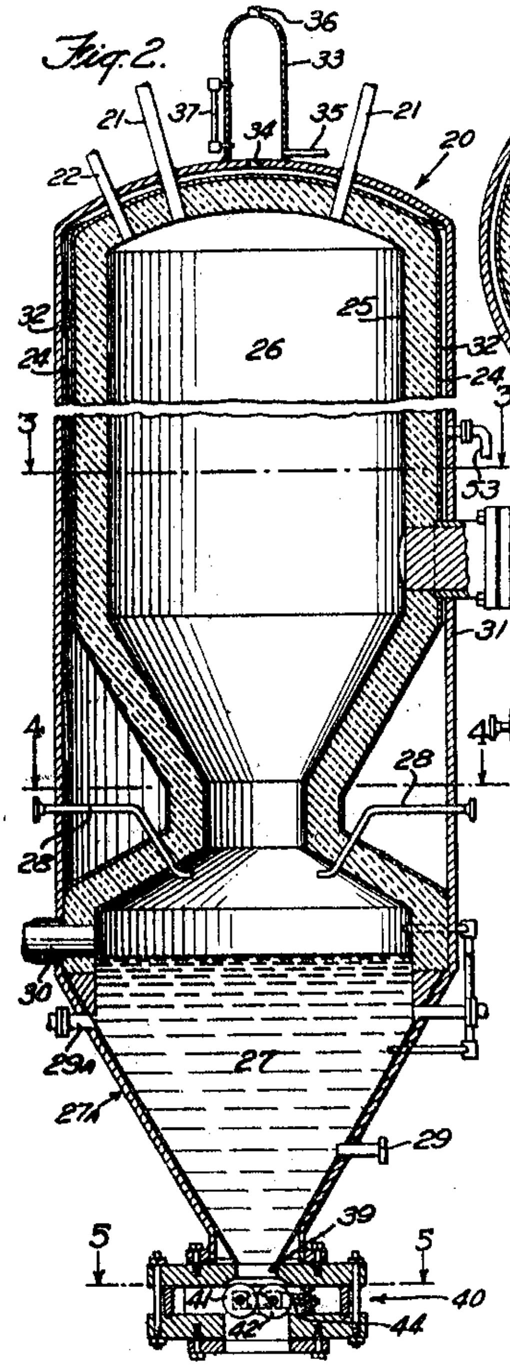
Fig. 2.



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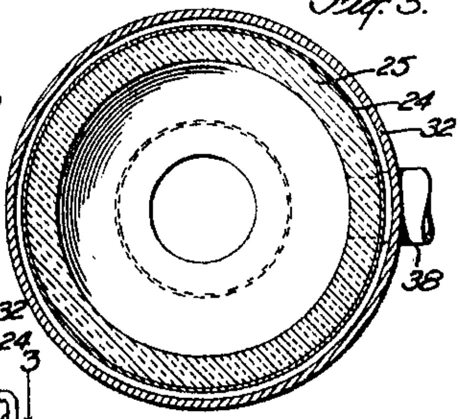

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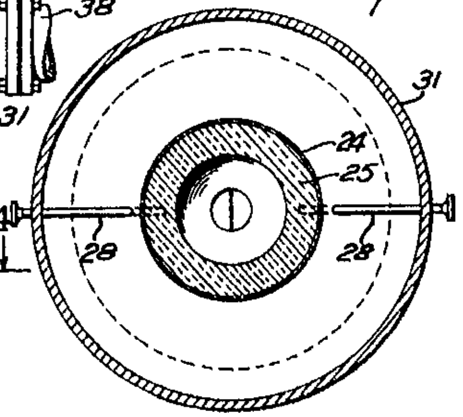

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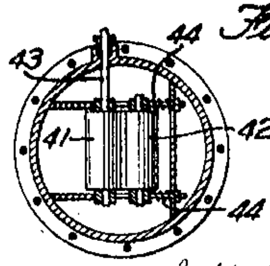

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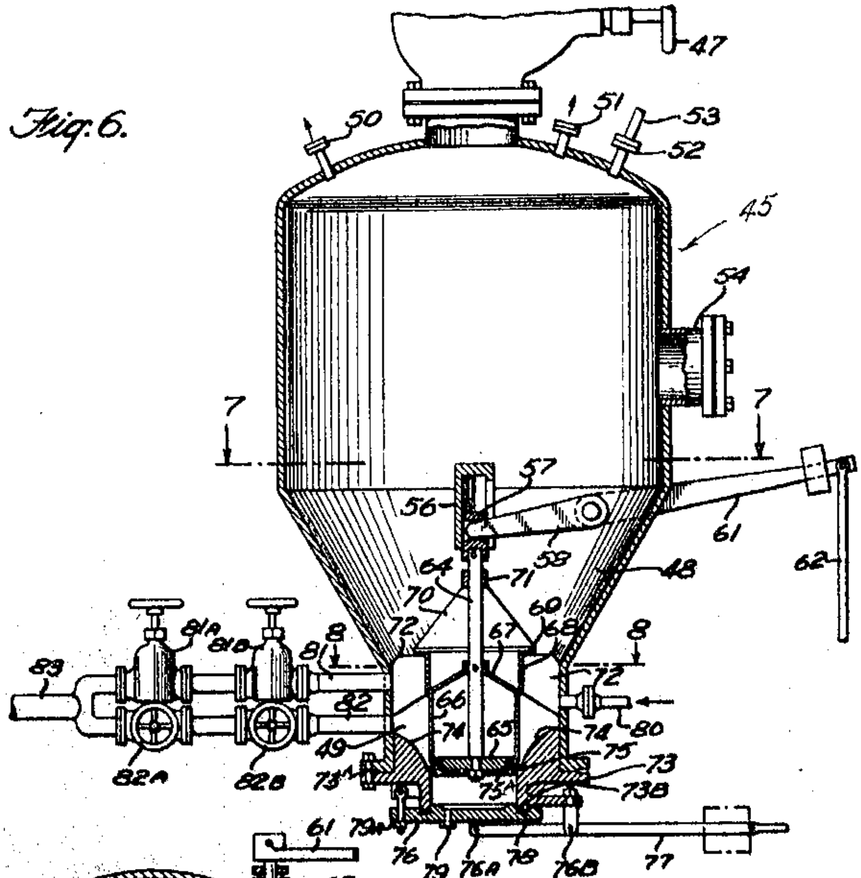
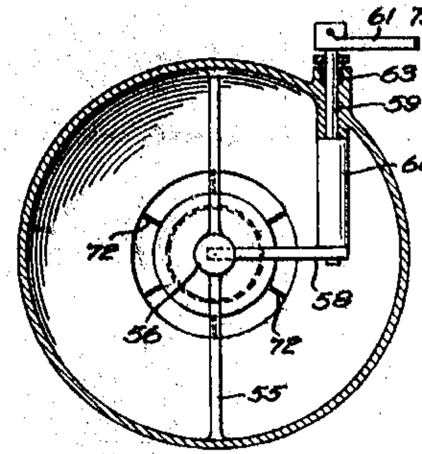
Fig. 6.





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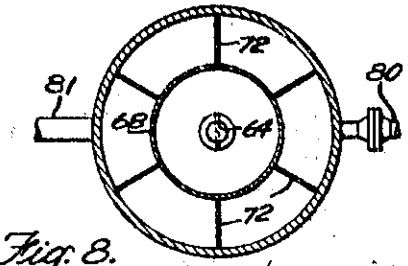

Fig. 8.

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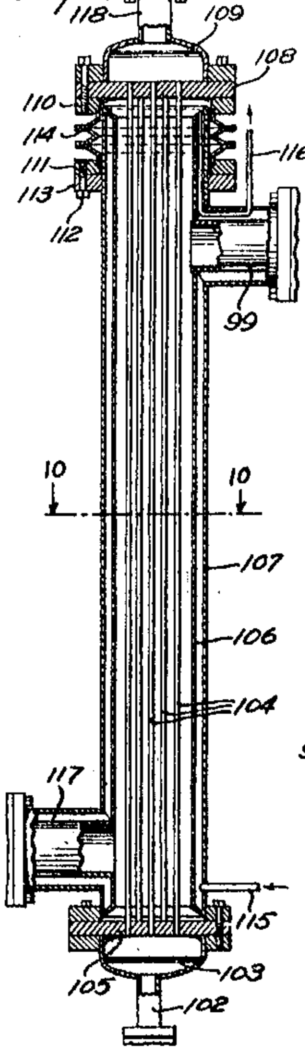
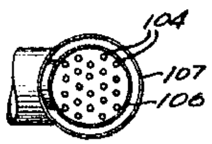
Fig. 9.





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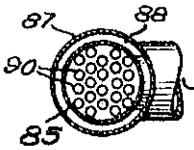

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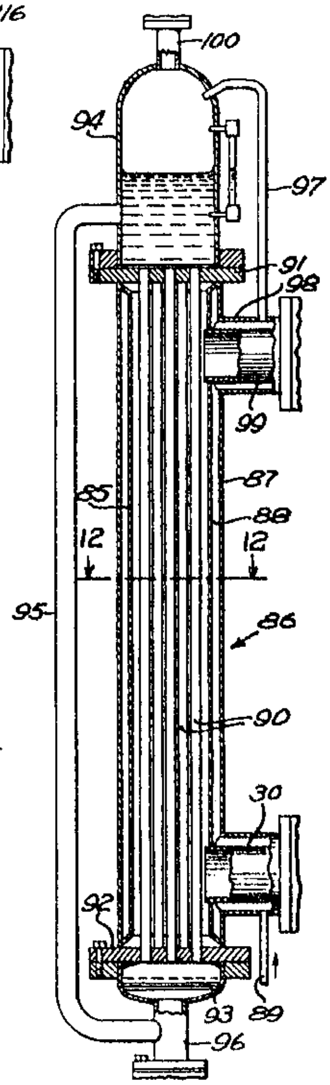


Fig. 11.

Fig. 14.

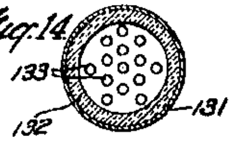
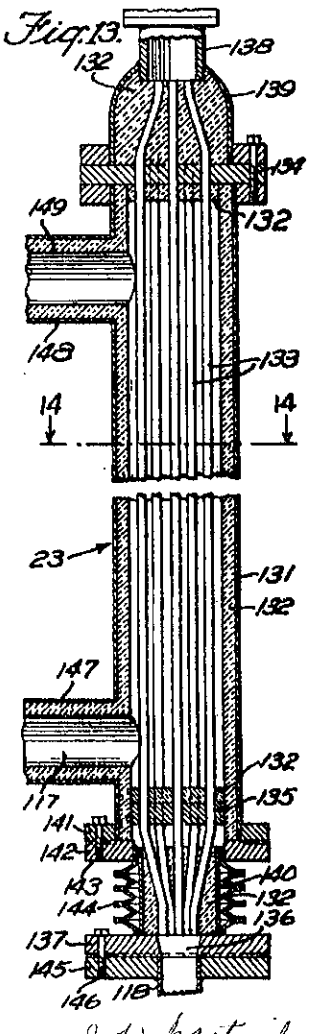


Fig. 13.



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