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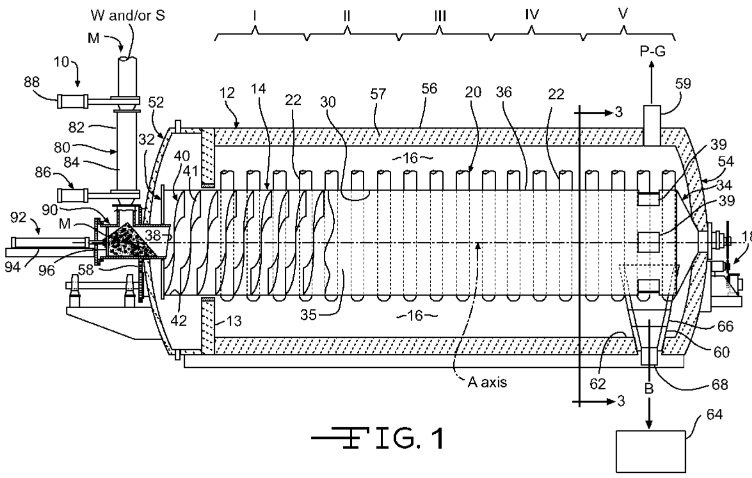

—FIG. 1

(57) Abstract: A process for the pyrolysis of at least one material includes: introducing the material into a pressurized rotary retort system, heating the material in the pressurized rotary retort system within a desired temperature range and within a desired pressure range for a desired period of time; and, advancing the heated and pressurized material from a first end to a second end of the pressurized rotary retort by rotating the pressurized retort about its longitudinal axis; where at least a quantity of the material is converted into one or more end products. Also the system generally includes: a pressurized rotary retort system configured for producing at least one gaseous product from pyrolysis of material, and having a pressurized furnace vessel and a retort positioned within the pressurized furnace vessel; and; a solids reactor system operatively connected to the rotary retort for receiving material from the pressurized rotary retort system.

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TITLE

PYROLYSIS SYSTEM

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CROSS-REFERENCE TO RELATED APPLICATIONS AND STATEMENT REGARDING SPONSORED RESEARCH

[0001] The present invention claims the benefit of the provisional patent application Ser. No. 61/218,197 filed June 18, 2009. This invention was made with no government support and the government has no rights in this invention.

BACKGROUND OF THE INVENTION

[0002] There is no admission that the background art disclosed in this section legally constitutes prior art.

[0003] To ensure a sustainable energy future, businesses are moving away from the current use of fossil fuel energy sources, such as gas, coal and petroleum, as the only sources of energy. Also, global climate change and possible decrease in the availability of fossil fuels are providing challenges to businesses and communities alike.

[0004] One solution being investigated is the use of organic materials (often called biomass feedstock) to both sequester carbon and to produce renewable energy. Generally, the biomass feedstock is heated to produce synthesis gas, or syngas, which is a gas mixture that contains varying amounts of carbon monoxide and hydrogen. For example, a pyrolysis process involves a thermal decomposition of the biomass feedstock organic materials at elevated temperatures under low-oxygen conditions.

[0005] While there are many proposed systems to process biomass feedstock, there remains an urgent need for more efficient and cleaner systems.

SUMMARY OF THE INVENTION

[0006] In a first broad aspect, there is provided herein a process for the pyrolysis of at least one material, that generally includes:

introducing the material into a pressurized rotary retort system;

heating the material in the pressurized rotary retort system within a desired temperature range and within a desired pressure range for a desired period of time; and,

advancing the heated and pressurized material from a first end to a second end of the pressurized rotary retort by rotating the pressurized retort about its longitudinal axis;

wherein at least a quantity of the material is converted into one or more end products.

[0007] In certain embodiments, the pressurized rotary retort system is configured for producing at least one gaseous product from pyrolysis of the material; and further including a gas reactor for receiving the gaseous product from the pressurized rotary retort system.

[0008] In certain embodiments, the material is supplied under elevated pressures and at elevated temperatures.

[0009] In certain embodiments, the pressure within the rotary retort system provides forces for driving the gaseous products from the rotary retort system.

[0010] In certain embodiments, the process further includes subjecting by-products of the pyrolysis process to a further pyrolization process.

[0011] In certain embodiments, the process further includes a solids system reactor for receiving a supply of un-pyrolyzed material and/or by-products from the rotary retort system.

[0012] In certain embodiments, the process further includes a solids reactor system operatively connected to the rotary retort for receiving un-pyrolyzed by-product and for generating at least one additional gaseous product.

[0013] In certain embodiments, a supply of the gaseous product is used to supply heat to the rotary retort system.

[0014] In certain embodiments, the process includes advancing the material through the pressurized rotary retort system using a plurality of flights positioned within the rotary retort system.

[0015] In certain embodiments, the rotary retort is rotated about a longitudinally extending axis at more than one speed.

[0016] In another broad aspect, there is provided herein a pyrolysis system that generally includes:

a pressurized rotary retort system configured for producing at least one gaseous product from pyrolysis of material; and having a pressurized furnace vessel and a retort positioned within the pressurized furnace vessel; and;

a solids reactor system operatively connected to the rotary retort for receiving and pyrolyzing un-pyrolyzed material from the pressurized rotary retort system.

[0017] In certain embodiments, the pyrolysis system further includes a gas reactor for receiving the gaseous product from the pressurized rotary retort system.

[0018] In certain embodiments, the material is supplied under elevated pressures and at elevated temperatures.

[0019] In certain embodiments, the pressure within the rotary retort system provides forces for driving the gaseous products from the rotary retort system.

[0020] In certain embodiments, the system further includes a heat exchanger system configured for capturing heat generated by pyrolysis of material and/or heat generated by production of gaseous products.

[0021] In certain embodiments, a supply of the gaseous product is used to supply heat to the rotary retort system.

[0022] In certain embodiments, the system includes advancing the material through the pressurized rotary retort system using a plurality of separately spaced flights positioned within the pressurized rotary retort system.

[0023] In certain embodiments, the pressurized rotary retort is rotated about a longitudinally extending axis at more than one speed.

[0024] Other systems, methods, features, and advantages of the present invention will be or will become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Figure 1 is a side elevational view, in cross-section and partially in phantom, of a rotary retort pyrolyzer system.

[0026] Figure 2 is a cross-sectional view, partially in phantom, an end view of the rotary retort pyrolyzer system shown in Figure 1.

[0027] Figure 3 is a cross-sectional view, partially in phantom, of the rotary retort pyrolyzer system taken along the line 3-3 in Figure 1.

[0028] Figure 4 is a side elevational view, in cross-section and partially in phantom, of a solids reactor system.

[0029] Figure 5 is a cross-sectional view, partially in phantom, of an end view of the solids reactor system shown in Figure, 4.

[0030] Figure 6 is a cross-sectional view, partially in phantom, of the solids reactor system taken along the line 6-6 in Figure 4.

[0031] Figure 7 is a schematic process flow diagram showing use of a rotary retort pyrolyzer system and a solid reactor system.

[0032] Figure 8 is a schematic illustration showing use of a rotary retort pyrolyzer system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0033] Described herein is a rotary retort system 10 that can be used for the thermal treatment of waste or other material M.

[0034] The material M being processed by the rotary retort system 10 is converted into a desired end product, described herein as a pyrolyzer gas product P-G. The rotary retort system 10 provides an improved and high heat transfer efficiency to the material M such that the pyrolysis process occurring within the system is more rapid than could previously be achieved. The substantially complete and rapid pyrolysis of the material M generally means that there need only be a relatively short residence time of the feedstock material within the rotary retort system 10. As such, in certain embodiments, the rotary retort system 10 can be configured to occupy a small, yet efficient area where a pyrolyzing process is needed.

[0035] Referring first to Figures 1-3, the rotary retort system 10 generally includes a pressurized furnace vessel 12 and a rotary retort 14. In the embodiment shown, the rotary retort 14 is co-axially positioned (about a longitudinally axis A) within the pressurized furnace vessel 12, each of which will be described in detail below. It is to be understood, however, in certain embodiments, the rotary retort 14, while positioned within the furnace vessel 12, need not be in a co-axial alignment or in a horizontal plane. Further, it is to be understood that the rotary retort, while shown as cylindrical, in other embodiments, can have other shapes, such as conical, frustroconical, and the like.

[0036] The rotary retort 14 is mounted in a radially spaced apart relationship to the pressurized furnace vessel 12 such that an annularly extending space 16 is defined between the rotary retort 14 and the pressurized furnace vessel 12.

[0037] The rotary retort 14 is sealed within the pressurized furnace vessel 12 such that the annular space 16 and the rotary retort 14 can be operated at elevated temperatures and at elevated pressures. In operation, the annular space 16 and the rotary retort 14 within the furnace 12 are held at substantially the same pressure. In certain embodiments, the rotary retort 14 can be fabricated of high temperature resistant materials, but does not necessarily need to be designed to withstand high pressures since the pressures with the rotary retort 14 and the annular space 16 are substantially the same during operation of the rotary retort system 10. The rotary retort 14 as described herein is cost effective, while alternative designs involving increased pressures are cost prohibitive.

[0038] The rotary retort 14 is configured to be rotated about its longitudinally extending axis A by a drive system 18. In certain embodiments, the mechanical components of the drive system 18 are external to the pressurized furnace vessel 12. In certain embodiments, the drive system 18 can be a variable drive system such that the rotary retort 14 can be rotated at different speeds, depending on the desired operating parameters, as further explained herein.

[0039] The rotary retort system 10 further includes a heating system 20 that is configured to supply heat to the rotary retort 14 and to the annular space 16. In certain embodiments, the heating system 20 can be an indirect heating system that supplies heat to the annular space 16 which, in turn, allows heat to be transferred to the rotary retort 14.

[0040] It is to be understood that, in certain embodiments, the heating system 20 can be configured to deliver varying amounts of heat to one or more temperature zones I, II, III, etc., within the pressurized furnace vessel 12. In such embodiments, the different temperature zones within the pressurized furnace vessel 12 can provide different amounts of heat along the length of the rotary retort 14. The different temperature zone allow temperatures within the rotary retort system 10 to be adjusted to meet a specific time/temperature profile and/or to supply sufficient heat to the feedstock materials M being advanced through the rotary retort 14, as further described herein.

[0041] It is to be understood that various suitable heating systems 20 are within the contemplated scope of the present invention. For example, the heating members 22 can be heated by various means such as electricity, fossil fuels and/or off-gases from the pyrolyzer process itself, as further described herein.

[0042] As illustrated in Figures 1 and 3, the heating system 20 can include a plurality of heating members 22 which extend into the annular space 16. The heating system 20 acts to heat to the pressurized furnace vessel 14 which, in turn, heats and pyrolizes the material M within the rotary retort 14. In certain embodiments, heat is supplied indirectly through one or more (and/or sets of) the radiant heating members 22 that are arranged in zones to provide a desired amount of heat energy to specific zones where such heat is needed for the pyrolysis process. In certain embodiments, each radiant heating element can be individually controlled.

[0043] The rotary retort 14 includes a pyrolization chamber 30 having a charge end 32, a discharge end 34 and an annularly extending wall 36. The charge end 32, the discharge end 34 and the annularly extending wall 36 generally define an open interior annular space 35. The charge end 32 has at least a first inlet port 38 for receiving a supply of material M. Adjacent to the discharge end 24, the annular wall 36 contains one or more discharge openings 39.

[0044] In operation, the material M is moved through the pyrolization chamber 30 from the charge end 32 toward the discharge end 34 by the rotation of the rotary retort 14. In certain embodiments, the rotary retort system 10 can be configured such that the by-product solids exit and fall from the rotary retort 14 through the discharge openings 39. No other separating devices, such as cyclones or filters, are required in order to separate gas product from by-products.

[0045] It is to be noted that the rotary retort system 10 achieves both a desired high internal temperature and a desired high internal pressure while maintaining a much lower outer casing temperature. Also, it is to be noted that the rotary retort 14 is sealed, or encapsulated, within the insulated pressure furnace vessel 12, but is also removable therefrom. This encapsulation configuration allows different sized and shaped rotary retorts to be used within the pressurized furnace vessel. The rotary retort system10 provides a versatility that will meet many end-users' specifications. This sealing, or encapsulation, of the rotary retort 14 within the pressurized furnace vessel 12 provides additional benefits since rotary retorts can be manufactured at lower costs and with less material as such rotary retorts do not have to be manufactured to withstand elevated pressures.

[0046] Another advantage of the rotary retort system 10 and process described herein is that there is no differential pressure across the revolving rotary retort. This lack of differential pressure allows the rotary retort system 10 and process to be run at very efficient operating parameters. There is no need to have cyclic pressurization-depressurization, temperature increases-decreases, or batch loading of materials into the rotary retort system. As such, the rotary retort system 10 can process high volumes of material in a substantially continuous process, while simultaneously providing a substantially continuous supply of end products.

[0047] It is also to be noted that, at least in certain embodiments, the rotary retort system 10 can be constructed based on thermal and feedstock loading conditions, rather than on pressure requirements. Consequently, the stresses on the rotary retort are reduced and a lighter, less expensive rotary retort can be used.

[0048] Certain uses of the rotary retort system include the separation of gases and solids. As gases are produced (for example, by the volatilization of a feedstock material being pyrolyzed, the gases travel to a discharge end of the pressurized rotary retort and exit out a top opening in the rotary retort. As feedstock is reduced to by-product solids, the by-product solids are conveyed to a discharge end of the rotary retort.

[0049] Also, since there are no moving parts within the rotary retort 14, the rotary retort system 10 can be efficiently operated without the need for frequent cleaning and/or repairs.

[0050] In certain embodiments, the rotary retort 14 includes a plurality of flights 40 disposed along an interior surface 42 of the wall 36 of the rotary retort 14. Upon rotation of the rotary retort 14 about the axis A by the drive system 18, the material M is advanced from the charge end 32 of the rotary retort 14 to the discharge end 36 by the flights 40, as further explained herein.

[0051] The flights 40 can be attached to the interior surface 42 by bolts, screws, welding or other suitable means. The flights 40 can be mounted on the interior surface 42 of the rotary retort 14 in a desired pattern. It is to be understood that the number and/or the lengths of flights 40 arranged in the rotary retort 14 can depend, at least in part, on the material M, the length and/or diameter of the rotary retort 14 and the desired residence time of the material M within the rotary retort 14.

[0052] As the rotary retort 14 rotates, the flights 40 "lift" portions of the material M in a generally circumferentially upward and generally forward spiral direction. The "lifted" portion of material M within each flight 40 is discharged in a cascading manner onto a "bottom" section of the interior surface 42 that is momentarily at, or near, a bottom of the rotation of the rotary retort 14. When the "cascaded" portion of material M is in contact with the interior surface 42, heat is transferred from the rotary retort 14 (and the flights 40) to the material M, aiding in pyrolyzing the material M. As the rotary retort 14 continues to axially rotate, each succeeding portion of "cascaded" feedstock M is "lifted/cascaded" again by succeeding flights 40. The heat and pressure within the pyrolization chamber 30 and the contact of the "lifted/cascaded" material M with the interior surface 42 and/or flight 12 together act to heat/pyrolize the material M.

[0053] As the capturing flight 40 is rotated and reaches a certain angle of inclination, gravity causes the material M to begin to cascade out of the flight 40 at a cascading point onto the bottom of the rotary retort 14. As the capturing flight 40 moves in the upward circumferential direction, the flight 40 is gradually emptied. In certain embodiments, the shape of the flight 40 allows the flight 40 to hold a quantity of material M when the flight is at its highest point of rotation. As the flight 40 continues its rotation back toward its lowest point, the flight 40 is further emptied. The flight 40 can provide a substantially continuous supply of material M falling though the pyrolization chamber 30.

[0054] Thus, both the mixing and the movement of the material M through the rotary retort 14 act to provide an efficient pyrolization of the feedstock M and to provide an efficient formation of the pyrolyzer gas product P-G. That is, as the material M cascades through the pyrolization chamber 30, the numerous cascading events efficiently exposes the material M to heat within the pyrolization chamber 30.

[0055] The flights 40 within the rotary retort 14 allow the cascading material M to move and fall in a generally forward direction toward the discharge end 34. In contrast to an auger or screw action (which merely slides or pushes a majority of the feedstock along a bottom surface), the flights 40 provide a substantially continuous lifting, cascading and mixing action to the material M within the rotary retort 14. The rotation of the rotary retort 14 generally prevents (or lessens) any warping of the rotary retort 14 that could be caused by uneven heating of a bottom of the rotary retort 14. Also, in contrast to the sliding/pushing forces of an auger or screw action (where materials often jam or bind up), the flights 40 actually lift and advance quantities of the feedstock materials M off from the interior surface 42.

[0056] In the embodiment shown in the Figures herein, the rotary retort 14 has multiple flights 40 with the same configuration, where each flight 40 extends radially inward toward the axis A to the same depth and/or is placed along interior surface 42 at equally spaced distances. It is to be understood, however, that it is within the contemplated scope of the present invention that, in other embodiments, one or more of the flights 40 can have different dimensions. The material M is thus advanced from the charge end 32 toward the discharge end 36 by being scooped and tumbled along the axis A.

[0057] It is to be understood that, in certain embodiments, the configuration and/or arrangement of the flights 40 can be uniform throughout the pyrolization chamber 30. Also, in certain embodiments, the spacing between successive flights 40 on the interior surface 42 can be varied to optimize the residence time of the material M within the rotary retort 14.

[0058] In one non-limiting example, the flights 40 can have a configuration and/or can be arranged such that each cascading event from one flight 40 to the next flight 40 moves the feedstock materials M along a path through the rotary retort 14 where the material M can be "stopped," or held in, each flight before continuing onto a subsequent flight. In certain other embodiments, the flights can be arranged to continuously advance the material M through the pyrolization chamber 30.

[0059] In one non-limiting example, the rotary retort 14 can include different shaped and/or sized flights, such as one or more flights 40 each having a flight face 41 having a length and/or depth differing from other flights 40. In one non-limiting example, the flights 40 extend generally radially inward toward the axis A only to a certain distance such that there is a sufficiently large open interior annular space 35' between radially opposing flights 40 so that the material M can easily move from the charge end 32 to the discharge end 34. For example, in one embodiment, the flights 40 can have a width that is about one-fourth of the diameter of the rotary retort 14 such that the open interior annular space 35' is approximately one half of the diameter of the rotary retort 14.

[0060] Also, in another non-limiting example, one or more of the "last" flights 40 (i.e., adjacent to the discharge end 34) in the rotary retort 14 the can have different configurations. For example, the last flight(s) 40 can have a greater length than other flights, to aid in the delivery of the material M out from the rotary retort 14. Also, in certain embodiments, one or more of the last flight(s) 40 adjacent to the discharge end 34 can have a paddle or scoop configuration to aid in pushing the by-product B out of the rotary retort 14.

[0061] In another non-limiting example, one or more of the flights 40 (for example, flights adjacent to the charge end 32) can have extending faces 41 with a pitch fork configuration that includes tines to aid in lifting and separating the material M. It is also to be noted that the speed of the rotation of the rotary retort 14 can be varied, to increase or decrease the length of time the feedstock materials M is cascaded in the rotary retort 14.

[0062] It is to be understood that the interior surface 42 and the flights 40 may be made of any material that will withstand the operating conditions inside the pyrolization chamber 30. In certain embodiments, the interior surface and/or the flights 40 are made of a material that can withstand the mechanical wear caused by the "lifting/cascading" of the material M, the heat and elevated pressures within the rotary retort 14, and the caustic wear of the feedstock materials M being pyrolyzed into the desired gas product G and the by-product B.

Also, in certain embodiments, the interior surface 42 and/or the flights 40 can be made with (or coated with) a material that substantially prevents, or minimizes, the material M from undesirably reacting with or adhering to the interior surface 42 of the rotary retort 14. In certain embodiments, the interior surface 42 and/or the flights 40 can be coated with a non-adherent polymer coating to facilitate movement of the material M and/or cleaning of the rotary retort 14.

[0063] Also, in certain embodiments, the rotary retort 14 can be configured such that one or more of the flights 40 can be removably mounted within the rotary retort 14. The removable flights allow the end-user to remove and/or interchange one or more of the flights 40. Thus, the rotary retort 14 can be configured to handle different types of material M. For example, when the material M has a straw-like consistency, one or more of the flights 40 can have a tine-like configuration to separate and lift such straw-like material M. Also, if the material M is bulky, one or more of the flights 40 can be removed and/or spaced at different positions to accommodate the bulky material M and prevent any jamming or binding of the material M.

[0064] Referring now generally to Figure 2, it is to be understood that, as the rotary retort 14 is heated within the pressurized furnace vessel 12, the rotary retort 14 expands. In the embodiment generally schematically illustrated in Figure 2, the rotary retort 14 is not fixedly secured to the pressurized furnace vessel 12; rather, the rotary retort 14 is supported such that the rotary retort 14 can expand/contract during the heating/cooling operation cycles of the rotary retort system 10. Figure 2 shows that, in certain embodiments, the pressurized furnace vessel 12 can include a support system 13 that keeps the rotary retort 14 in a co-axial alignment within the pressurized furnace vessel 12.

[0065] Referring again to the embodiment shown in Figure 1, the pressurized furnace vessel 12 generally includes a charge end 52, a discharge end 54 and an annularly extending wall 56, all of which can contain a desired amount of insulation material 57. It is to be noted that the pressurized furnace vessel 12 can be substantially insulated so that, while the rotary retort 14 is being operated at high temperatures and high pressures, the exterior of the pressurized furnace vessel 12 can be substantially cooler, often at about room temperatures.

[0066] The charge end 52 of the pressurized furnace vessel 12 has at least a first inlet port 58 through which the first inlet port 38 of the rotary retort 14 extends. The discharge end 54 of the pressurized furnace vessel 12 has one or more outlet ports 59 through which the pyrolyzer gas product P-G is discharged.

[0067] When the annularly extending space 16 and the rotary retort 14, are all under high pressure, the pyrolyzer gas product P-G being produced is driven out of the rotary retort 14 through the discharge opening 39 and out of the pressurized furnace vessel 12 through one or more gas outlet ports 59.

[0068] The pressurized furnace vessel 12 also includes at least one discharge assembly 60 that is disposed adjacent a bottom portion 62 near the discharge end 54 of the pressurized furnace vessel 12.

[0069] During operation, upon rotation of the rotary retort 14 about the axis A by the drive system 18, the material M is advanced from the charge end 32 of the rotary retort 14 to the discharge end 36. After pyrolization of the material M, any remaining material (i.e., the by-product material B) is discharged out of one or more of the discharge openings 39 in the rotary retort 14, and out through the discharge assembly 60.

[0070] It is to be understood that, in certain embodiments, the discharge assembly 60 can be connected to a by-products repository 64 that is under pressure such that the pressure in the rotary retort 14, the annular space 16 and the pyrolization chamber 30 are maintained at desired operating pressures and temperatures. In such embodiments, the discharge assembly 60 can include a collecting member 66 that is positioned to receive by-product material B being discharged out of the discharge openings 39. The discharge assembly 60 can include a connector 68 to the by-products repository 64.

[0071] Alternatively, as discussed herein with respect to Figs. 4-6, instead of a by-products repository 64, the connector 68 can deliver by-product material to a solids reactor system 110, as shown in Figures 4-6 and as further discussed herein.

[0072] Referring again to Figure 1, the charge end 52 of the pressurized furnace vessel 12 is connected to a feedstock delivery system 80 for providing a desired quantity of material M into the rotary retort 14. The delivery system 80 is operatively connected to both the charge end 52 of the pressurized furnace vessel 12 and to the charge end 32 of the rotary retort 14.

[0073] It is to be understood that different configurations of delivery systems can be used. In the embodiment shown in Figure 1, the delivery system 80 includes a pressurizing system 82 that is configured to provide a desired quantity of material M into the rotary retort 14 under pressure (and, optionally under elevated/pre-heated temperatures). The pressurizing system 82 can be configured to deliver discrete quantities of material M into the rotary retort 14 such that the pressures and temperatures within the rotary retort 14 are not lowered below desired operating ranges. Also, the pressurizing system 82 prevents the entrance of external or ambient environments into the rotary retort 14, thereby preventing undesired combustion of the material M within the rotary retort 14.

[0074] The pressurizing system 82 can include a pressurizing chamber 84 having a pair of opposing first and second gate valves 86 and 88, respectively. As material M is introduced into the pressurizing chamber 84, the first gate valve 86 is closed. After a desired quantity of material M is supplied into the pressurizing chamber 84, the second gate valve 88 is closed, and the pressurizing chamber 84 is pressurized to at least approximately the pressure being maintained in the rotary retort 14 and in the annular space 16.

[0075] After the desired pressure is achieved in the pressurizing chamber 84, the first gate valve 86 is opened and the supply of material M is delivered into a holding chamber 90.

[0076] It is to be understood that, during the pyrolyzing process, the supply of feedstock materials M may only momentarily remain in the holding chamber 90 before being delivered into the rotary retort 14. In the embodiment shown in Figure 1, the holding chamber 90 includes a suitable mechanism 92 for forcing or ejecting the supply of material M into the rotary retort 14. In one non-limiting example, the ejecting mechanism 92 can be a pneumatic cylinder 94 that is operatively connected to a plate 96 that pushes the supply of material M through the inlet port 38 of the rotary retort 14. The ejecting mechanism 92 can be synchronized with the pressurizing chamber 84 to meter desired quantities of material M into the rotary retort 14 without obstructing or jamming the rotary retort 14. For example, in certain embodiments, the quantity of material M delivered from one stroke of the ejection mechanism 92 of the holding chamber 90 can have substantially the same volume as is lifted/cascaded by one flight 40.

[0077] In certain embodiments, the pressurized material M can be rapidly injected through the inlet port 38 and into the pyrolization chamber 30 of the rotary retort 14. In such embodiments, the rapid injection into the rotary retort 14 is synchronized with the speed of the rotary retort 14 and the position of the filed to be coincident with material M being deposited between flights 40.

[0078] Referring now to Figures 4-6, in certain embodiments, a solids reactor system 110 can be operatively connected to the discharge assembly 60 to receive the any un-pyrolyzed material/by-product M-B. The un-pyrolyzed material/by-product M-B is subjected to a further pyrolization process and to a steam reforming process, thereby generating and capturing a gas product G, such as synthetic gas (or "syn gas"). Such embodiments are especially useful in situations where the by-product B still contains some "useful" feedstock material that may not have been completely pyrolyzed and which still contains materials that can produce the gas product G. In such embodiments, the un-pyrolyzed material/by-product M-B still retains the heat from the initial pyrolization process and is still under pressure such that any subsequent pyrolization process requires little additional heating of the un-pyrolyzed material/by-product M-B.

[0079] The solids reactor system 110 generally includes a pressurized furnace vessel 112 and a solids reactor 114 that is co-axially positioned (about a longitudinally extending axis A') within the pressurized furnace vessel 112. It is to be understood, however, in certain embodiments, the solids reactor 114, while positioned within the furnace vessel 112, need not be in a co-axial alignment or in a horizontal plane.

[0080] The solids reactor 114 is mounted in a radially spaced apart relationship to the furnace 110 such that an annularly extending space 116 is defined between the solids reactor 114 and the pressurized furnace vessel 112.

[0081] The solids reactor 114 is sealed within the pressurized furnace vessel 112 such that the annular space 116 and the solids reactor 114 can be operated at elevated temperatures and at elevated pressures. In operation, the annular space 116 and the solids reactor 114 within the furnace 112 are held at substantially the same pressure. In certain embodiments, the solids reactor 114 can be fabricated of high temperature resistant materials, but does not necessarily need to be designed with materials that withstand high pressures since the pressures with the solids reactor 114 and the annular space 116 are substantially the same during operation of the solids reactor system 110.

[0082] The solids reactor 114 is rotated about its longitudinally extending axis A' by a drive system 118. In certain embodiments, the mechanical components of the drive system 118 are external to the pressurized furnace vessel 112. In certain embodiments, the drive system 118 can be a variable drive system such that the solids reactor 114 can be rotated at different speeds, depending on the desired operating parameters, as further explained herein.

[0083] The solids reactor system 110 further includes a heating system 120 for supplying heat to the solids reactor 114 and to the annular space 116. In certain embodiments, the heating system 120 can include an indirect heating system that supplies heat to the annular space 116 which, in turn, allows heat to be transferred to the solids reactor 114.

[0084] It is to be understood that, in certain embodiments, the heating system 120 can be configured to deliver varying amounts of heat to one or more temperature zones within the pressurized furnace vessel 112. In such embodiments, the temperatures along the length of the solids reactor 114 can be varied, allowing the solids reactor system 110 to be adjusted to meet a specific time/temperature profile and/or to supply sufficient heat to the un-pyrolyzed material/by-product M-B being advanced through the solids reactor 114.

[0085] The heating system 120 can include one or more radiant heating members 122 which extend along an interior surface 113 of the pressurized furnace vessel 112 and can extend into the annular space 116. In the embodiment shown in Figure 4, the radiant heating members 122 can be electrical elements. It is to be understood that various suitable heating systems performing this function are, of course, conceivable and within the contemplated scope of the present invention.

[0086] As the solids reactor 114 is heated within the pressurized furnace vessel 112, the solids reactor 114 expands. In the embodiment shown in Figure 5, the solids reactor 114 is not fixedly secured to the pressurized furnace vessel 112 such that the solids reactor 114 can expand within the pressurized furnace vessel 112. In certain embodiments, the pressurized furnace vessel 112 can include a support system 113 that keeps the solids reactor 114 in a co-axial alignment within the pressurized furnace vessel 112.

[0087] Referring now in particular to the solids reactor 114 shown in Figure 4, the solids reactor 114 generally includes a pyrolization/reforming chamber 130 having a charge end 132, a discharge end 134 and an annularly extending wall 136. The charge end 132 has at least a first inlet port 138 for receiving the un-pyrolyzed material/by-product M-B from the rotary retort system 10. Also, it is to be understood, that in certain embodiments, the inlet port 138 can be used for the introduction of steam into the pyrolization/reforming chamber 130; in other embodiments, a separate port (not shown) can be used to introduce steam into the pyrolization/reforming chamber 130. The discharge end 134 contains one or more discharge openings 139.

[0088] The solids reactor 114 also includes a plurality of flights 140 that are disposed along an interior surface 142 of the wall 136 of the solids reactor 114. It is to be understood that the solids reactor 114 can have flights 140 in the same or in different configurations as the flights 140 in the rotary retort system 110.

[0089] Upon rotation of the solids reactor 114 about the axis A' by the drive system 118, the un-pyrolyzed material/by-product M-B is advanced from the charge end 132 of the solids reactor 114 to the discharge end 136 by the flights 140.

[0090] The pressurized furnace vessel 112 has a charge end 152, a discharge end 154 and an annularly extending wall 156. It is to be noted that the pressurized furnace vessel 112 can also be substantially insulated with a suitable material 157 so that, while the solids reactor 114 is being operated at high temperatures and high pressures, the exterior of the pressurized furnace vessel 112 can be substantially cooler, often at about room temperatures.

[0091] The charge end 152 of the pressurized furnace vessel 112 has at least a first inlet port 158 through which the first inlet port 138 of the solids reactor 114 extends. The discharge end 154 of the pressurized furnace vessel 112 has one or more gas outlet ports 159 through which the gas product G is discharged.

[0092] As shown Figure 4, the charge end 152 of the pressurized furnace vessel 112 is connected to a delivery system 180 for supplying un-pyrolyzed material/by-product M-B into the solids reactor 114. It is to be understood that the delivery system 180 can be operatively connected to the connector 68 of the rotary retort system 10 to receive the un-pyrolyzed material/by-product M-B at elevated temperatures and at elevated pressures.

[0093] The delivery system 180 is operatively connected to both the charge end 152 of the pressurized furnace vessel 112 and to the charge end 132 of the solids reactor 114.

[0094] It is to be understood that different configurations of delivery systems 180 can be used. In the embodiment shown in Figure 4, the delivery system 180 includes a pressurized system 182 that is configured to provide a desired quantity of un-pyrolyzed material/by-product M-B into the solids reactor 114 at an elevated pressure and at an elevated temperature. The pressurized system 182 can be configured to deliver discrete quantities of the un-pyrolyzed material/by-product M-B into the solids reactor 114 such that the pressures and temperatures within the solids reactor 114 are not lowered below desired operating ranges. Also, the pressurized system 182 prevents the entrance of external or ambient environment into the solids reactor 114, thereby preventing undesired combustion of the un-pyrolyzed material/by-product M-B within the solids reactor 114.

[0095] The pressurized system 182 can include a pressurized chamber 184 having at least one gate valve 186. As the un-pyrolyzed material/by-product M-B is introduced into the pressurized chamber 184, the gate valve 186 is closed. After a desired quantity of un-pyrolyzed material/by-product M-B is supplied into the pressurized chamber 184, the gate valve 186 is opened and the supply of un-pyrolyzed material/by-product M-B is delivered into a holding chamber 190.

[0096] It is to be understood that, during the solids reaction process, the supply of un-pyrolyzed material/by-product M-B may only momentarily remain in the holding chamber 190 before being delivered into the solids reactor 114. In the embodiment shown in Figure 4, the holding chamber 190 includes a suitable mechanism 192 for forcing or ejecting the supply of un-pyrolyzed material/by-product M-B into the solids reactor 114. In one non-limiting example, the ejecting mechanism 192 can be a pneumatic cylinder 94 that is operatively connected to a plate 196 that pushes the supply of un-pyrolyzed material/by-product M-B through the inlet port 138 of the solids reactor 114. The ejecting mechanism 192 can be synchronized with the pressurized chamber 184 to meter desired quantities of un-pyrolyzed material/by-product M-B into the solids reactor 14 without obstructing or jamming the solids reactor 114.

[0097] In certain embodiments, the un-pyrolyzed material/by-product M-B can be rapidly injected through the inlet port 138 and into the pyrolization/reformer chamber 130. In such embodiments, the rapid injection into the solids reactor 114 aids in preventing un-pyrolyzed material/by-product M-B from accumulating at the charge end 132 of the solids reactor 114.

[0098] The pressurized furnace vessel 112 includes at least one discharge assembly 160 that is disposed adjacent a bottom portion 162 near the discharge end 154 of the pressurized furnace vessel 112. Upon rotation of the solids reactor 114 about the axis A' by the drive system 118, the un-pyrolyzed material/by-product M-B is advanced from the charge end 132 of the solids reactor 114 to the discharge end 136. After this further pyrolyzing of the un-pyrolyzed material/by-product M-B, any remaining by-product B-B is discharged out of one or more of the discharge openings 139 in the solids reactor 114, and through the discharge assembly 160. It is to be understood that, in certain embodiments, the discharge assembly 160 can be connected to a final by-products repository 164.

[0099] In certain embodiments, the solids reactor system 110 can include a de-pressurizing system 170 having a de-pressurizing chamber 172 and a pair of opposing first and second control devices 174 and 176, respectively. In certain embodiments, the final by-product B-B is dispensed into the de-pressurizing chamber 172 when the first control device 174 is in a closed position and the de-pressurizing chamber 172 is still at substantially the same pressures as the operating pressures of the second pyrolysis system 110.

[00100] After a supply of final by-products B-B is introduced into the de-pressurizing

chamber 172, the second control device 176 is closed, thereby maintaining the pressure within the solids reactor system 110. The first control device 174 can then be opened, releasing the final by-product B-B into the by-products repository 164. The pressure being released from the de-pressurizing chamber 172 can help expel the final by-product B-B into the by-products repository 164.

[00101] Referring now to Figure 7, a schematic process flow diagram shows use of a rotary retort system 10 and a solids reactor system 110 in a thermal recapture system 200. The rotary retort system 10 is operatively connected to the solids reactor system 110, as generally described above, and both are operatively connected to a gas reactor 210.

[00102] In general, the pyrolyzer gas product P-G generated in the rotary retort system 10 exits via the outlet port 59. The gas product G generated in the solids reactor system 110 exits via the outlet port 159. The gas products P-G and G can then be supplied to the gas reactor 210 for additional processing, use and/or consumption.

[00103] In the embodiment illustrated in Figure 7, the pyrolyzer gas product P-G and the un-pyrolyzed material/by-product M-B exit that the rotary retort 10 at a first temperature, 1^{st} T°. The solids reactor gas product G and the un-pyrolyzed final byproduct B-B exit the solids reactor system 110 at a second and different temperature, 2^{nd} T°.

[00104] In addition, in certain embodiments, the gas reactor 210 can generate excess heat energy.

[00105] In order to capture excess heat that is generated and to reduce energy consumption, the rotary retort system 10 can be operatively connected to one or more of a suitable economizer 215, a heat exchanger 220 and/or a super heat exchanger 230 to recapture heat from the products-of-combustion POC and to supply heat energy to the solids reactor system 110.

[00106] In one non-limiting example, the solids reactor system 110 can be operated at a temperature that is higher than the operating temperature of the rotary retort pyrolyzer system 110 such that 2^{nd} T° is higher than the 1^{st} T°.

[00107] Referring now to Figure 8, a schematic process flow diagram shows use of a rotary retort system 10 in another embodiment of a thermal recapture system 300. The rotary retort system 10 is operatively connected to a gas reactor 310.

[00108] The gas product P-G generated in the rotary retort system 10 exits via the outlet port 59 which can then be supplied to the gas reactor 310 for additional processing, use and/or consumption.

[00109] In the embodiment illustrated in Figure 8, the pyrolyzer gas product P-G exits the rotary retort system 10 at a first temperature, 1^{st} T°.

[00110] In order to reduce energy consumption, the rotary retort system 10 can be operatively connected to one or more of a suitable economizer 315, a heat exchanger 320 and/or a super heat exchanger 330 to recapture from the products-of-combustion POC and to supply heat energy to the gas reactor 310.

[00111] It is to be noted that the rotary retort pyrolyzer systems described herein are useful in pyrolyzing different types of feedstock material. It is further to be noted that, in certain specific embodiments, additional amounts of water W and/or steam S can be supplied into the rotary retort, as indicated in Figure 1 (W and/or S) where the pyrolysis may be efficient when the material M (and, optionally water and/or steam S) can be combined into one stream before being dispensed into the pressurizing chamber 84. Also, as shown in Figure 2, in certain embodiments, an additional steam supply system 70 can be operatively connected to the rotary retort system 10.

[00112] While the invention has been described with reference to various and preferred embodiments, it should be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the essential scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof.

[00113] Therefore, it is intended that the invention not be limited to the particular embodiment disclosed herein contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the claims.

CLAIMS

What is claimed is:

1. A process for the pyrolysis of at least one material, comprising:

i) introducing the material into a pressurized rotary retort system;

ii) heating the material in the pressurized rotary retort system within a desired temperature range and within a desired pressure range for a desired period of time; and,

iii) advancing the heated and pressurized material from a first end to a second end of the pressurized rotary retort by rotating the pressurized retort about its longitudinal axis;

wherein at least a quantity of the material is converted into one or more end products.

2. The process of Claim 1, wherein the pressurized rotary retort system is configured for producing at least one gaseous product from pyrolysis of the material; and further including a gas reactor for receiving the gaseous product from the pressurized rotary retort system.

3. The process of Claim 1 or 2, wherein the material is supplied under elevated pressures and at elevated temperatures.

4. The process of Claim 1 or 2, wherein the pressure within the rotary retort system provides forces for driving the gaseous products from the rotary retort system.

5. The process of Claim 1 or 2, further including subjecting by-products of the pyrolysis process to a further pyrolization process.

6. The process of Claim 1 or 2, further including a solids system reactor for receiving a supply of un-pyrolyzed material and/or by-products from the rotary retort system.

7. The process of Claim 1 or 2, further including a solids reactor system operatively connected to the rotary retort for receiving un-pyrolyzed by-product and for generating at least one additional gaseous product.

8. The process of Claim 1 or 2, wherein a supply of the gaseous product is used to supply heat to the rotary retort system.

9. The process of Claim 1 or 2, including advancing the material through the pressurized rotary retort system using a plurality of flights positioned within the rotary retort system.

10. The process of Claim 1 or 2, wherein the rotary retort is rotated about a longitudinally extending axis at more than one speed.

11. A pyrolysis system comprising:

i) a pressurized rotary retort system configured for producing at least one gaseous product from pyrolysis of material; and having a pressurized furnace vessel and a retort positioned within the pressurized furnace vessel; and;

ii) a solids reactor system operatively connected to the rotary retort for receiving and pyrolyzing un-pyrolyzed material from the pressurized rotary retort system.

12. The system of Claim 11, further including a gas reactor for receiving the gaseous product from the pressurized rotary retort system.

13. The system of Claim 12, wherein the material is supplied under elevated pressures and at elevated temperatures.

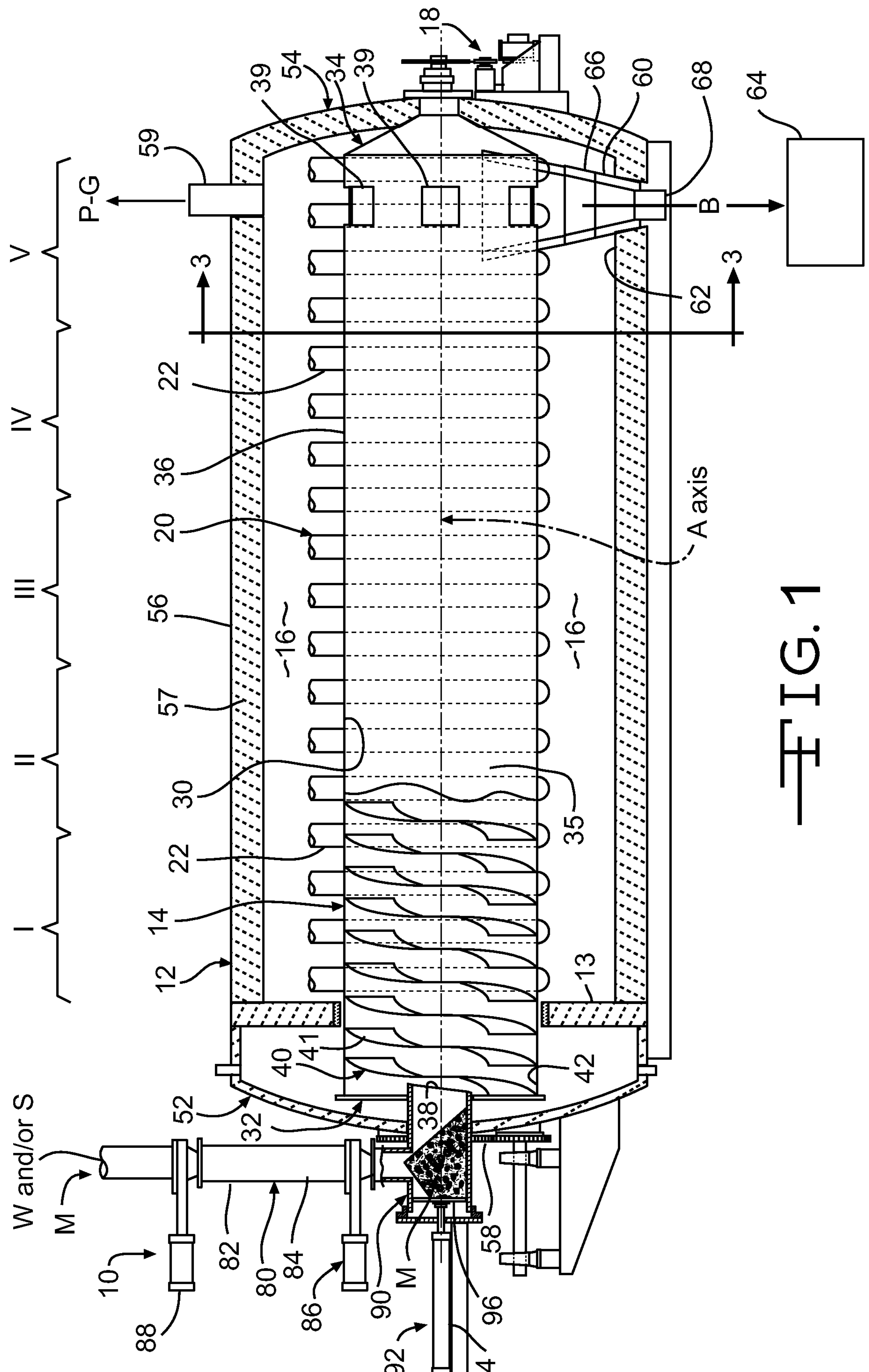
14. The system of Claim 12, wherein the pressure within the rotary retort system provides forces for driving the gaseous products from the rotary retort system.

15. The system of Claim 12, further including a heat exchanger system configured for capturing heat generated by pyrolysis of material and/or heat generated by production of gaseous products.

16. The system of Claim 12, wherein a supply of the gaseous product is used to supply heat to the rotary retort system.

17. The system of Claim 12, including advancing the material through the pressurized rotary retort system using a plurality of separately spaced flights positioned within the pressurized rotary retort system.

18. The system of Claim 12, wherein the pressurized rotary retort is rotated about a longitudinally extending axis at more than one speed.



P-G
59
39
54
34
39
18
66
60
68
64
B
V
3
3
62
22
IV
36
A axis
20
III
56
16
16
57
II
30
35
I
22
14
12
13
41
40
42
52
38
32
W and/or S
M
82
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84
58
90
M
96
10
88
86
92
94

FIG. 1

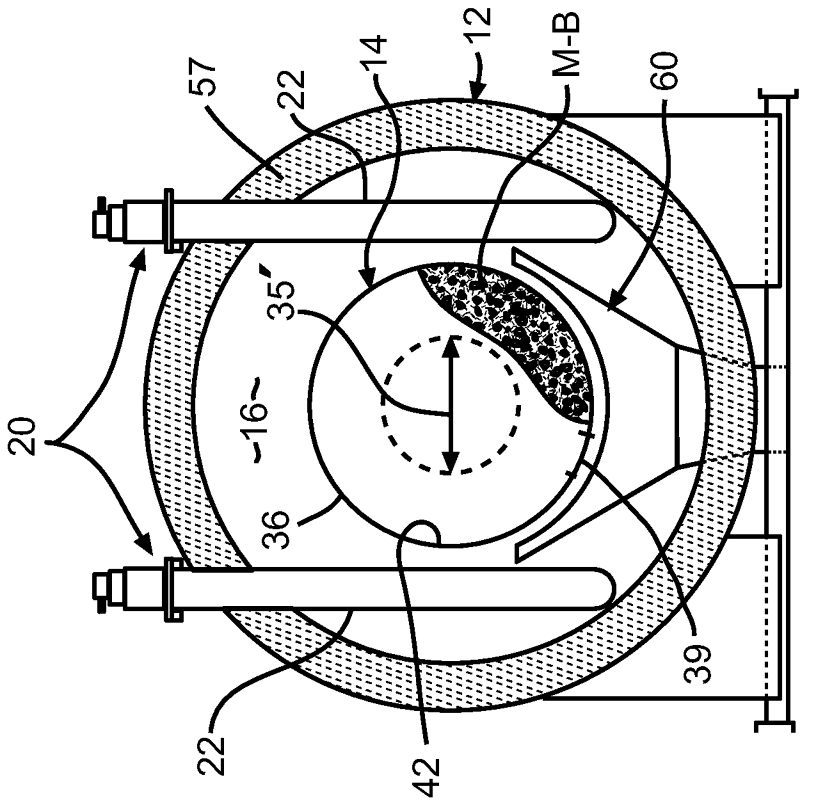

FIG. 3

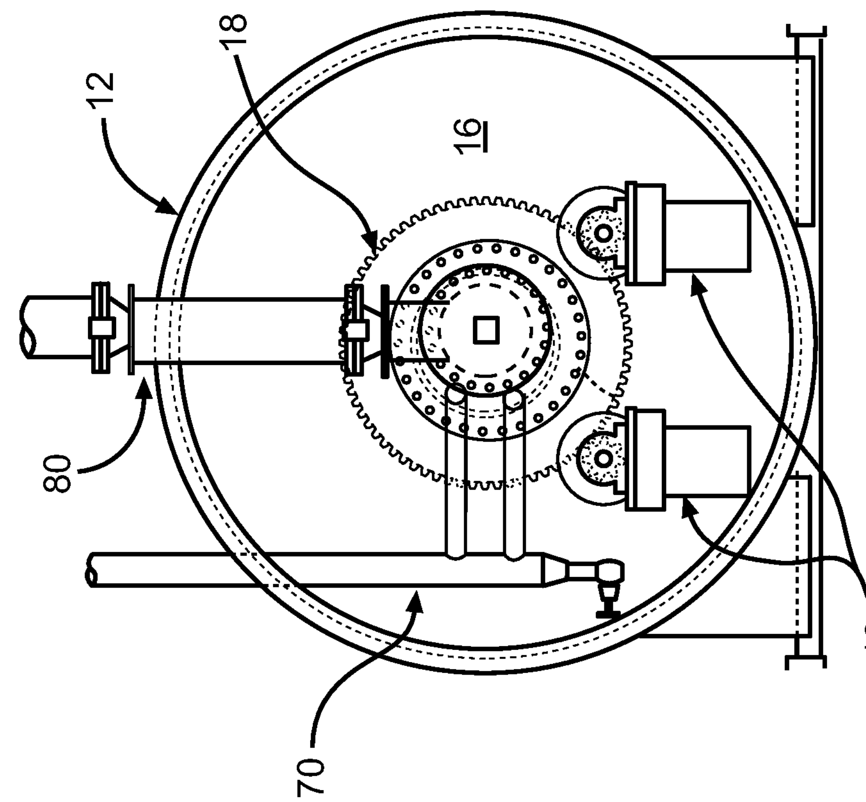

FIG. 2

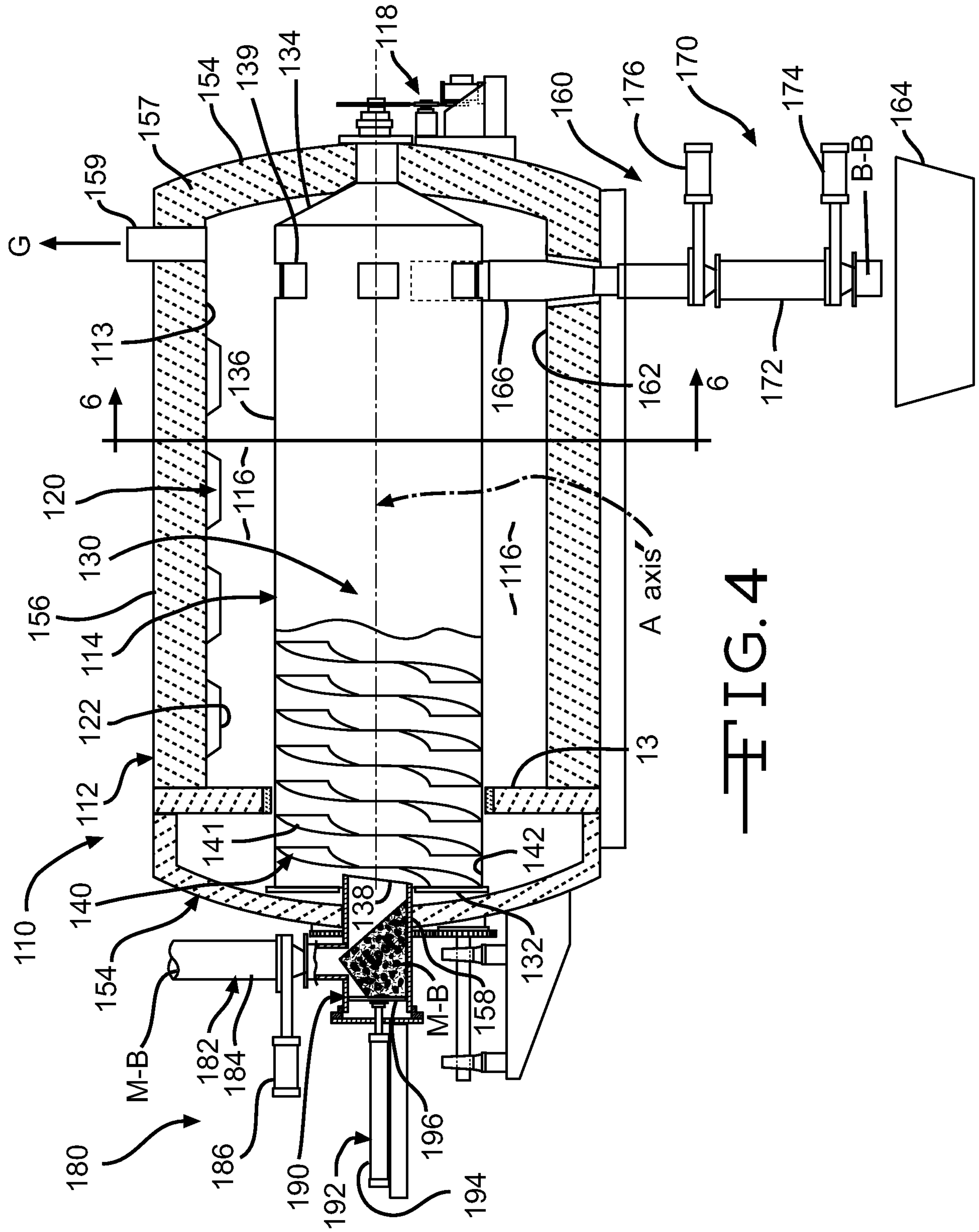
G
159
157
154
139
134
118
160
176
170
174
164
B-B
113
136
166
162
172
6
6
120
116
116
130
A axis
156
114
122
13
112
110
141
142
140
138
132
154
158
M-B
M-B
182
184
186
180
190
196
192
194

FIG. 4

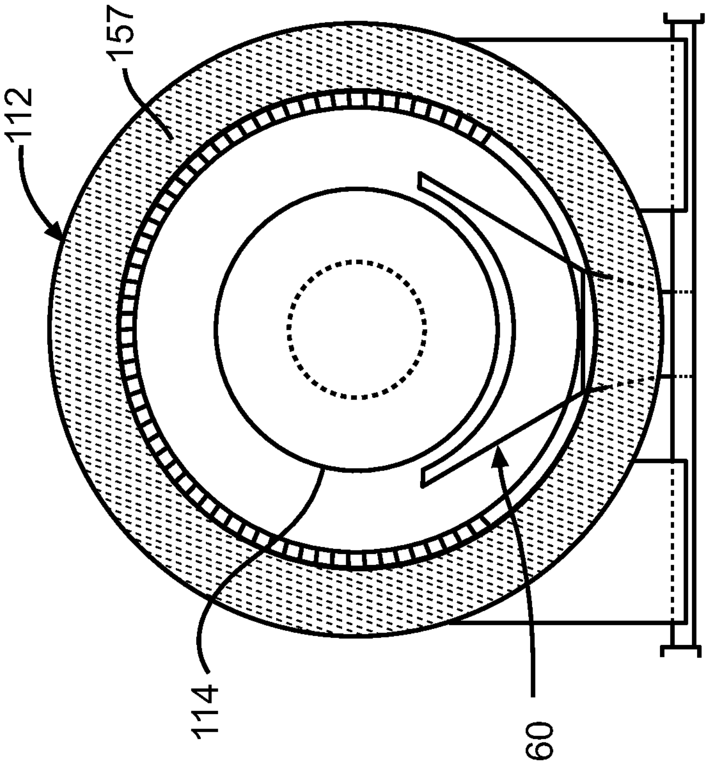

FIG.6

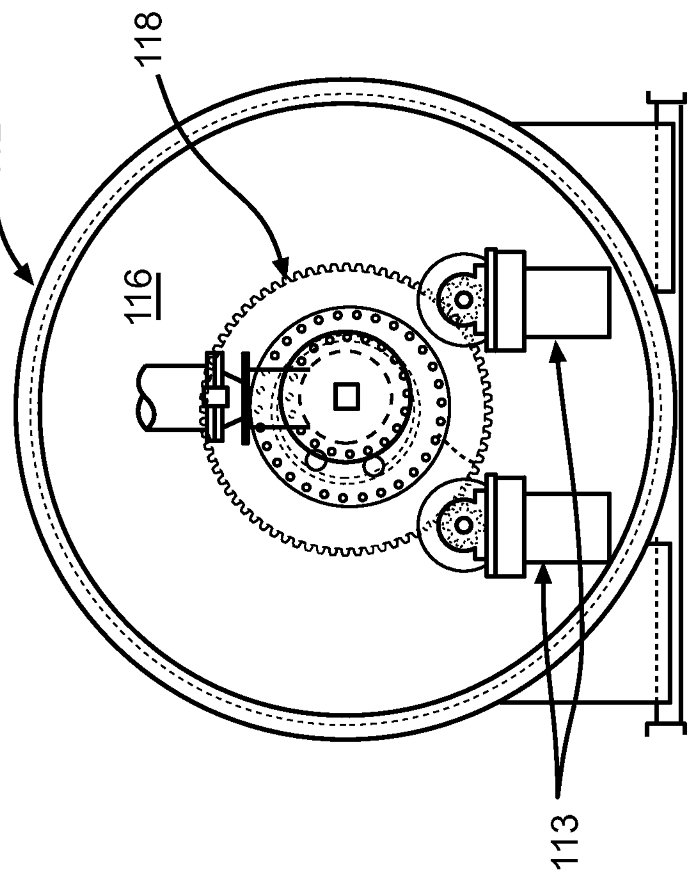

FIG.5

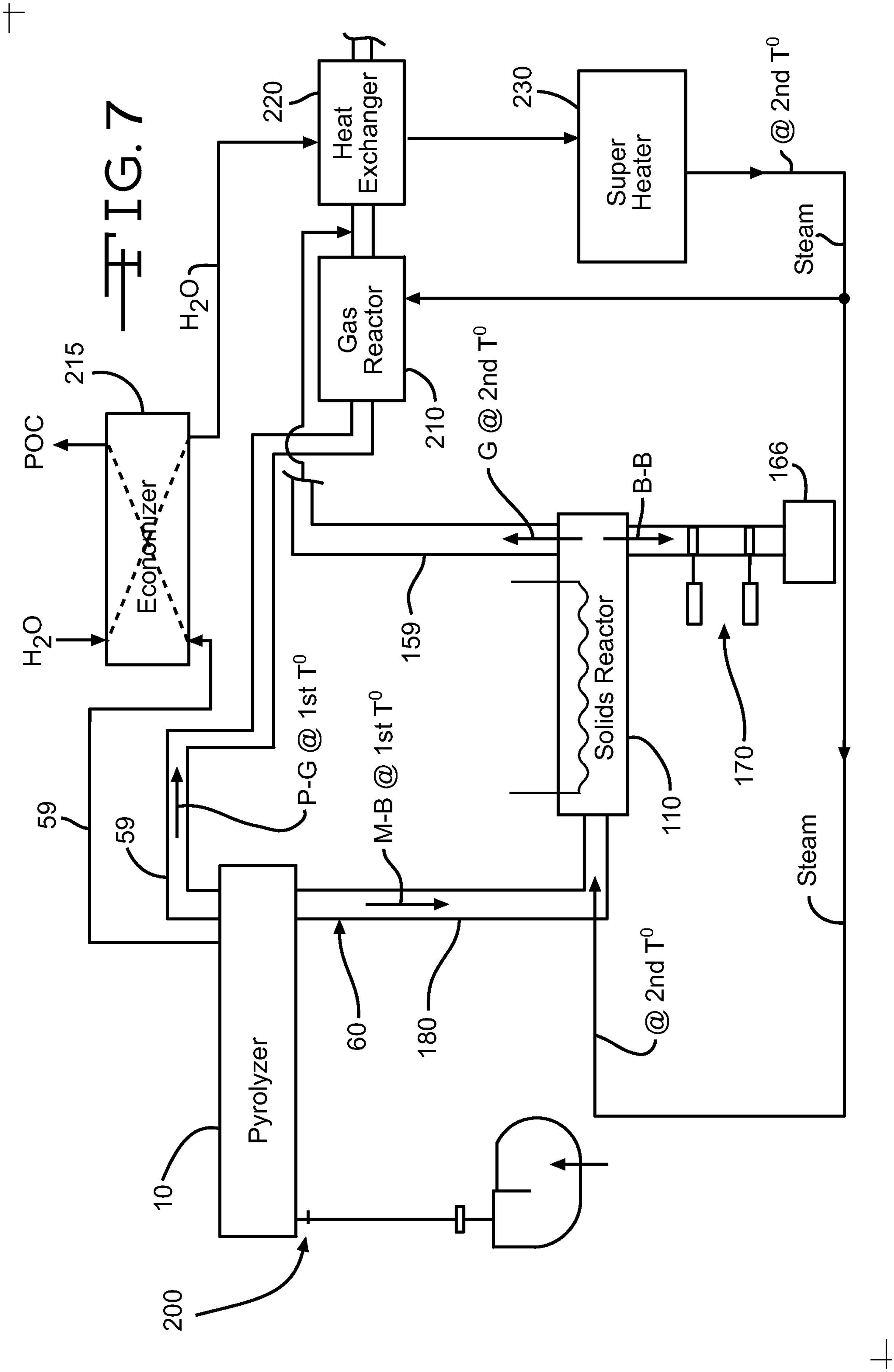
Heat Exchanger
220
230
Super Heater
@ 2nd T0
Steam
Gas Reactor
210
G @ 2nd T0
B-B
166
Solids Reactor
110
170
159
215
POC
Economizer
H2O
H2O
59
59
P-G @ 1st T0
M-B @ 1st T0
60
180
Pyrolyzer
10
200
@ 2nd T0
Steam

FIG. 7

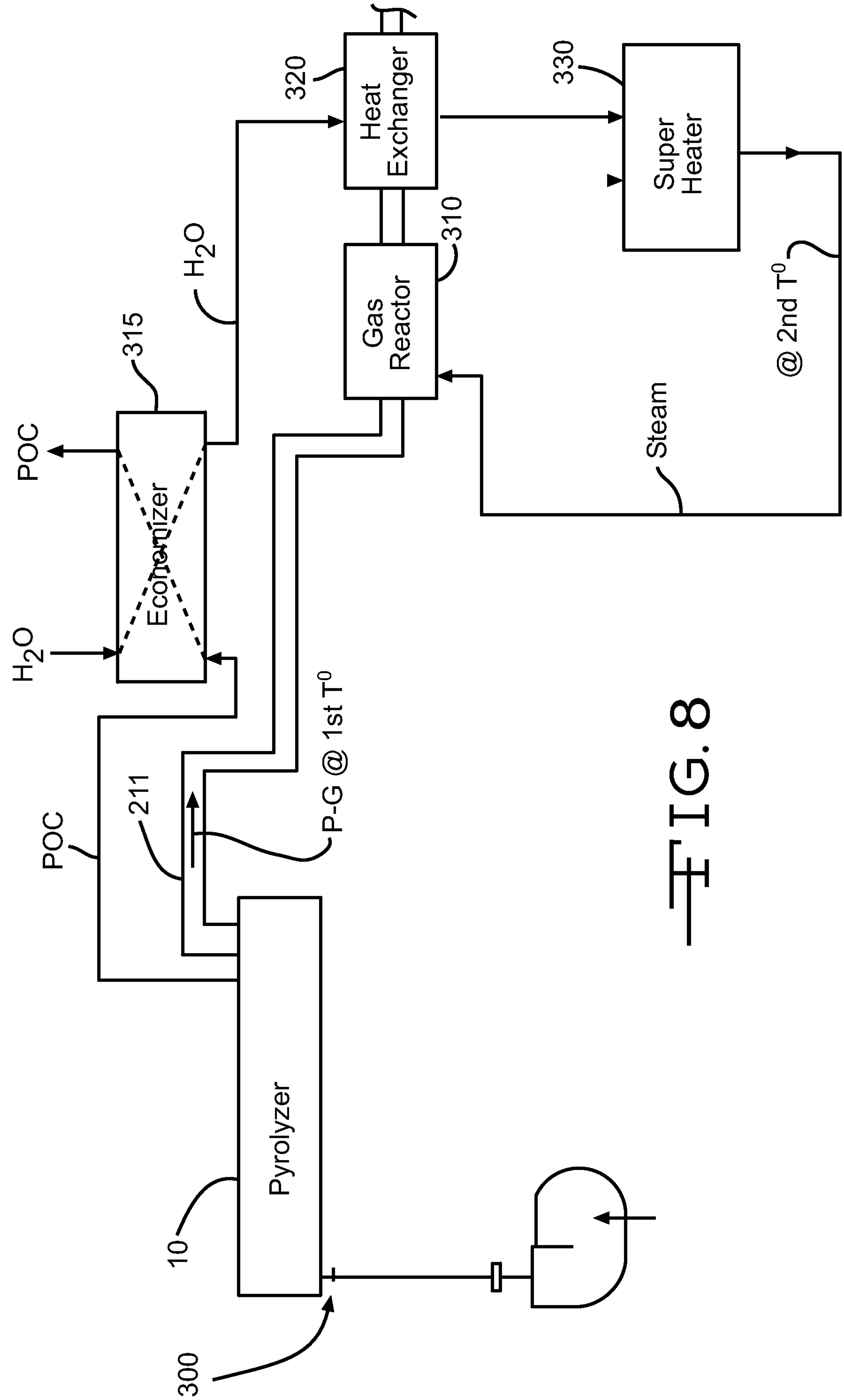
Heat Exchanger
320
330
Super Heater
H2O
310
Gas Reactor
315
POC
Economizer
H2O
@ 2nd T0
Steam
POC
211
P-G @ 1st T0
Pyrolyzer
10
300

FIG.8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/039058

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - C10B 1/10 (2010.01)
USPC - 202/105
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - C10B 1/00, 1/06, 1/10; C10J 3/06; F23G 5/00, 5/20; F27B 7/00 (2010.01)
USPC - 110/246; 201/16; 202/100, 105, 136; 422/209

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,477,331 A (REED et al) 16 October 1984 (16.10.1984) entire document	1, 11 --- 2-10, 12-18
Y	US 4,013,516 A (GREENFIELD et al) 22 March 1977 (22.03.1977) entire document	2-10, 12-18
Y	US 3,776,150 A (EVANS et al) 04 December 1973 (04.12.1973) entire document	3, 13
Y	US 2008/0286557 A1 (TUCKER) 20 November 2008 (20.11.2008) entire document	5

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 August 2010	20 AUG 2010

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774