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(12) **Patent:** (11) **CA 596937**

(54) PRESSURE SHELL ENCLOSED SYNTHESIS GAS GENERATOR WITH TUBULAR HEAT EXCHANGER

(54)

(72) Inventors (Country):	**ERNEST A. BROOKS** (Not Available) **ROLFE SHELLENBERGER** (Not Available) **THEODORE S. SPRAGUE** (Not Available)
(73) Owners (Country):	**BABCOCK-WILCOX AND GOLDIE MCCULLOUGH**
(71) Applicants (Country):	
(74) Agent:	
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ABSTRACT

CLAIMS (English)

*** Note: Data on abstracts and claims is shown in the official language in which it was submitted.

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This invention relates to tubular heat exchanger and, more particularly, to a steam generator having its steam generating and superheating components disposed within and upright elongated circular row of steam generating tubes embraced by a cylindrical metal casing or pressure shell, the casing and tubes being in heat conductive contact but disconnected from each other except for being suspended from a common support at their upper ends which support is, in turn, suspended from an elevated support framework. The invention is further directed to a method of erecting such a steam generator.

The lower portions of the tubes forming the circular row are covered with an inner lining of refractory material, preferably built of refractory shapes, forming a combustion chamber in which the heating gases for the steam generator are produced. Certain of the tubes have their lower ends bent radially inwardly, downwardly, and then radially outwardly for connection into an annular header supplied with water by downcomers connected into a horizontal steam and water drum suspended from the framework at the upper end of the generator and projecting outside the casing at each end, the downcomers being outside the casing. The inwardly bent ends of the tubes support the refractory lined floor of the combustion chamber, with the bends at the inner ends of the radial tube portions defining an opening into a slag tank receiving slag from an axial opening in the floor. The bent sections of the tubes act as cantilever supports with the bending moments being absorbed at the annular header. The upper ends of all the tubes of the bank are connected into the drum, and the lower ends of

those tubes not bent radially inwardly are connected directly into the annular header.

The bottom floor of the combustion chamber is sealed. To effect such sealing while providing for differential expansion of the bent tube ends, V-shape metal plates are placed between adjacent tubes and welded thereto at their outer edges.

While the novel features of the steam generator are of general utility in the steam generating field, they are particularly adapted to use in a vertical synthesis gas reaction unit, or a coal gasifier, incorporating the steam generator to cool the product gases by utilizing heat extracted therefrom to generate steam either for use in the synthesis gas reaction or for other uses. In the synthesis gas reaction, a mixture of pulverized carbonaceous fuel (coal) with steam and commercially pure oxygen, or air, with the oxygen or air being in an amount insufficient to support complete combustion of the fuel, is burned in an exothermic reaction to raise the temperature of the reactants to a value high enough to support a subsequent endothermic reaction in which the reactants combined to form the synthesis gas.

A feature of the invention is the method of erecting the reaction unit. In this method, the steam and water drum is first suspended from an elevated part of a supporting structural framework. Next, a heavy circular ring, forming the common support for the circular row of tubes and the

cylindrical casing or shell, is suspended from the framework. The circular row of tubes is then suspended from its support, and the other tubes and connected elements assembled in position. Finally, the casing is assembled by first connecting an upper section and the top head to the support ring, and then proceeding section by section downward to the lower end of the casing, the latter being completed by assembly of the bottom head thereto. The casing, the projecting ends of the upper drum, and the downcomers are covered with heat insulating refractory.

For an understanding of the invention principles, reference is made to the following description to a typical embodiment thereof as illustrated in the accompanying drawings. In the drawings:

Fig. 1 is an axial sectional view through a vertically disposed, cylindrical atmospheric pressure pulverized coal gasifier unit incorporating the steam generator of the invention;

Figs. 2 and 3 are enlarged axial sectional views of, respectively, the upper and lower ends of the gasifier unit;

Figs. 4 and 5 are enlarged part elevation and part axial sectional views of the upper and lower ends of the unit, the views being at right angles to those of Figs. 1, 2 and 3;

Figs. 6 and 7 are diametric sectional views on the correspondingly numbered section lines of Fig. 1;

Fig. 8 is a greatly enlarged partial sectional view illustrating the suspension of the cylindrical tube bank and its enclosing casing;

Fig. 9 is a greatly enlarged partial diametric sectional view of the tube bank and casing;

Fig. 10 is a vertical sectional view, on the line 10-10 of Fig. 3, illustrating the floor sealing construction;

Fig. 11 is a top plan view of the steam generator;

Fig. 12 is an enlarged axial sectional view of the slag outlet;

Fig. 13 is a diametric sectional view, on the line 13-13 of Fig. 1, illustrating a soot blower arrangement;

Fig. 14 is a sectional view on the line 14-14 of Fig. 13 illustrating a soot blower support;

Fig. 15 is a top plan view, partly in section, corresponding to Fig. 14;

Figs. 16, 17 and 18 are partial elevation views illustrating the method of erecting the steam generator;

Fig. 19 is an elevation view of the cylindrical casing of the steam generator; and

Fig. 20 is a diametric sectional view on the line 20-20 of Fig. 19.

Referring to Fig. 1, the synthesis gas reaction unit, or coal gasifier 15 incorporating the steam generator embodying the novel features of the invention, is suspended from cross beams 11 of a structural steel framework 10 including columns 12 and other beams 13 supporting beams 11. Rods 14, adjustably secured to depend from beams 11 as indicated at 16, have clevises 19 on their lower ends hingedly connected to upright elongated plates 20 by means of pins 18 as best seen in Fig. 8.

Plates 20 extend partially through radial slots in the periphery of an upper dished head 21 having a layer of insulation 22 on its outer surface. The lower end of each bar 20 has a substantially rectangular notch 23 fitting a heavy annular ring 25, the bars 20 being welded to ring 25 as indicated at 24. Ring 25 serves as the common connection and suspension means for an elongated upright cylindrical outer shell 30 enclosing an upright circular row of steam generating tubes 40. Ring 25 also supports head 21, whose rim is welded to ring 25 as indicated at 26.

Casing 30, which has an outer layer of insulation 31 thereon, is secured at its upper end to ring 25 by weld 32 and is thus suspended from the ring. Plates 27 welded to the under edges of ring 25 at substantially 4° centers therearound and have holes receiving pins 28 in clevises 33 on rods 34. The lower ends of rods 34 have plates 36 welded thereto and secured to plates 35 by pins 29. Plates 35 are contoured for welding to inwardly curved portions of tubes 40, so that these tubes, comprising the circular row enclosing the main portion of the unit, are thus suspended from ring 25. As casing 30 and tubes 40 are interconnected only at their upper ends through ring 25, the casing and tubes may expand downwardly independently of each other. The inner surface of casing 30 is in heat conductive contact with tubes 40 so as to maintain the casing and tubes at substantially equal temperatures to minimize differential expansion.

Casing 30, as described more fully hereinafter, is preferably formed of arcuately bent sections of 1/2" steel plate, the sections preferably extending through arcs of 120° and being welded to each other with the vertical seams of vertically adjacent sections preferably staggered circumferentially of the casing. Casing 30 is designed to withstand a pressure of 130 psig.

Support for casing 30 and tubes 40 is also provided by steam and water drum 50 which is supported from beams 11 by U-shape hangers 51 and projects through casing 30 at each end as seen in Fig. 4. The projecting ends of the drum 50 are covered with insulation ~~52~~. As the upper ends of tubes 40 connect into drum 50, the drum also assists in supporting the suspended cylindrical tube bank.

The tubes 40 not only laterally enclose the steam generating and superheating components but also form the lateral and bottom walls of a combustion chamber 45 which supplies the heating gases for the steam generator. In the particular example selected for illustration, the heating gases comprise the hot products of a synthesis gas reaction of constituents introduced into chamber 45. More specifically, the synthesis gas comprises CO and H_2 produced by the reaction of pulverized carbonaceous fuel, steam, and air or commercially pure oxygen introduced into chamber 45. The air or oxygen, which is supplied in an amount less than required for complete combustion of the fuel, is used for combustion of the pulverized carbonaceous fuel in the presence of steam, this combustion being an exothermic reaction to raise the

temperature of the reactants to a level at which a succeeding endothermic reaction will occur to form the synthesis gas as the hot gases pass over the steam generating and superheating sections of the steam generator and are cooled thereby.

The lateral walls of the furnace or combustion chamber 45 are provided by built up refractory linings on the inner surface of tubes 40, supported from the furnace floor and extending over substantially half the height of the tube row. The lining is indicated as comprising three layers 41, 42 and 43 which are built up of refractory shapes. The layer 41 immediately against the circumferentially substantially contiguous studded tubes 40 may comprise 4 1/2 inch thick refractory shapes and extends substantially the full height of furnace 45. The intermediate layer 42 may comprise 9 inch thick refractory shapes and extends the full height of furnace 45 and overlaps the upper end of layer 41. The innermost layer 43 may also comprise 9 inch thick refractory blocks, and extends for substantially half the height of furnace 45.

Referring to Figs. 3 and 12, the refractory lined furnace floor is provided by bending the lower ends of alternate tubes 40 radially inwardly and slightly downwardly as indicated at 44. The intermediate tubes are connected into a lower annular header 55 or into an arcuate stub header 56 connected at each end into header 55. The inner ends of bent sections 44 are curved downwardly and radially outwardly, forming bights 46, for connection into header 55.

As the bent portions of the alternate tubes 40 approach the axis of the unit, they converge toward each other. To accomodate such conversion and to permit the radially innermost ends or bights of the bent sections to be substantially contiguous, every other alternate tube 40 is curved downwardly and laterally outwardly for connection into header 55, as indicated at 47 at a point intermediate the header 55 and the bights 46 in bent tube ends 44.

The downwardly curved innermost ends 46 of tubes 40 have welded thereto a peripherally notched flange 37 to the inner edge of which is welded an outer cylindrical ring or band 38 welded at its bottom, to an inner cylindrical ring or band 48 spaced from band 38 except at the welded connection therebetween. Ring 48 defines a large diameter slag passage communicating with a small diameter axial slag outlet 49 of furnace 45. Band 38 freely telescopes into an angular annulus 67 welded to the upper end of an outer, relatively thick metal shell 54 having an inner, relatively thin metal shell 53 supported in concentric, circumferentially spaced relation therewith by a relatively heavy flange 59 welded to the bottoms of shells 53 and 54. Outer shell 54 is welded into an axial opening in the lower dished head 64 of casing 30, and inner shell 53 further defines the slag passage leading into a slag quenching and cooling tank or container (not shown). A water inlet connection 68 is connected to the space between shells 53 and 54, it being noted that shell 53 is of less height than shell 54 so as to provide a gap between the annulus 67 and the upper end of shell 53.

A helical coil 56 is mounted on an angular annulus 39 welded to the upper end of ring 48 and is supplied with cooling water. It will be noted that this helical coil is substantially frusto-conical so that its upper and smaller diameter end defining slag outlet 49 is substantially above the level of the furnace floor 57. The upper runs of the inwardly bent ends of tube 40 are studded for supporting the refractory lining of the furance floor. In operation, an annular pool of slag accumulates on floor 57 up to the level of outlet 49, thus serving as some protection for the refractory lining of the floor.

A slag knocker 58 in the form of a water cooled tube having an upward arch section is mounted immediately beneath slag outlet 49, with the arch section being oscillatable about the axis of the unbent portions of the tube which extend coaxially in diametrically opposite directions through rings 38 and 48, one unbent portion being extended outside casing 30 as seen in Fig. 3, for oscillation of the slag knocker. At one limit of the oscillation, the slag knocker 58 abuts a water cooled tubular stop 69 connected to a spray ring 60 supplied with suitable cooling fluid as is also helical coil 61. Stop 69 has a channel 74 secured in embracing relation thereon and having serrated edges for dislodging slag from knocker 58.

It is desired that the furnace floor 57 be completely sealed. Therefore, a metal sealing means must be provided between the bent ends of tubes 40 as these converge toward each other. This introduces the problem of compensating for expansion of the tubes 40. Referring to Fig. 10, the

expansion spaces between the tubes 40 are sealed by plates 65 bent radially to form a vee and having their outer edges welded to adjacent tubes 40 as indicated at 66. These bent plates are suitably cut to fit the spaces between tubes 40 and to accomodate tube bights 47 during expansion and contraction, bent to maintain the sealing of the floor 57.

Water is supplied from drum 50 to annular header 55 by downcomers 62 connected at their upper ends into the outer ends of drum 50, and covered with insulation. The lower ends of downcomers 60 are connected to header 55 at uniformly circumferentially spaced intervals by means of bent tubes 63. The tubes 63 may be suitably enclosed in an insulated casing section 89 and extend through thermal sleeves 95 in head 64.

Portions of the tubes 40 defining the furnace or combustion chamber 45 are suitably bent, at uniformly spaced intervals around the circumference of the combustion chamber, to form openings for burners 70 for introducing the reactants into chamber 45, and for gas burners 71 which may be used to bring the furnace up to its operating temperature. The tubes 40 are also suitably bent to provide access openings 72 closed by refractory filled doors 73. The spaces defined by the outer surfaces of adjacent tubes 40 and the inner surface of casing 30 are packed with refractory 109 as best seen in Fig. 9.

The portions of tubes 40 forming the lateral wall of the unit above the furnace or combustion chamber 45 generate steam by radiant heat absorption from the hot reactants leaving chamber 45. In addition to their outer-wall-forming function, the tubes 40 also define the major gas pass

75 containing the boiler tube banks and superheater of the steam generator. These tubes, in the specific example selected for illustration, may be 3 1/4 inch O.D. tubes which are fully studded wherever they are in contact with a refractory lining and are substantially contiguous circumferentially to at least the upper end of the refractory lined furnace 45.

A short distance above the upper end of furnace 45, alternate tubes 40 are bent inwardly from opposite sides of the unit, as indicated at 76, and then vertically upward to form parallel vertical walls defining the transverse gas pass 75 in which are disposed the steam generating and superheating sections of the steam generator. The vertical tube portions 77 comprise 4 1/2 inch O.D. diameter tubes which are swaged to form the 3 1/2 inch O.D. tubes 40. The bottom wall of gas pass 75 is formed by inwardly and upwardly extending 4 1/2 inch O.D. tube sections 78 which are swaged to 3 1/2 inch O.D. at their lower and outer ends for connection into wall tubes 40. A plastic refractory lining 79 is placed over the bottom tube sections 78, and the upper and inner ends of these tube sections support a relatively thick refractory wall 81. The upper and inner ends of tube section 78 are swaged to 3 1/4 inch O.D. for connection to screen tubes 82. Tubes 82 are spaced on approximately 6 inch centers to form a vertical screen at the entrance to gas pass 75, as best seen in Fig. 4, and the upper ends of tubes 77 are swaged to 3 1/2 inch O.D. for connection into drum 50. Screen tubes 82 are also connected into drum 50, as are the upper ends of the tubes 40 continued along the inside of casing 30.

The upper ends of these latter tubes are bent radially inwardly and at a slight upward angle to connect into drum 50 and are covered with a layer of refractory 83 to form, in cooperation with drum 50, the roof of the gas pass 75. Immediately above the tube sections 78, the tubes 40 continued along the inside of casing 30 are bent outward, as at 86, to provide a side outlet leading to economizer 80.

The steam generating section includes a lower drum 85 connected by banks of tubes 87 to upper drum 50. The drums 50 and 85 are vertically aligned but offset somewhat from a diameter of casing 30. Drum 85 has an access opening or manhole 84. There are two boiler tube banks formed by generally upright tubes 87. All of the boiler tubes are 2 1/2 outside diameter tubes arranged in rows spaced 6 inches apart center to center, with the tubes in each row being on 4 inch centers. The front boiler tube bank comprises 10 rows each having 22 tubes, and the rear boiler tube bank comprises 11 rows each having 22 tubes, with there being a vertical space between the two banks. Lower drum 85 abuts against refractory wall 81, and some of the tube sections 77 are bent outwardly to enclose the outer ends of the lower drum, as shown in Fig. 7. Those portions of the walls formed by tubes 77 adjacent the boiler tube banks are covered with an outer layer of refractory, as indicated at 91. The tubes 77 in advance of the boiler tube banks and adjacent superheater 90 are completely covered with refractory, as indicated at 92.

Saturated steam from drum 50 is delivered from a saturated steam line 88 to the inlet heater 93 of superheater 90. This is a pendant type, parallel flow superheater comprising 2 inch O.D. tubes 94 connected into heater 93 and 1 1/2 inch O.D. tubes 96 connected into superheater outlet header 97. The lower end of the superheater 90 extends to a point adjacent refractory wall 81, and this section of the superheater comprises an elongated multiple sinuous loop. The tubes connected directly into outlet header 97 form a shorter loop adjacent the upper end of gas pass 75. A superheated steam line 98 delivers superheated steam from outlet header 97 to a flanged steam supply connection 99 outside the shell.

The hot gases from furnace 45 flow upwardly and to the left, as viewed in Fig. 1, being deflected by the lower wall of gas pass 75. They then turn and flow between screen tubes 82 and along gas pass 75 across the tubes of superheater 90. The somewhat cooler gases then flow along pass 75 through the two boiler tube banks, sweeping over the under surface of drum 50 and the upper surface of drum 85. The further cooled gases then flow through the outlet of gas pass 75 formed by the bent out tube portions 86.

Connected to this outlet is a converging conduit section 100 directing the gases to economizer 80. Conduit section 100 is made up of insulating casing sections 101, 102 and 103 interconnected by expansion joints 104 and 105. An expansion joint 106 connects section 103 to the upper end of an insulated casing section 107 enclosing economizer 80. The economizer comprises four (4) horizontal tube banks

108 each comprising 2 inch O.D. tubes extending transversely of casing 107. All except the second highest section 108 comprise 11 rows of horizontal tubes having a vertical spacing of 3 inches, with there being 15 tubes in each row at a lateral spacing of 3 1/2 inches. The second highest section 108 comprises 12 rows of tubes with a vertical spacing of 3 inches, with each row having 15 tubes on 3 1/2 inch centers.

A water supply pipe 110 delivers feed water to the lower header 111 of economizer 80, and heated feed water from upper header 112 is delivered through a control valve 113 to a feed water line 114 connected by a valve 115 to drum 50. Water from drum 50 flows into drum 85 through riser tube 87. The water also flows through downcomers 62 and pipes 63 into annular header 55 and its connected stub header 56, where it is supplied to the lower ends of water wall tubes 40.

Some heat is extracted from the hot slag falling through slag opening 49. Other heat is absorbed by the exposed portions of wall tubes ~~45~~ 40 above furnace 45 to generate steam in these tubes. Steam is also generated in the boiler tubes 87 connecting drums 50 and 85. Suitable steam and water separating means may be incorporated in drum 50 so that only saturated steam is delivered to line ~~92~~ 88. The outlet temperature of superheated steam from header97, in the specific embodiment illustrated, is approximately 600 F.

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The reactants leaving economizer 80 are cooled substantially to a stabilizing temperature and are then processed as desired. The steam from connection 99 may be used in the coal gasification process or may be used otherwise.

In the gasification of coal to form synthesis gas, there is a carry over of soot through the steam generator, resulting in soot deposits accumulating on the heat exchange surfaces. For efficient extraction of heat from the gases sweeping over the tube surfaces, the soot deposits must be periodically removed before they have built up to any substantial depth. For this purpose, soot blowers 120 are mounted in gas pass 75, at the locations indicated in Fig. 1, a typical mounting of a soot blower being illustrated in Figs. 13, 14 and 15.

To position the soot blower, a short piece of heavy walled pipe 116 is welded to casing 30 concentric with an opening in the casing having a diameter substantially equal to the I.D. of the piece of pipe. This opening is so located that soot blower 120 may be positioned as to dislodge soot from a selected bank of tubes, such as the tubes 96 of superheater 90 in the specific illustration of Figs. 13, 14 and 15. The wall tubes 40 and gas pass defining tubes 77 may be suitably bent out of line to form openings for the soot blower.

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Apertured support members 117 are welded to spaced entrance tubes 87 of the first boiler bank, with their apertues 118 substantially coaxial with pipe 116. Soot blower 120 is then inserted through pipe 116 and supports 117 and positioned so that its nozzle or discharge openings 120 are directed toward superheater tubes 96. The soot blower is secured in position by suitable coupling means, generally indicated at 122 and cooperable with pipe 116. In operation, steam or air discharged from nozzle openings 121 toward tubes 96 dislodges soot accumulations from the latter.

A feature of the invention is the method of erecting the unit as illustrated in Figs 16 through 20. After the framework 10 has been erected, drum 50 is suspended from beams 11 by hangers 51 and ring 25 with top head 21 welded thereto, is suspended from the beams by rods 14. The tubes 40 are then supported from ring 25 by rods 34 and connected into drum 50, after which the boiler pass tubing and superheater tubing is erected. The boiler pass tubing is connected into lower drum 85 supported on the portions of tube 40 forming gas pass 75, and the superheater tubing is connected into its headers which are supported from tubing 40.

After the assembly of the steam generator has been completed, the casing 30 is erected. Casing 30 comprises four vertically adjacent sections or rings 30-1, 30-2, 30-3, and 30-4, each formed of three horizontally arcuate plates 130. Each plate has an arcuate extent of

substantially 120°. The plates 130 of the top ring 30-1 are first suitably cut to form openings 131 for the projecting ends of drum 50. These top plates are then welded to ring 25 by welds 32 (Fig. 1) and the circumferentially adjacent edges are butt welded. At the openings 131, the plates are welded to drum 50, preferably to metal annuli welded in embracing relation on the drum adjacent its ends. The rings 30-2, 30-3, and 30-4 are then successively assembled in a downward direction by welding their plates 130 to the bottom edges of the ring next above and then butt welding the circumferentially adjacent edges of their plates 130 to each other. Finally, the enclosure is completed by welding bottom head 64 to the lower edge of ring 30-4. The downcomers 62 are then connected to the header 55 by tubes 63 extended through thermal sleeves ~~95~~ in head 64. The superheater outlet connection 99 may be made through a thermal sleeve (not shown) in top head 21.

While a specifc embodiment of the invention has been shown and described in detail to illustrate the application of the invention principles, it will be understood that the invention may be embodied otherwise without departing from such principles.

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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a synthesis gas reactor, an upwardly extending circular row of steam generating tubes; a cylindrical metal casing laterally enclosing said tube row; a supporting framework; a support means interconnecting the upper ends of said tubes and said casing; means suspending said support means from said framework, whereby said casing and said tubes may expand downwardly independently of each other; a refractory-lined reaction chamber enclosed within the lower portion of said row of tubes, the lower ends of the tubes of said row being connected into an annular header, with alternate tubes being connected directly into said header and the intermediate tubes between said alternate tubes being bent radially inwardly, above said header, and then radially outwardly into said header to form, with the alternate tubes, cantilever truss supports for the refractory lining of the floor of said chamber, with the bending moments being absorbed at said header, the bights of inwardly bent intermediate tubes defining a slag passage having a diameter not greater than one-half that of said circular row; and burner means for introducing a mixture of pulverized fuel, steam and an oxygen-containing gas into said chamber.

2. In a steam generator, an upwardly extending circular row of steam generating tubes; a cylindrical metal casing laterally enclosing said tube row; a supporting framework; a support means interconnecting the upper ends of said tubes and said casing; means suspending said support means from said framework, whereby said casing and said tubes may expand downwardly independently of each other; and a

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refractory-lined combustion chamber enclosed within the lower portion of said row of tubes, the lower ends of the tubes of said row being connected into an annular header, with alternate tubes being connected directly into said header and the intermediate tubes between said alternate tubes being bent radially inwardly, above said header, and then radially outwardly into said header to form, with the alternate tubes, cantilever truss supports for the refractory lining of the floor of said chamber, with the bending moments being absorbed at said header, the bights of inwardly bent intermediate tubes defining a slag passage having a diameter not greater than one-half that of said circular row.

3. In a steam generator, an upwardly extending circular row of steam generating tubes; a cylindrical metal casing laterally enclosing said tube row; a supporting framework; a support means interconnecting the upper ends of said tubes and said casing; means suspending said support means from said framework; whereby said casing and said tubes may expand downwardly independently of each other; a refractory-lined combustion chamber enclosed within the lower portion of said row of tubes, the lower ends of alternate tubes of said row having radially inwardly extending bends supporting the refractory lining of the floor of said chamber; and flexible metal plate means closing the spaces between adjacent bends and secured to the latter to seal said floor.

4. In a synthesis gas reactor, an upwardly extending circular row of steam generating tubes; a cylindrical metal casing laterally enclosing said tube row; a supporting framework; a support means interconnecting the upper ends of said tubes and said casing; means suspending said

support means from said framework; whereby said casing and said tubes may expand downwardly independently of each other; a refractory-lined reaction chamber enclosed within the lower portion of said row of tubes, the lower ends of alternate tubes of said row having radially inwardly extending bends supporting the refractory lining of the floor of said chamber; flexible metal plate means closing the spaces between adjacent bends and secured to the latter to seal said floor; and burner means for introducing a mixture of pulverized fuel, steam, and an oxygen-containing gas into said chamber.

5. In a synthesis gas reactor, an upwardly extending circular row of steam generating tubes; a cylindrical metal casing laterally enclosing said tube row; a supporting framework; a support means interconnecting the upper ends of said tubes and said casing; means suspending said support means from said framework, whereby said casing and said tubes may expand downwardly independently of each other; a refractory-lined reaction chamber enclosed within the lower portion of said row of tubes, the lower ends of the tubes of said row being connected into an annular header, with some of said tubes being connected directly into said header and other of said tubes being bent radially inwardly, above said header, and then radially outwardly into said header to form, with said first named tubes, supports for the refractory lining of the floor of said chamber, with the bending moments being absorbed at said header, the bights of said inwardly bent second named tubes defining a slag passage from said reaction chamber; and burner means for introducing a mixture of pulverized fuel, steam and an oxygen-containing gas into said chamber.

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6. In a steam generator, an upwardly extending circular row of steam generating tubes; a cylindrical metal casing laterally enclosing said tube row; a supporting framework; a support means interconnecting the upper ends of said tubes and said casing; means suspending said support means from said framework; whereby said casing and said tubes may expand downwardly from said support means independently of each other; a combustion chamber enclosed within the lower portion of said row of tubes, the lower ends of some of said tubes of said row having radially inwardly extending bends supporting the floor of said chamber; and flexible metal plate means closing the spaces between adjacent bends and secured to the latter to seal said floor.

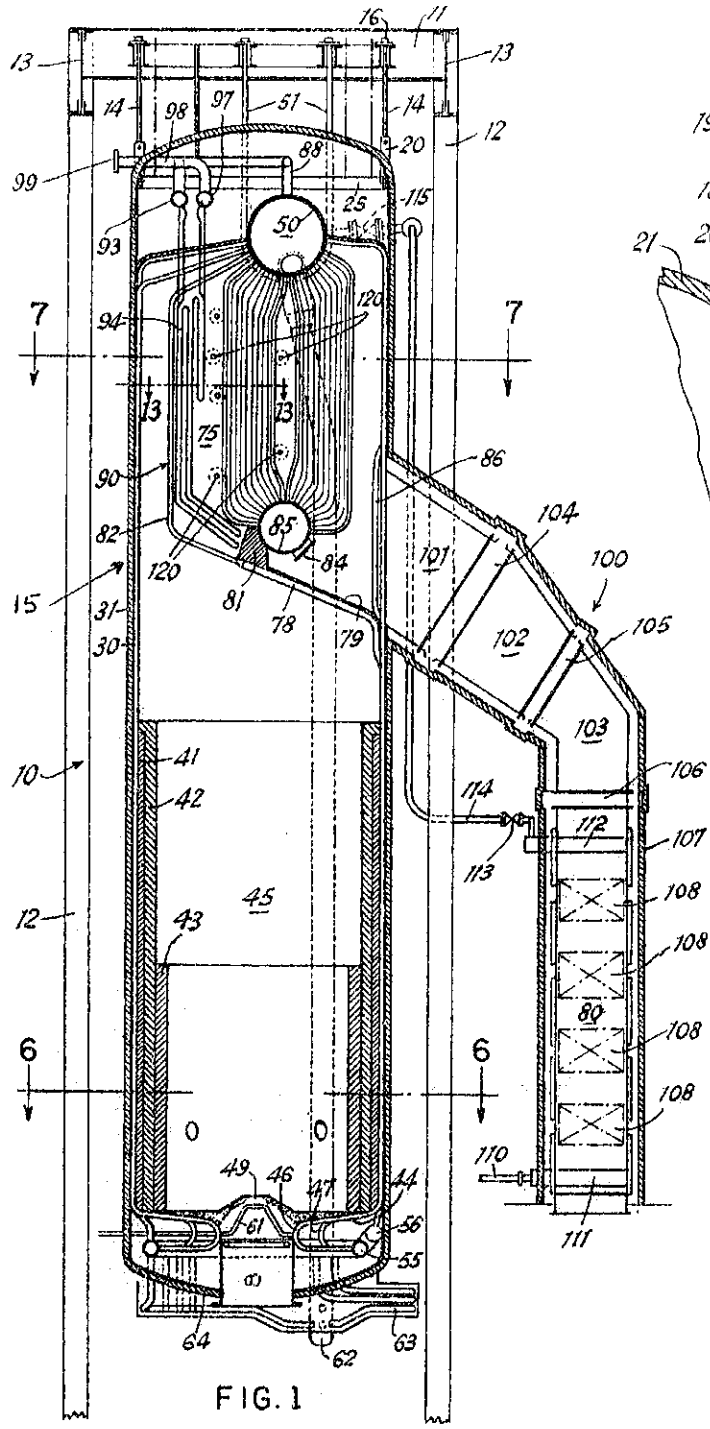


FIG. 1

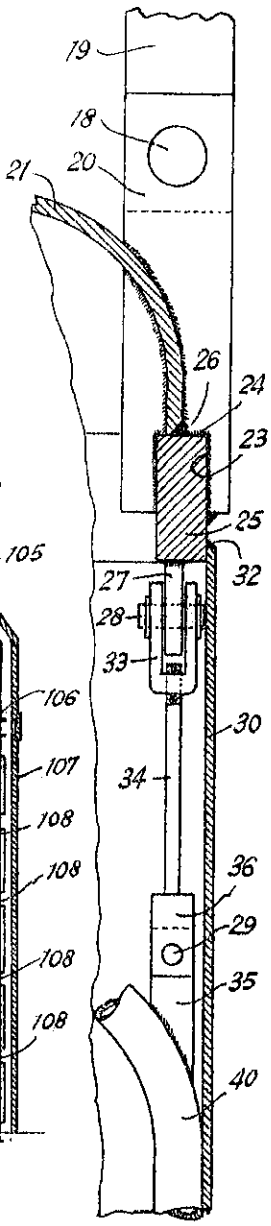


FIG. 8

INVENTORS
E.A. BROOKS
R. SHELLENBERGER
T.S. SPRAGUE
PATENT AGENT
Ridout & Maybee

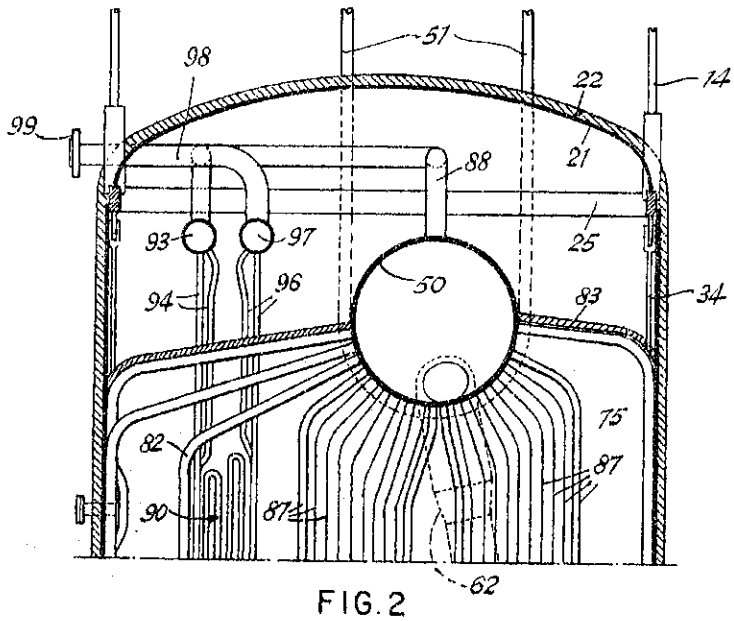


FIG. 2

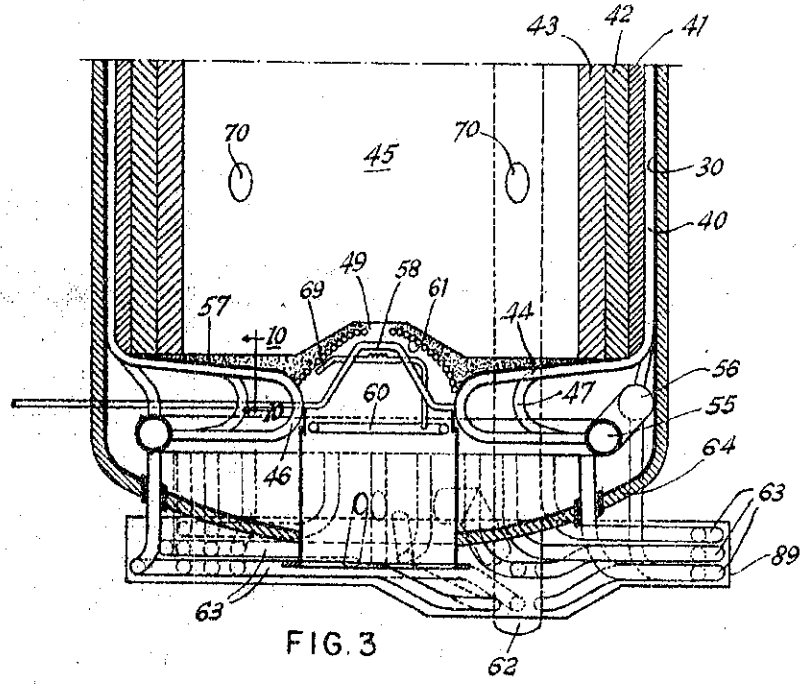


FIG. 3

INVENTORS
E.A. BROOKS
R. SHELLENBERGER
T.S. SPRAGUE

PATENT AGENT
Kidout & Maybee

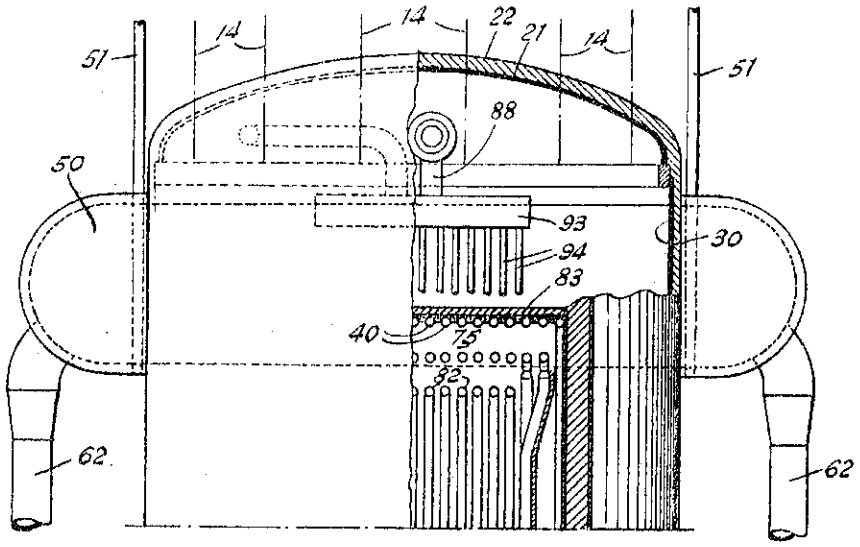


FIG. 4

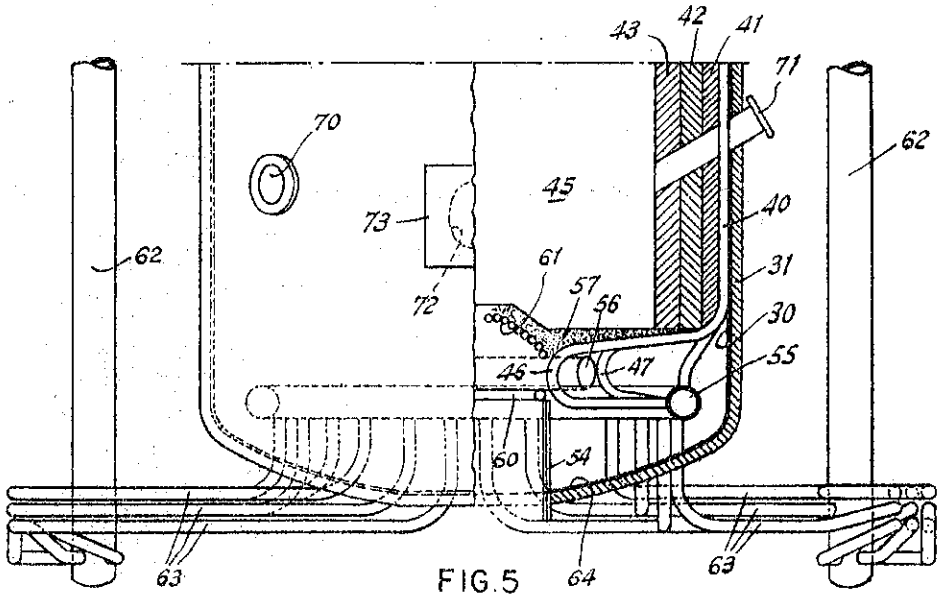


FIG. 5

INVENTORS
E.A. BROOKS
R. SHELLENBERGER
T.S. SPRAGUE
PATENT AGENT
Kidout & Maybee

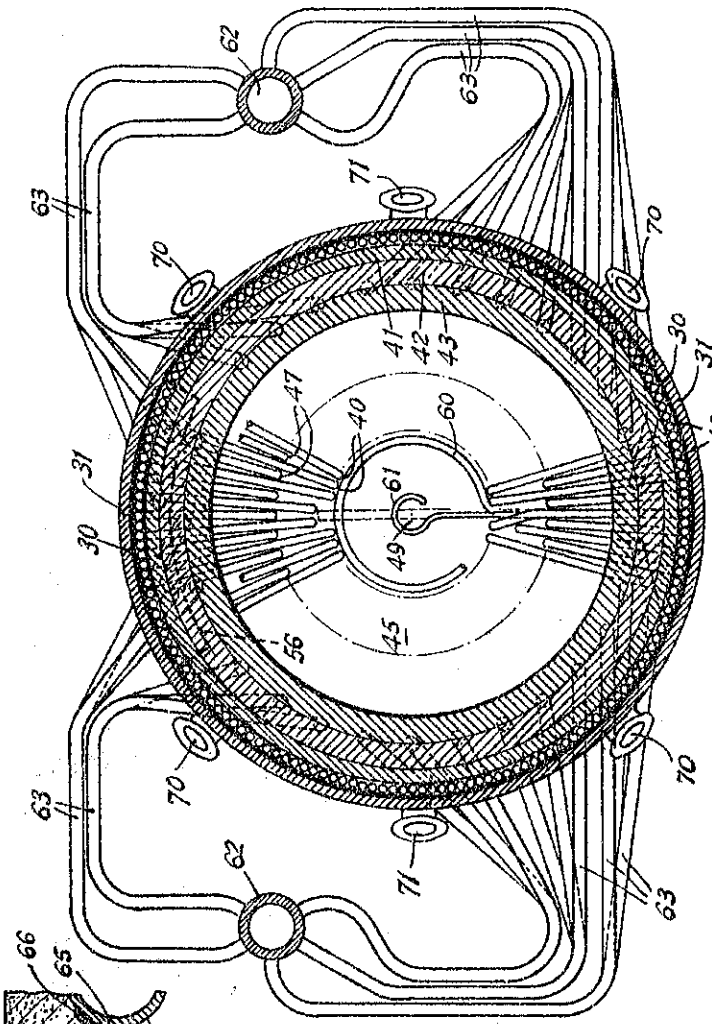


FIG. 6

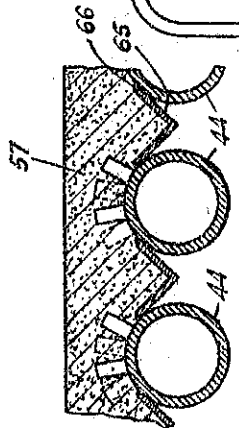


FIG. 10

INVENTORS
E. A. BROOKS
R. SHELLENBERGER
T. S. SPRAGUE
PATENT AGENT
Ridout & Maybee

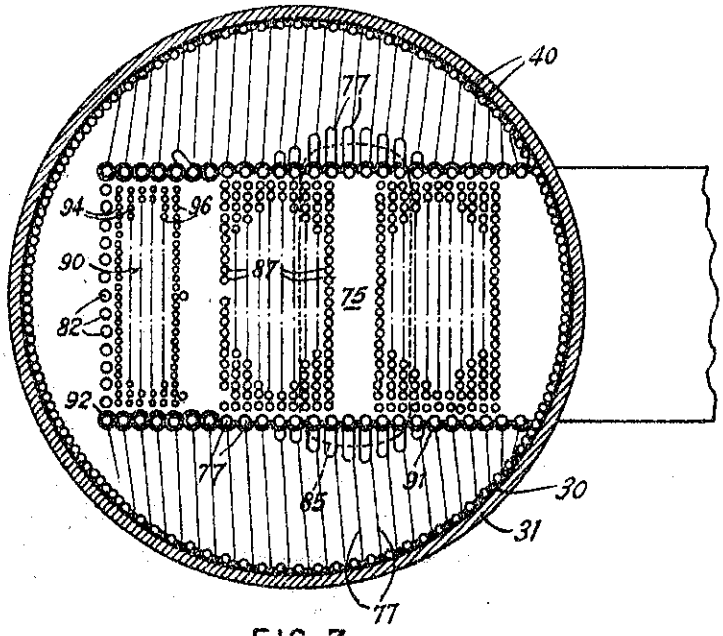


FIG. 7

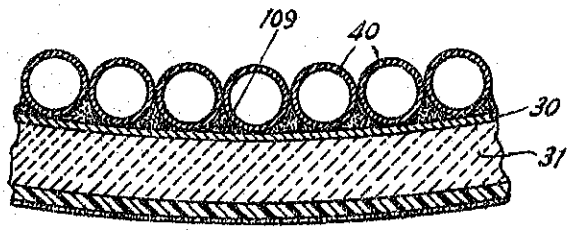


FIG. 9

INVENTORS
E.A. BROOKS
R. SHELLENBERGER
T.S. SPRAGUE
PATENT AGENT
Ridout & Maybee

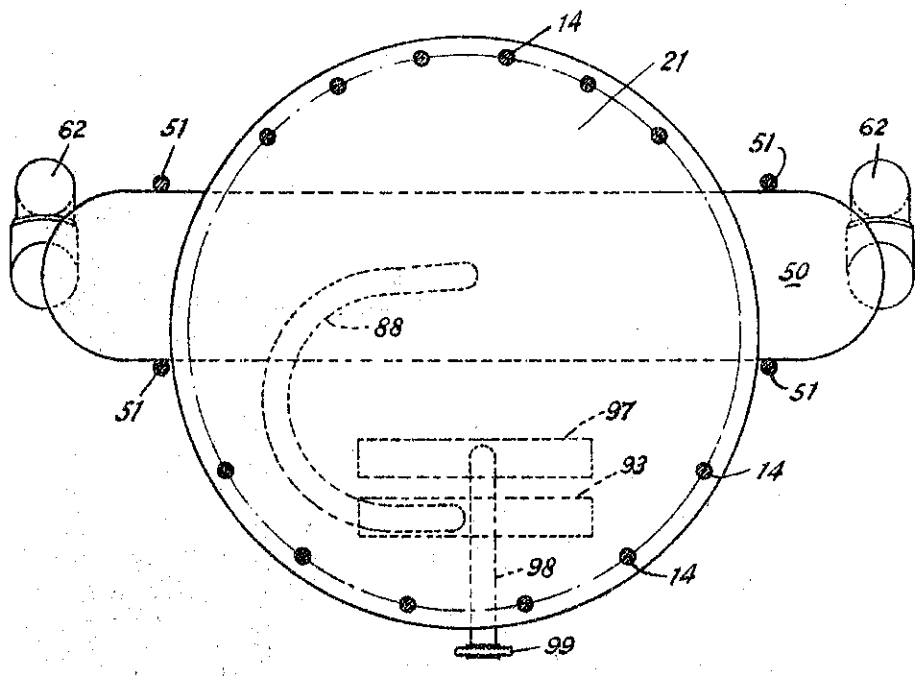


FIG.11

INVENTORS
E.A. BROOKS
R. SHELLENBERGER
T.S. SPRAGUE
PATENT AGENT
Ridout & Maybee

FIG. 13

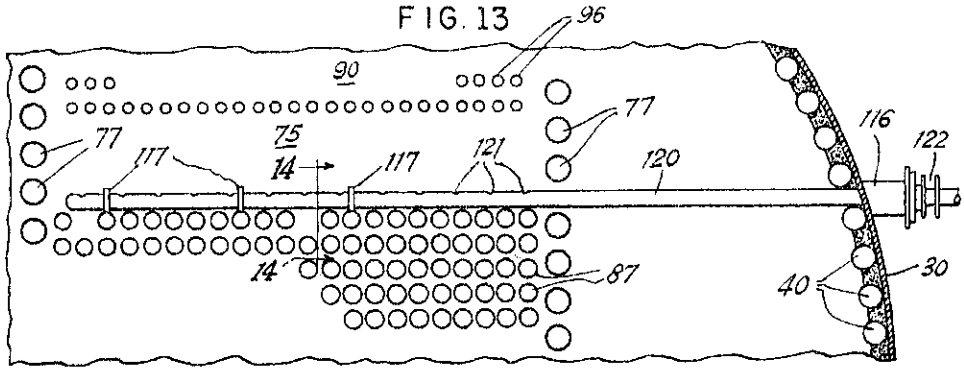
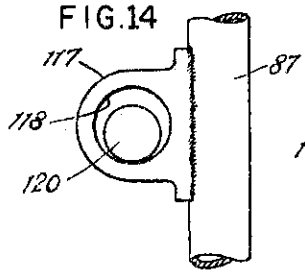


FIG. 14



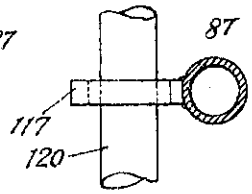


FIG. 15

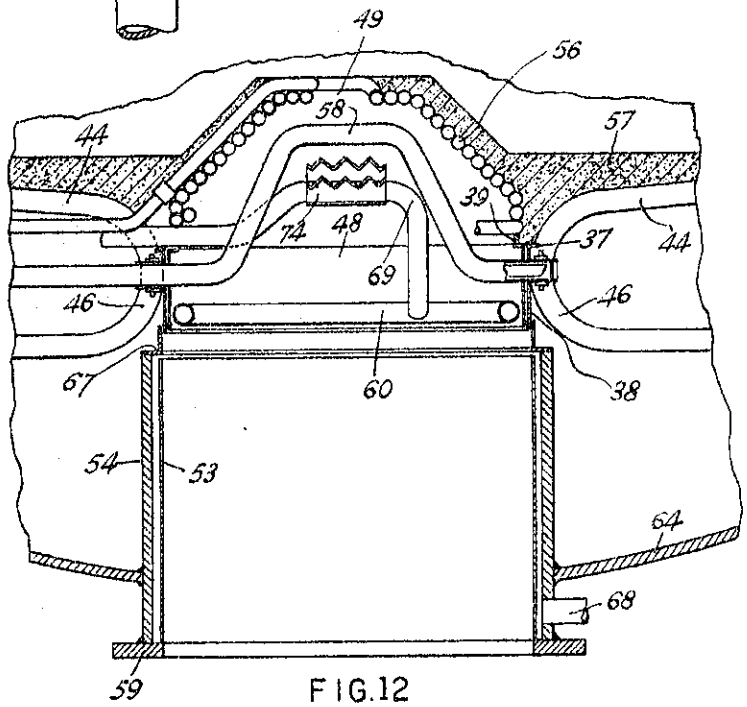


FIG. 12

INVENTORS
E.A. BROOKS
R. SHELLENBERGER
T.S. SPRAGUE
PATENT AGENT
Ridout & Maybee

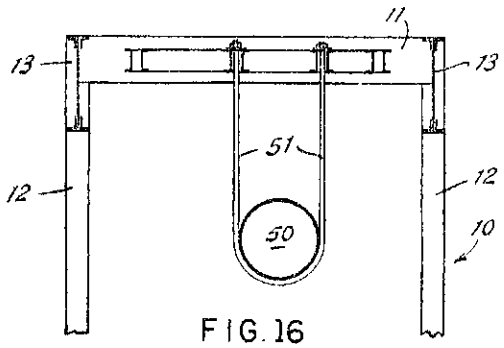


FIG. 16

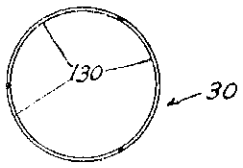


FIG. 20

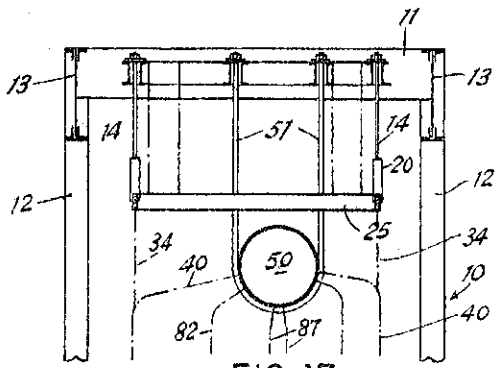


FIG. 17

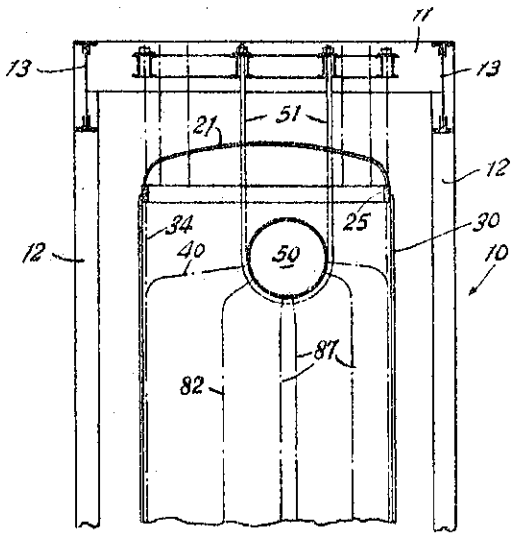


FIG. 18

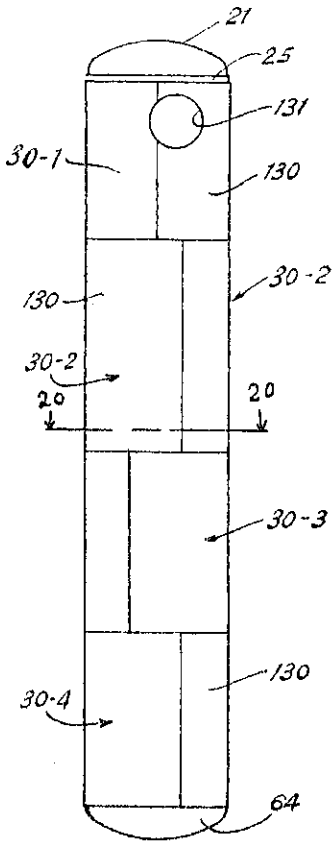


FIG. 19

INVENTOR S
E.A. BROOKS
R. SHELLENBERGER
T. S. SPRAGUE
PATENT AGENT

Kidout & Maybee