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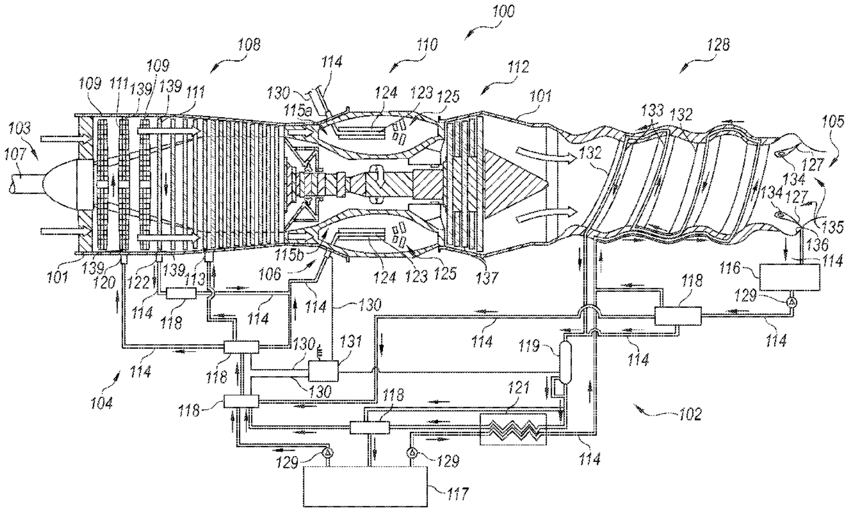

Fig. 1

(57) Abstract: Advanced gas turbines and associated components, systems and methods are disclosed herein. A gas turbine configured in accordance with a particular embodiment includes a rotor operably coupled to a shaft and a stator positioned adjacent to the rotor, A coolant line extends at least partially through the stator to transfer heat out of an air flow within a compressor section of the gas turbine.

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FUEL CONDITIONER, COMBUSTOR AND GAS TURBINE IMPROVEMENTS

CROSS-REFERENCE TO RELATED APPLICATION(S) INCORPORATED BY REFERENCE

[0001] The present application claims priority to and the benefit of U.S. Provisional Patent Application No. 61/788,756, entitled "FUEL CONDITIONER, COMBUSTOR AND GAS TURBINE IMPROVEMENTS," and filed March 15, 2013, and U.S. Patent Application No. 14/137,585, entitled "FUEL CONDITIONER, COMBUSTOR AND GAS TURBINE IMPROVEMENTS," and filed December 20, 2013, each of which is incorporated herein in its entirety by reference.

TECHNICAL FIELD

[0002] The present disclosure is directed generally to gas turbine improvements, including fuel conditioners, combustors and associated systems and methods.

BACKGROUND

[0003] Gas turbines of various designs provide power for electrical generators, aircraft, ships and other transportation systems. For many applications, gas turbines provide several advantages over other internal combustion engine designs. However, although modern gas turbines operate dependably during extended times between major maintenance requirements and provide relatively high power to weight ratios, increased fuel efficiencies could greatly improve performance and reduce operational costs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Figure 1 is a partially schematic cross-sectional view of a gas turbine or turbine 100 having a thermochemical regeneration (TCR) system 102, a compressor cooling system 104 and a fuel injection system 106 configured in accordance with an embodiment of the present disclosure.

[0005] Figure 2 is a schematic cross-sectional view of a reactor for thermochemical regeneration configured in accordance with an embodiment of the present disclosure.

[0006] Figure 3 is a cross-sectional schematic view of an injector-igniter configured in accordance with an embodiment of the present disclosure.

[0007] Figure 4 is a partially schematic, cut-away illustration of a portion of a reactor having transmissive surfaces positioned annularly in accordance with an embodiment of the disclosed technology.

[0008] Figure 5 is a partially schematic, partially cross-sectional illustration of a system having a reactor with a re-radiation component in accordance with an embodiment of the presently disclosed technology.

[0009] Figure 6 illustrates absorption characteristics as a function of wavelength for a representative reactant and re-radiation material, in accordance with an embodiment of the presently disclosed technology.

[0010] Figure 7 is an enlarged, partially schematic illustration of a portion of the reactor shown in Figure 8 having a re-radiation component configured in accordance with a particular embodiment of the presently disclosed technology.

[0011] Figure 8 is a schematic cross-sectional view of a thermal transfer device configured in accordance with an embodiment of the present technology.

[0012] Figures 9A and 9B are schematic cross-sectional views of thermal transfer devices configured in accordance with other embodiments of the present technology.

[0013] Figure 10A is a schematic cross-sectional view of a thermal transfer device operating in a first direction in accordance with a further embodiment of the present technology, and Figure 10B is a schematic cross-sectional view of the thermal transfer device of Figure 10A operating in a second direction opposite the first direction.

[0014] Figure 11 is a partially schematic illustration of a heat pump suitable for transferring heat in accordance with an embodiment of the present technology.

[0015] Figure 12 is a partially schematic illustration of a system having a solar concentrator that directs heat to a reactor vessel in accordance with an embodiment of the disclosed technology.

[0016] Figure 13 is a partially schematic, enlarged illustration of a portion of a reactor vessel, including additional features for controlling the delivery of solar energy to the reaction zone in accordance with an embodiment of the disclosed technology.

[0017] Figure 14 is a partially schematic, cross-sectional illustration of an embodiment of a reactor vessel having annularly positioned product removal and reactant delivery systems in accordance with an embodiment of the disclosure.

[0018] Figure 15 is a partially schematic, partial cross-sectional illustration of a system having a solar concentrator configured in accordance with an embodiment of the present technology.

[0019] Figure 16 is a partially schematic, partial cross-sectional illustration of an embodiment of the system shown in Figure 1 with the solar concentrator configured to emit energy in a cooling process, in accordance with an embodiment of the disclosure.

[0020] Figure 17 is a partially schematic, partial cross-sectional illustration of a system having a movable solar concentrator dish in accordance with an embodiment of the disclosure.

[0021] Figure 18 is a partially schematic illustration of a system having a reactor with facing substrates for operation in a batch mode in accordance with an embodiment of the presently disclosed technology.

[0022] Figure 19 is a partially schematic, partially cross-sectional illustration of a reactor system that receives energy from a combustion engine and returns reaction products to the engine in accordance with an embodiment of the presently disclosed technology.

[0023] Figure 20 is a partially schematic, cross-sectional illustration of a reactor having interacting endothermic and exothermic reaction zones in accordance with an embodiment of the disclosure.

DETAILED DESCRIPTION

[0024] The following disclosure describes advanced gas turbines and associated components, systems and methods. As described in greater detail below, gas turbines configured in accordance with the present disclosure can include thermochemical regeneration systems, compressor cooling systems, fuel injection systems and/or other systems or components that can increase turbine efficiency and/or power output. An efficiency increase in a particular gas turbine may enable a greater power output for a given amount of fuel. However, as used in reference to the gas turbines and associated systems and components herein, the terms efficiency and power output refer generally to gas turbine performance with respect to fuel efficiency, power output, and/or other operational parameters, and are not limited strictly to any particular measurement of performance, including either efficiency or power output. Certain details are set forth in the following description and in Figures 1-20 to provide a thorough understanding of various embodiments of the disclosure. However, other details describing well-known structures and systems often associated with turbines, compressors, fuel injectors, and/or other aspects of gas turbines are not set forth below to avoid unnecessarily obscuring the description of various embodiments of the disclosure.

[0025] Many of the details, dimensions, angles, and other features shown in the Figures are merely illustrative of particular embodiments of the disclosure. Accordingly, other embodiments can have other details, dimensions, angles, and features without departing from the spirit or scope of the present disclosure. In addition, those of ordinary skill in the art will appreciate that further embodiments of the disclosure can be practiced without several of the details described below. Furthermore, certain aspects of the following disclosure described in the context of particular embodiments may be combined or eliminated in other embodiments.

[0026] Gas turbines may have less mass than piston-driven engines of equal power output. Hence, gas turbines may have greater power-to-mass ratios (specific power) than piston-driven engines of equal power output. Gas turbines also reject more heat at higher temperatures than piston-driven engines having equal power output. These characteristics of gas turbines provide several operational benefits. For example, the greater specific power can provide performance that is not achievable by other combustion technologies (e.g., sufficient thrust along with a low weight requisite for particular aircraft designs). Additionally, the greater heat output can enable efficiency gains by combining gas turbines with other systems. Cogeneration, for example, can include the combination of a gas turbine with a heating system that recaptures waste heat and increases the overall efficiency of the system.

[0027] Gas turbines may include a compressor, a combustor system having one or more combustion chambers (combustors), and a turbine. The compressor draws in and compresses air and delivers the resulting high pressure air to the combustor system. The combustor system provides fuel preparation and mixes the fuel with the compressed air within the combustors. The fuel-air mixture is ignited and burned in the combustors, and the resulting combustion gases and heated air then pass from the combustors through one or more flow directors such as nozzle guide vanes to the turbine. Pressure and energy are extracted from the flow of gases to drive the turbine and the compressor (both of which may be coupled to a common shaft). In jet engines, a relatively smaller portion of the turbine energy may be used to drive the compressor, and the remaining high pressure gases may be used to produce jet thrust for propulsion. In other designs, such as natural gas turbines for electrical generation, more energy may be extracted by the turbine to generate electrical energy via a generator coupled to the shaft.

[0028] The combustor system of a gas turbine may facilitate, contain, and maintain stable combustion through a wide range of fuel addition and air flow circumstances. Combustors also provide for the mixing of fuel and air particles, ignition of the resultant mixture, and containment during the combustion process. To improve efficiency, combustors are often carefully designed to provide vaporization of liquid fuels and/or preheating of slow burning fuels such as natural gas. A variety of combustor configurations have been developed to achieve the above-mentioned objectives. For example, combustor designs include types referred to as can, annular, and cannular. In addition to combustion within combustors, some gas turbines include various types of afterburners that can produce additional thrust via combustion outside of the combustors. Accordingly, the combustor system of a particular gas turbine can include features designed to operate in conjunction with an afterburner.

[0029] Combustor system design may be beneficial to achieving fuel efficiency, reducing objectionable emissions, and providing sufficient transient response to rapid changes of fuel flow, air speed, and air temperature and/or pressure. Combustor system design considerations include balancing several competing objectives that often require compromise between one another. For example, several competing objectives are listed below.

[0030] 1) Providing adequate completion of fuel combustion at an air/fuel ratio, without stalling or wasting unburned fuel.

[0031] 2) Reducing pressure losses and efficiency decreases from excessive resistance or constrictions within the air, fuel or combustion gas pathways of the combustor.

[0032] 3) Maintaining the combustion process within the combustor.

[0033] 4) Reducing non-uniform hot gas temperature profiles or "hot spots" within the combustors or in the exit flow. (Hot spots can rapidly damage the combustor cans and/or the turbine.)

[0034] 5) Providing sufficient heat resistance and/or flow characteristics without increasing the overall weight or the dimensions of the turbine beyond constraints imposed by the particular application (e.g., weight and drag requirements for aircraft).

[0035] 6) Providing satisfactory performance within a wide range of operating conditions.

[0036] 7) Reducing emission levels, particularly with respect to oxides of nitrogen and particulates produced during transient operations. (Increasingly strict regulations have been imposed on aircraft emissions of pollutants and greenhouse gases, including oxides of nitrogen and carbon dioxide.)

[0037] Figure 1 is a partially schematic cross-sectional view of a gas turbine or turbine 100 having a thermochemical regeneration (TCR) system 102, a compressor cooling system 104 and a fuel injection system 106 configured in accordance with an embodiment of the present disclosure. In the illustrated embodiment, the turbine 100 includes a compressor section 108, a combustion section 110, a turbine section 112 and an exhaust section 128. A casing 101 extends from a first or inlet end 103 of the turbine 100 to a second or exhaust end 105 and at least partially envelopes several of the internal processes and components. The compressor section 108 can include a plurality of rotors 109 that are operably coupled to a shaft 107 that may extend from the first end 103 to the second end 105. A plurality of stators 111 can be positioned within the compressor section 108, with individual stators 111 positioned adjacent to and downstream (i.e., in the direction of the second end 105) of corresponding rotors 109.

[0038] The combustion section 110 of the illustrated embodiment is a cannular design having a plurality of combustor cans 115 (two visible and identified individually as a first combustor can 115a and a second combustor can 115b). Fuel injectors 123 can include insulator tubes 124 and can be positioned in corresponding combustor cans 115 to deliver fuel for combustion. In some embodiments, the fuel injectors 123 can be injector-igniters, and can include ignition features for initiating combustion. Additionally, the injectors 123 can provide for rapidly adjustable fuel combustion patterns, including stratified zones of fuel combustion 125 within insulating compressed air to ensure completeness of combustion without hot spots or loss of combustion containment. The turbine section 112 can include a plurality of turbine rotors 137 operably connected to power shaft 107.

[0039] The gas turbine 100 can include several features and operational characteristics that may be similar to that of existing gas turbines. For example, air can be drawn in through the inlet end 103, compressed by the rotors 109 and stators 111 in the compressor section 108, and combined with fuel in the combustion section 110. The resulting fuel and air mixture can be ignited and combusted within the combustor cans 115, producing hot gases that can be directed through the turbine section 112 to provide a driving force for the shaft 107. The gases can then be directed through the exhaust section 128 and exit via the second end 105. Although the general operational characteristics described above may be similar to that of existing turbines, gas turbines configured in accordance with the present disclosure, including the gas turbine 100, can include one or more features that provide increased efficiency and/or increased power, as further described below.

[0040] Gas turbines configured in accordance with the present disclosure can include features that utilize Joule-Thomson ("JT") expansion to provide expansive cooling or expansive heating. For example, as further described below, gases having a positive JT coefficient (e.g., hydrocarbon gases such as natural gas) can be expanded to produce cooling by passage through components or within the gas mixture passing through the compressor section of a turbine to increase the efficiency and/or power output of a gas turbine. Similarly, gases having a negative JT coefficient (e.g., hydrogen and other substances such as neon and helium) can be expanded to produce heating in the combustor section of a turbine to increase efficiency and/or power output. For example, hydrogen may be used as an expansive heating agent and as a combustant. Helium and/or neon may be used in a closed loop system within passageways of components of the combustion and/or expansion sections to produce heating.

[0041] The compressor cooling system 104 can increase the efficiency and/or power output of the gas turbine 100 by cooling air within the compressor section 108. For example, gases and/or liquid coolants can be transported to the compressor section 108 from the TCR system 102, or from a fuel supply system 117, via a plurality of conduits 114 and headers 118. Although shown schematically, it is to be understood that the headers 118 can include a variety of tubes, pipes, valves, actuators, switches, and/or other mechanical, electrical, or electromechanical components or devices to receive and direct various gases and/or liquids from one or more sources to one or more destinations. Similarly, the fuel supply system 117 can include multiple tanks, valves, pumps, headers, and/or other components to contain and deliver a variety of gaseous and/or liquid fuels including cryogenic or cold storage fuels such as LNG, H2, and various nitrogenous substances and hydrocarbons to multiple components. For example, although only one conduit 114 is shown extending to each of the injectors 123 of Figure 1, it is to be understood that multiple conduits 114 can extend to the injectors 123 to provide multiple fuels that can be selectively injected, as further described below. Electrical cables 130 (e.g., signal and/or power cables) can operably connect the headers 118 to a controller 131 that can actuate the valves and/or other components of the headers 118 to control the flow of gases and/or liquids. For ease of illustration, cables 130 are shown connecting the controller 131 to some of the headers 118 and one of the fuel injectors 123. However, it is to be understood that the controller 131 can be connected to various components and systems of the gas turbine 100. Additionally, although the controller 131 is shown schematically as a single component, it is to be understood that the controller 131 can include various combinations of electronic control components and devices, including processors, circuits, sensors, converters, drivers, logic circuitry, input/output (I/O) interfaces, connectors or ports, computer readable media (e.g., random access memory (RAM), read-only memory, and/or non-volatile random access memory (NVRAM)), software, and/or other components to operate and control the gas turbine 100 and/or to interface with other systems, devices or machines (e.g., a flight control system of an aircraft employing the gas turbine 100).

[0042] The cooling system 104 can direct coolants to and from the compressor section 108 via an inlet 120 and an outlet 122. The inlet 120 and/or other components of the cooling system 104 can include an expansion valve that expands a gaseous coolant providing a temperature drop to the coolant. The inlet 120 and the outlet 122 can extend through the casing 101 and be operably connected via an internal coolant line 139 that extends through at least a portion of the compressor section 108. Specifically, the internal coolant line 139 can extend through at least a portion of the compressor (e.g., through one or more of the components including members such as one or more stators within the compressor section 108) to provide cooling of the airflow that is compressed within the compressor section 108. In the illustrated embodiment, the internal coolant line 139 extends through a portion of the casing 101 and through two of the stators 111. Air drawn into the compressor section 108 by the rotors 109 is directed through the casing 101 and past the stators 111. As the air passes through the portions of the casing 101 and the stator 111 having the internal coolant line 139, heat is transferred from the air to the coolant in the internal coolant line 139. Accordingly, the air is cooled and undergoes a commensurate decrease in volume, thereby reducing the amount of work required by the compressor section 108 to produce a desired final air pressure and volume. This reduced work by the compressor section 108 results in an improved efficiency and/or higher power output for the turbine 100.

[0043] In the illustrated embodiment, the cooling system 104 can utilize fluid coolant in the form of water vapor, fog or gaseous fuel from the fuel supply system 117, and/or other gases produced in the TCR system, as described further below. In some embodiments, the cooling system 104 can operate a refrigeration cycle that compresses and expands a dedicated coolant to drive a cooling cycle. In other embodiments, the coolant in the cooling system 104 can include exhaust products from the gas turbine 100 or other gases (e.g., methane, carbon monoxide, ammonia or nitrogen). Furthermore, in addition to extending through one or more stators 111 and/or a portion of the casing 101, the internal coolant line 139 can extend through dedicated heat exchangers or other components positioned to remove heat from air passing through the compressor section 108.

[0044] The cooling system 104 can also include an injection port 113 to provide direct cooling within the airflow of the compressor section 108. In the illustrated embodiment, the injection port 113 is operably coupled to the fuel supply system 117 and the TCR system 102 via the conduits 114 and headers 118. The injection port 113 can receive fluids including gaseous fuels from the fuel supply system 117 and/or from the TCR system 102 and expand them into the compressor section 108, resulting in a temperature drop for the expanded fuels. The cooled fuel can thus decrease the temperature of the airflow, increasing the efficiency of the compressor section 108. In addition to, or in place of, fuel from the fuel supply system 117 or the TCR system 102, other cooling gases can be directed through the injection port 113 and into the air flow of the compressor section 108. For example, carbon monoxide, ammonia, nitrogen and/or other gases can be injected into the compressor section 108 to provide cooling.

[0045] The exhaust section 128 can include a variety of components that can extract energy from the flow of gases and/or capture exhaust products from the gas stream. For example, in the illustrated embodiment the exhaust section 128 includes a plurality of helical fins 132 having fin tubes 133 extending therethrough. Fluid such as fuel and/or water can be directed through the fin tubes 133 of the fins 132, which collectively comprise a counter-current heat exchanger, to cool the exhaust stream and pre-heat the fuel and/or water. The pre-heated fuel and/or water can be directed to the TCR system 102 for TCR conversion, as further described below.

[0046] In addition to the helical fins 132, the exhaust section 128 can include an exducer 135 positioned to capture or otherwise extract substances such as water from the exhaust stream. In the illustrated embodiment, the exducer 135 includes a plurality of stator volutes 127 having cooling channels 134. Coolant fluids can be directed through the coolant channels 134 to cool the stator volutes and the exhaust stream flowing over them. Illustratively, water in the exhaust stream can condense on the stator volutes 127 and be directed to a water reservoir 116 via a collector 136 and a conduit 114. Although the exducer 135 in the illustrated embodiment includes a plurality of stator volutes 127, in other embodiments, the exducer 135 can include a rotor that slings condensates such as water out of the exhaust stream to the collector 136 for delivery to the reservoir 116.

[0047] The exducer 135 can be cooled by circulation of cool incoming fuel and/or precooled water through coolant channels 134 within each stator 137 or rotor. For example, the coolant channels 134 can be operably coupled to the fuel supply system 117 and/or the cooling system 104. Fuel that is directed through the coolant channels 134 to cool the exducer 135 for water removal can be subsequently directed to the fuel supply system 117, to the compressor section 108 or the combustion section 110 for combustion, and/or to the TCR system 102 for TCR conversion, as further described below.

[0048] Gas turbines configured in accordance with embodiments of the present disclosure can utilize a variety of gases that undergo JT cooling during expansion. For example, hydrocarbon gases such as natural gas, ethane and propane, and other fluids such as ammonia, carbon dioxide, carbon monoxide, water vapor or steam, oxygen, and nitrogen can be employed as expansive cooling agents within passageways of selected components and/or mixed with oxidants such as air to provide increased efficiency. In such instances such JT cooling agents may be from a cool source or may be pre-cooled below ambient temperature by heat exchange with a cool fuel from an underground source such as a pipeline or from another cold storage source such as a cryogenic tank for hydrogen or methane. This provides beneficial preheating of the fuel from such cool sources and the JT expansive cooling capacity is increased. Additionally, permafrost, underwater clathrates, subsoil water, groundwater, or other cold sources can provide cooling for JT expansive cooling agents. In some embodiments, the JT expansive cooling agents and/or other fluids can be provided to the gas turbine 100 from an external source. In several embodiments, however, these gases can be produced by the gas turbine 100, or components or systems thereof. Equations 1-5 (below) represent various reactions that can occur within components or systems of the gas turbine 100, as further described below. Reaction products from equations 1-5 can be used to provide cooling within the gas turbine 100 via expansive JT cooling, as described above.

[0049] $C_xH_y + XH_2O + Heat_1 \rightarrow XCO + (y/2 + X)H_2$ Equation 1

[0050] $CH_4 + Heat \rightarrow \text{Carbon products} + 2H_2$ Equation 2

[0051] $CH_4 + H_2O + HEAT \rightarrow CO + 3H_2$ Equation 3

[0052] $2NH_3 + HEAT \rightarrow N_2 + 3H_2$ Equation 4

[0053] Urea or $CO(NH_2)_2 + HEAT \rightarrow N_2 + 2H_2 + CO$ Equation 5

[0054] Reactions such as shown by equations 1-5 can be carried out, for example, in the TCR system 102. As shown in Figure 1, the TCR system 102 can be operably coupled to a variety of components of the gas turbine 100. For example, in the illustrated embodiment, the TCR system 102 is operably coupled to the exhaust section 128, the compressor cooling system 104 and the fuel injection system 106.

The TCR system 102 can include a reactor 119, the fin tubes 133, a counter-current heat exchanger 121, the water reservoir 116, a pump 129, and a plurality of conduits 114 operably connecting these components in a variety of manners. Reaction products such as shown by equations 1-5 can be provided to the reactor 129 via the fuel supply system 117 and/or the water reservoir 116.

[0055] Equations 1-3 are examples of thermochemical regeneration (TCR) by which typical hydrocarbons such as diesel, jet fuel, natural gas, or other hydrogen donor fuels can be endothermically reacted to produce pressurized hydrogen-characterized gas for operation of a gas turbine engine. The amount of heat energy rejected through the hot exhaust gases by conventional gas turbine operation may be more than the heat requirement shown in equation 1. Combustion of hydrogen-characterized fuels (i.e., fuel mixtures including at least some hydrogen) can provide 15% to 30% more heat energy and provide heat release rates that are about 9 to 15 times greater than non-hydrogen characterized fuels. Furthermore, the negative JT coefficient of hydrogen can provide for expansive heating within combustors prior to or during combustion, thereby increasing combustion rate, pressure and power output. Additionally, combustion completion distances can be shortened in comparison to combustion of an original feed stock hydrocarbon. Rapid combustion in short distances can reduce hot spots or general overheating of components of the gas turbine 100 and/or provide for more compact designs.

[0056] Hydrogen-characterized fuels, and their precursor feed stocks, can produce adequate water vapor upon combustion to enable the reactions of equations 1 and 3. For example, the exhaust stream of the gas turbine 100 can provide about three times as much water as used for the conversion of natural gas or methane feed stock to hydrogen-characterized fuel, such as the TCR reaction of equation 3. Additionally, steam and/or pre-heated fuel exiting the fin tubes 133 can be close to the temperature of the exhaust gases from the turbine section 112. Such temperatures can be sufficient to drive the endothermic reactions of equations 1-5.

[0057] Various types or reactors 129 can be utilized to carry out TCR in accordance with the present technology. Figure 2 is a schematic cross-sectional view of the reactor 129 of Figure 1 configured in accordance with an embodiment of the present disclosure. In the illustrated embodiment, the reactor 129 includes an insulating canister 201, an inlet 202, and two outlets 203 (identified individually as a first outlet 203a and a second outlet 203b). A separator tube 204 having a tubular chamber 205 can be positioned within the canister 201 and receive pressurized and preheated fuels (e.g., methanol, ammonia, or mixtures of selected hydrocarbons such as natural gas and steam from the fin tubes 133 (Figure 1)) through the inlet 202. The separator tube 204 can include a helical resistance and/or induction coil 206 that can further heat fuels and/or water within the reactor 129. The separator tube 204 can include a porous cathode 207, a porous anode 208, and a membrane 210 therebetween. Hydrogen ions can be driven to the cathode 207 via a pressure gradient and/or galvanic impetus from a voltage gradient controlled by the controller 131 (Figure 1). The anode 208 can be a catalytic promoter of TCR reactions, such as those of equations 1-5. Pressurized gases and/or liquids can exit the reactor 129 via the outlets 203. Although the reactor 129 of Figure 2 includes the anode 208 internal to the cathode 207, in other embodiments and duty cycles these relative positions can be reversed such as to perform cleaning operations.

[0058] The reactor 129 can produce pressurized hydrogen via multiple reactions and processes. For example, a sufficient voltage gradient between the anode 208 and cathode 207 can produce hydrogen via electrolysis. Additionally, pressurized hydrogen at 700 Bar (10,200 PSI) can be produced from waste (e.g., urea or acids that can be produced via anaerobic digestion), as shown in equation 5. Production of hydrogen from urea can require a far reduced amount of thermal and/or electrical power compared to ambient-temperature electrolysis of water. In the process of equation 3, methane can be reacted with steam in the reactor 129 to produce carbon monoxide and hydrogen. Similarly, the endothermic reaction of equation 4 can be carried out in the reactor 129 to produce hydrogen. In each instance combustion of the resultant hydrogen (e.g., in hydrogen-characterized fuel mixtures) can provide 15% to 30% more heat energy in comparison with combustion of the feed stock compound.

[0059] The reactor 129 can include one or more semipermeable membranes 210 that can assist in removing hydrogen from a production zone and increasing the pressure of the hydrogen. Proton conduction for such separation and pressurization can be provided by various ceramics and composites (e.g., carbon-fiber-reinforced graphene, silicon carbide or perovskite-type oxides). The hydrogen yield from the reactor 129 can be increased by functionalized substances including graphene, silicon carbide, and doped perovskite-type oxides. For example, enhanced proton conductivity can be provided by doped $SrCeO_3$, $CaZrO_3$, $BaCeO_3$ and/or $SrZrO_3$. Suitable dopants include yttrium, ytterbium, europium, samarium, neodymium, and gadolinium.

[0060] In addition to dopants, hydrogen separation by oxide ceramics can be enhanced by increased pressure gradients and/or application of a DC bias. In non-galvanic hydrogen separation processes that include pressure differentials, hydrogen may be transported from a membrane side having a higher partial pressure of hydrogen to a side having a lower partial pressure of hydrogen. In contrast, in embodiments employing a DC bias or galvanic drive in the hydrogen separation process, the hydrogen can permeate from a lower partial pressure of hydrogen produced on one side of a membrane to a higher partial pressure of hydrogen on the other side, or vice versa according to process mode designation by controller 131.

[0061] The rate of hydrogen production within the reactor 129 can also be influenced by the heat provided by the exhaust section of the gas turbine 100 (Figure 1). For example, increased heat can shift the reactions of equations 1-5 toward greater yields and/or allow higher reactant pressures without reducing yields. Improvement in reaction rate and/or yield may be further provided by removal of a product such as hydrogen as it is formed to shift the reaction toward the products. Additionally, catalysts may be utilized at a reaction surface to favorably influence surface exchange reactions such as those of equations 1-5. For example, hydrogen permeation and thus the process yield can be enhanced by coating the membrane with a surface catalyst to reduce the activation energy for the surface exchange reactions. To some extent some anode material selections may be favorable catalysts. Anodes of galvanic hydrogen pumps include porous films of Ni, Ag, Pt, and Ni/BCY porous layers. In such hydrogen pumping processes, the gas mixture in the anode and cathode zones can include steam or be humidified with water vapor to improve the proton conductivity of the electrolyte and suppress its electronic conductivity.

[0062] In accordance with Faraday's law, hydrogen separation rates increase as the applied current in the electrode 206 is increased. Depending upon factors such as reactant pressure and temperature, dopant selection, membrane thickness, and humidity, applied galvanic voltage gradients in the range of, e.g., 0.2 to 20 Volts DC are adequate to produce substantially higher pressure hydrogen. Such net bias of galvanic voltage gradients may be produced by much higher voltage AC or DC electricity delivered to resistive and/or inductive heating of the reactor-separator tube.

[0063] Various mixtures of reactants and products such as hydrogen along with CO, CO_2, H_2O, and/or N_2 at or near the anode 208 can be separated to provide pressurized hydrogen at the cathode 207. Such hydrogen pressurization driven by an applied external voltage can move hydrogen from a suitably pressurized gas mixture such as lower pressure to assure high yield efficiency, including reactants and products, to higher pressure for product delivery such as hydrogen for denser storage and injection purposes. Pressurized gases for expansive cooling can be collected at the anode 208 of the membrane for injection and expansive cooling within the compressor section 108 (Figure 1), and pressurized hydrogen from the cathode 207 can be collected at high pressure for injection into the combustors 115 (Figure 1) to produce expansive heating.

[0064] Endothermic heat can be added in various steps, including heat from engine exhaust gases at around 425°C (800°F) or higher temperatures, and heat from electrical bias, inductive heating, and/or resistance heating at about 650 °C to about 1600°C (1200 °F to 2900°F). The heat can be controlled via the controller 131 (Figure 1) to achieve the conversion rate and pressurization of hydrogen for the operation of the gas turbine 100. Renewable or regenerative sources of energy for heat can include regenerative deceleration of a vehicle, utilization of suspension energy from regenerative shock absorber/spring systems, energy conversion streamlining of a vehicle, or utilization of off-peak electricity in stationary applications.

[0065] Depending upon the pressure desired for hydrogen storage, a flow circuit may be utilized that provides for reactants to first gain a portion of heat from exhaust gases and then enter into the reactor 129 to utilize galvanic hydrogen separation and pressurization. This can provide a thermal gradient from exhaust gases to supply the first portion of heat, and also provide flexibility to the process by enabling rapid application of regenerative energy (e.g., electrical energy) to provide additional heat at higher adaptively controlled temperatures as may be used to produce hydrogen at the desired rate and/or pressure for direct injection and stratified charge combustion in gas turbine operations.

[0066] The TCR system 102 of the present disclosure can include one or more components, devices or systems, described in U.S. Patent Application No. 13/684,987, entitled CHEMICAL PROCESSES AND REACTORS FOR EFFICIENTLY PRODUCING HYDROGEN FUELS AND STRUCTURAL MATERIALS, AND ASSOCIATED SYSTEMS AND METHODS, and filed November 26, 2012; U.S. Patent Application No. 13/027,244, entitled THERMAL TRANSFER DEVICE AND ASSOCIATED SYSTEMS AND METHODS, and filed February 14, 2011; U.S. Patent Application No. 13/481,673 entitled REACTORS FOR CONDUCTING THERMOCHEMICAL PROCESSES WITH SOLAR HEAT INPUT, AND ASSOCIATED SYSTEMS AND METHODS, and filed May 25, 2012; U.S. Patent Application No. 13/685,075 entitled INDUCTION FOR THERMOCHEMICAL PROCESS, AND ASSOCIATED SYSTEMS AND METHODS, and filed November 26, 2012; and U.S. Patent Application No. 13/584,749 entitled MOBILE TRANSPORT PLATFORMS FOR PRODUCING HYDROGEN AND STRUCTURAL MATERIALS, AND ASSOCIATED SYSTEMS AND METHODS, and filed August 13, 2012, each of which is incorporated by reference herein in its entirety.

[0067] In the combustion section 110 (Figure 1), hydrogen can be injected via the injectors 123 and expanded into the gases from the compressor section 108 to produce heat and accelerate the combustion of other fuels that may be present (including fuel fluids previously added through the compressor section 108). In instances that expansive cooling fuel fluids are directed through the internal coolant lines 139 of the stators 111 to cool air undergoing compression, such fuel gases can be injected as a mixture with hydrogen by the injectors 123 to provide accelerated hydrogen-boosted combustion. The expansive cooling of air in the compressor section 108 and the expansive heating of fuel and air in the combustion section 110 can both improve the effective brake mean effective pressure (BMEP) and fuel efficiency of the gas turbine 100.

[0068] The fuel injectors 123 can be of any suitable design and arrangement for injecting fuels, such as those produced by TCR. Compared to diesel and jet fuels, fuels produced via TCR (e.g., hydrogen and mixtures of hydrogen and gases such as nitrogen, carbon monoxide, carbon dioxide, gaseous hydrocarbons and other compounds) are up to about 3,000 times lower in volumetric energy density. Accordingly, larger volumes of such fuels must be used to produce sufficient power output. Hence, turbine operation may be improved by injectors or injector-igniters that can rapidly inject large volumes and/or efficiently ignite large volumes.

[0069] Figure 3 is a cross-sectional schematic view of the injector-igniter 123 configured in accordance with an embodiment of the present disclosure. The injector 123 can provide rapid selection of any of several fuels or fluids by a thermally isolated and/or insulated flow director 302. Conduits 114 and a control cable 131 can be operably coupled to the flow director 302 to provide fuel and control and ignition signals, respectively as scheduled by controller 131 and/or by a microcontroller within 123. A motion amplifier can magnify motion of a piezoelectric component of the flow director 302 to position a heat resistant shuttle valve 304 (e.g., a ceramic or super alloy valve). The flow director 302 can be integral with an elongated injector body 306 or mounted in any suitable orientation with respect to the injector body 306. The injector-igniter can include ignition coils, transformer sections, glass or ceramic insulator sleeves, capacitors and/or a variety of other components or devices associated with fuel injectors, igniters and/or injector-igniters.

[0070] The length of the injector-igniter 123 may be as long as needed to extend into a hot zone of the combustors 115 (Figure 1). Additionally, the injector 123 can be positioned to provide a desired angle of fuel projection into the combustion air to develop directional momentum of the JT expansion heating and combustion thrust into the power rotor section of the turbine section 112. The injector 123 can include a sheath having one or more fins or other features to produce desired flow patterns of gases delivered from the compressor section 108. The flow patterns can be chosen to help reduce the flame length of fuel combustion, impart a desired flow to increase the conversion efficiency by the turbine section 112, and/or to eliminate potentially damaging hot spots in the hot gases flowing to the turbine section 112.

[0071] The embodiments provided by the present disclosure may benefit thermal and fuel efficiencies.

[0072] The combustion of hydrogen-characterized fuels, along with the injection and ignition system disclosed herein, can provide several advantages with respect to gas turbine designs. For example, combustors can be much lighter and smaller than conventional designs. Additionally, one or more injector-igniters can provide changes in fuel rate to meet transient conditions. Combustion assurance and flame containment can be enhanced by TCR fuel products, without air-fuel premixing as is required with conventional fuel selections such as jet fuel and natural gas. The injectors may provide a benefit to ignition assurance throughout widely varying fuel rates, and fuel combustion patterns can be quickly adjusted to provide stratified zones of fuel combustion within insulating compressed air to ensure completeness of combustion without hot spots or loss of combustion containment.

Further Representative Reactors

[0073] The following sections describe representative reactors and associated systems that may be used alone or in any of a variety of suitable combinations for carrying out one or more of the foregoing processes described above with reference to Figures 1-3. In particular, any suitable component of the systems described in the following sections may replace or supplement a suitable component described in the foregoing sections.

[0074] In some embodiments, the reactants may be obtained on a local scale, the reactions may be conducted on a local scale, and the products may be used on a local scale to produce a localized result. In other embodiments, the reactants, reactions, products and overall effect of the process can have a much larger effect. For example, the technology can have continental and/or extra-continental scope. In particular embodiments, the technology can be deployed to preserve vast regions of permafrost, on a continental scale, and or preserve ecosystems located offshore from the preserved areas. In other embodiments, the technology can be deployed offshore to produce effects over large tracts of ocean waters. In still further, embodiments, the technology can be deployed on mobile systems that convey the benefits of the technology to a wide range of areas around the globe.

[0075] In general, the disclosed reactors dissociate, reform and/or respeciate a donor material (reactant) into multiple constituents (e.g., a first constituent and a second constituent). Particular aspects of the representative reactors described below are described in the context of specific reactants and products, e.g., a hydrogen and carbon bearing donor, a hydrogen-bearing product or constituent, and a carbon-bearing product or constituent. In certain other embodiments of the disclosed technology, the same or similar reactors may be used to process other reactants and/or form other products. For example, non-hydrogen feedstock materials (reactants) are used in at least some embodiments. In particular examples, sulfur dioxide can be processed in a non-combustion thermal reactor to produce sulfur and oxygen, and/or carbon dioxide can be processed to produce carbon and oxygen. In many of these embodiments, the resulting dissociation products can include a structural building block and/or a hydrogen-based fuel or other dissociated constituent. The structural building block includes compositions that may be further processed to produce architectural constructs. For example, the structural building blocks can include compounds or molecules resulting from the dissociation process and can include carbon, various organics (e.g. methyl, ethyl, or butyl groups or various alkenes), boron, nitrogen, oxygen, silicon, sulfur, halogens, and/or transition metals. In many applications the building block element does not include hydrogen. In a specific example, methane is dissociated to form hydrogen (or another hydrogen-bearing constituent) and carbon and/or carbon dioxide and/or carbon monoxide (structural building blocks). The carbon and/or carbon dioxide and/or carbon monoxide can be further processed to form polymers, graphene, carbon fiber, and/or another architectural construct. The architectural construct can include a self-organized structure (e.g., a crystal) formed from any of a variety of suitable elements, including the elements described above (carbon, nitrogen, boron, silicon, sulfur, and/or transition metals). In any of these embodiments, the architectural construct can form durable goods, e.g., graphene or carbon composites, and/or other structures.

Representative Reactors with Transmissive Surfaces

[0076] Figure 4 is a partially schematic, partially cut-away illustration of a reactor 1310 that includes a vessel 1311 formed from three annularly (e.g., concentrically) positioned conduits 1322. Accordingly, the reactor 1310 can operate in a continuous flow manner. As used herein, “continuous flow” refers generally to a process in which reactants and products can be provided to and removed from the reactor vessel continuously without halting the reaction to reload the reaction zone with reactants. In other embodiments, the reactor 1310 can operate in a batch manner during which reactants are intermittently supplied to the reaction zone and products are intermittently removed from the reaction zone. The three conduits 1322 include a first or inner conduit 1322a, a second or intermediate conduit 1322b, and a third or outer conduit 1322c. The first conduit 1322a bounds a combustion products passage 1318 and accordingly has an interior region 1320 through which the combustion products 1152 pass. The first conduit 1322a has a first transmissive surface 1319a through which radiant energy passes in a radially outward direction, as indicated by arrows B. In a particular aspect of this embodiment, the annular region between the first conduit 1322a and the second conduit 1322b houses a heater 1323, and the annular region between the second conduit 1322b and the third conduit 1322c houses a reaction zone 1312. The heater 1323 together with the radiant heat from the combustion products 1152 provides heat to the reaction zone 1312. Accordingly, the second conduit 1322b can include a second transmissive surface 1319b that allows radiant energy from both the combustion products 1152 and the heater 1323 to pass radially outwardly into the reaction zone 1312. In a particular aspect of this embodiment, the first transmissive surface 1319a and the second transmissive surface 1319b are not transmissible to chemical constituents of the combustion products 1152, in order to avoid contact (e.g., corrosive or other damaging contact) between the combustion products 1152 and the heater 1323. In another embodiment, the heater 1323 can be manufactured (e.g., with appropriate coatings, treatments, or other features) in a manner that protects it from chemical constituents passing through the first and second transmissive surfaces 1319a, 1319b. In still another embodiment, the heater 1323 can be positioned outwardly from the reaction zone 1312. In any of these embodiments, the heater 1323 can include an electrical resistance heater, an induction heater or another suitable device. In at least some instances, the heater 1323 is powered by combusting a portion of the hydrogen produced in the reaction zone 1312. In other embodiments, combustion is performed in the reactor itself, for example, with the second conduit 1322b serving as a gas mantle for radiating energy at frequencies selected to accelerate the desired reactions in reaction zone 1312.

[0077] In any of the forgoing embodiments, the reaction zone 1312 can house one or more steam distributors 1316 and one or more hydrogen donor distributors 1315. Each of the distributors 1315, 1316 can include pores 1324 and/or other apertures, openings or passages that allow chemical reactants to enter the reaction zone 1312. The donor distributors 1315, 1316 can include one or more spiral conduits, including, e.g., conduits arranged in a braided fashion to distribute reactants into the reaction zone uniformly in the axial, radial and circumferential directions. The reaction zone 1312 is bounded by the third conduit 1322c which can have an insulated reactor outer surface 1321 to conserve heat within the reaction zone 1312. During operation, the reaction taking place in the reaction zone 1312 can be controlled by adjusting the rate at which steam and the hydrogen donor enter the reaction zone 1312, the rate at which heat enters the reaction zone 1312 (via the combustion product passage 1318 and/or the heater 1323) and other variables, including the pressure at the reaction zone 1312. Appropriate sensors and control feedback loops carry out these processes autonomously, with optional controller intervention.

[0078] Still further embodiments of suitable reactors with transmissive surfaces are disclosed in pending U.S. Application No. 13/026,996, filed February 14, 2011, and incorporated herein by reference.

Representative Reactors with Re-Radiative Components

[0079] Figure 5 is a partially schematic illustration of a system 2100 that includes a reactor 2110 having one or more selective (e.g., re-radiative) surfaces in accordance with embodiments of the disclosure. The reactor 2110 further includes a reactor vessel 2111 having an outer surface 2121 that encloses or partially encloses a reaction zone 2112. In a representative example, the reactor vessel 2111 receives a hydrogen donor provided by a donor source 2101 to a donor entry port 2113. For example, the hydrogen donor can include methane or another hydrocarbon. A donor distributor or manifold 2115 within the reactor vessel 2111 disperses or distributes the hydrogen donor into the reaction zone 2112. The reactor vessel 2111 also receives steam from a steam/water source 2102 via a steam entry port 2114. A steam distributor 2116 in the reactor vessel 2111 distributes the steam into the reaction zone 2112. The reactor vessel 2111 can still further include a heater 2123 that supplies heat to the reaction zone 2112 to facilitate endothermic reactions. Such reactions can include dissociating methane or another hydrocarbon into hydrogen or a hydrogen compound, and carbon or a carbon compound. The products of the reaction (e.g., carbon and hydrogen) exit the reactor vessel 2111 via an exit port 2117 and are collected at a reaction product collector 2160a.

[0080] The system 2100 can further include a source 2103 of radiant energy and/or additional reactants, which provides constituents to a passage 2118 within the reactor vessel 2111. For example, the radiant energy/reactant source 2103 can include a combustion chamber 2104 that provides hot combustion products 2105 to the passage 2118, as indicated by arrow A. In a particular embodiment, the passage 2118 is concentric relative to a passage centerline 2122. In other embodiments, the passage 2118 can have other geometries. A combustion products collector 2160b collects combustion products exiting the reactor vessel 2111 for recycling and/or other uses. In a particular embodiment, the combustion products 2105 can include carbon monoxide, water vapor, and other constituents.

[0081] One or more re-radiation components 2150 are positioned between the reaction zone 2112 (which can be disposed annularly around the passage 2118) and an interior region 2120 of the passage 2118. The re-radiation component 2150 can accordingly absorb incident radiation R from the passage 2118 and direct re-radiated energy RR into the reaction zone 2112. The re-radiated energy RR can have a wavelength spectrum or distribution that more closely matches, approaches, overlaps and/or corresponds to the absorption spectrum of at least one of the reactants and/or at least one of the resulting products. By delivering the radiant energy at a favorably shifted wavelength, the system 2100 can enhance the reaction taking place in the reaction zone 2112, for example, by increasing the efficiency with which energy is absorbed by the reactants, thus increasing the reaction zone temperature and/or pressure, and therefore the reaction rate, and/or the thermodynamic efficiency of the reaction. In a particular aspect of this embodiment, the combustion products 2105 and/or other constituents provided by the source 2103 can be waste products from another chemical process (e.g., an internal combustion process). Accordingly, the foregoing process can recycle or reuse energy and/or constituents that would otherwise be wasted, in addition to facilitating the reaction at the reaction zone 2112.

[0082] In at least some embodiments, the re-radiation component 2150 can be used in conjunction with, and/or integrated with, a transmissive surface 2119 that allows chemical constituents (e.g., reactants) to readily pass from the interior region 2120 of the passage 2118 to the reaction zone 2112. Further details of representative transmissive surfaces were discussed above under heading 3.1. In other embodiments, the reactor 2110 can include one or more re-radiation components 2150 without also including a transmissive surface 2119. In any of these embodiments, the radiant energy present in the combustion product 2105 may be present as an inherent result of the combustion process. In other embodiments, an operator can introduce additives into the stream of combustion products 2105 (and/or the fuel that produces the combustion products) to increase the amount of energy extracted from the stream and delivered to the reaction zone 2112 in the form of radiant energy. For example, the combustion products 2105 (and/or fuel) can be seeded with sources of sodium, potassium, and/or magnesium, which can absorb energy from the combustion products 2105 and radiate the energy outwardly into the reaction zone 2112 at desirable frequencies. These illuminant additives can be used in addition to the re-radiation component 2150.

[0083] Figure 6 is a graph presenting absorption as a function of wavelength for a representative reactant (e.g., methane) and a representative re-radiation component. Figure 5 illustrates a reactant absorption spectrum 2130 that includes multiple reactant peak absorption ranges 2131, three of which are highlighted in Figure 5 as first, second and third peak absorption ranges 2131a, 2131b, 2131c. The peak absorption ranges 2131 represent wavelengths for which the reactant absorbs more energy than at other portions of the spectrum 2130. The spectrum 2130 can include a peak absorption wavelength 2132 within a particular range, e.g., the third peak absorption range 2131c.

[0084] Figure 6 also illustrates a first radiant energy spectrum 2140a having a first peak wavelength range 2141a. For example, the first radiant energy spectrum 2140a can be representative of the emission from the combustion products 2105 described above with reference to Figure 5. After the radiant energy has been absorbed and re-emitted by the re-radiation component 2150 described above, it can produce a second radiant energy spectrum 2140b having a second peak wavelength range 2141b, which in turn includes a re-radiation peak value 2142. In general terms, the function of the re-radiation component 2150 is to shift the spectrum of the radiant energy from the first radiant energy spectrum 2140a and peak wavelength range 2141a to the second radiant energy spectrum 2140b and peak wavelength range 2141b, as indicated by arrow S. As a result of the shift, the second peak wavelength range 2141b is closer to the third peak absorption range 2131c of the reactant than is the first peak wavelength range 2141a. For example, the second peak wavelength range 2141b can overlap with the third peak absorption range 2131c and in a particular embodiment, the re-radiation peak value 2142 can be at, or approximately at the same wavelength as the reactant peak absorption wavelength 2132. In this manner, the re-radiation component more closely aligns the spectrum of the radiant energy with the peaks at which the reactant efficiently absorbs energy. Representative structures for performing this function are described in further detail below with reference to Figures 6.

[0085] Figure 7 is a partially schematic, enlarged cross-sectional illustration of a portion of the reactor 2110 described above with reference to Figure 5, having a re-radiation component 2150 configured in accordance with a particular embodiment of the technology. The re-radiation component 2150 is positioned between the passage 2118 (and the radiation energy R in the passage 2118), and the reaction zone 2112. The re-radiation component 2150 can include layers 2151 of material that form spaced-apart structures 2158, which in turn carry a re-radiative material 2152. For example, the layers 2151 can include graphene layers or other crystal or self-orienting layers made from suitable building block elements such as carbon, boron, nitrogen, silicon, transition metals, and/or sulfur. Carbon is a particularly suitable constituent because it is relatively inexpensive and readily available. In fact, it is a target output product of reactions that can be completed in the reaction zone 2112. Further details of suitable structures are disclosed in co-pending U.S. Application No. 12/857,228 previously incorporated herein by reference. Each structure 2158 can be separated from its neighbor by a gap 2153. The gap 2153 can be maintained by spacers 2157 extending between neighboring structures 2158. In particular embodiments, the gaps 2153 between the structures 2158 can be from about 2.5 microns to about 25 microns wide. In other embodiments, the gap 2153 can have other values, depending, for example, on the wavelength of the incident radiative energy R. The spacers 2157 are positioned at spaced-apart locations both within and perpendicular to the plane of Figure 7 so as not to block the passage of radiation and/or chemical constituents through the component 2150.

[0086] The radiative energy R can include a first portion R1 that is generally aligned parallel with the spaced-apart layered structures 2158 and accordingly passes entirely through the re-radiation component 2150 via the gaps 2153 and enters the reaction zone 2112 without contacting the re-radiative material 2152. The radiative energy R can also include a second portion R2 that impinges upon the re-radiative material 2152 and is accordingly re-radiated as a re-radiated portion RR into the reaction zone 2112. The reaction zone 2112 can accordingly include radiation having different energy spectra and/or different peak wavelength ranges, depending upon whether the incident radiation R impinged upon the re-radiative material 2152 or not. This combination of energies in the reaction zone 2112 can be beneficial for at least some reactions. For example, the shorter wavelength, higher frequency (higher energy) portion of the radiative energy can facilitate the basic reaction taking place in the reaction zone 2112, e.g., disassociating methane in the presence of steam to form carbon monoxide and hydrogen. The longer wavelength, lower frequency (lower energy) portion can prevent the reaction products from adhering to surfaces of the reactor 2110, and/or can separate such products from the reactor surfaces. In particular embodiments, the radiative energy can be absorbed by methane in the reaction zone 2112, and in other embodiments, the radiative energy can be absorbed by other reactants, for example, the steam in the reaction zone 2112, or the products. In at least some cases, it is preferable to absorb the radiative energy with the steam. In this manner, the steam receives sufficient energy to be hot enough to complete the endothermic reaction within the reaction zone 2112, without unnecessarily heating the carbon atoms, which may potentially create particulates or tar if they are not quickly oxygenated after dissociation.

[0087] The re-radiative material 2152 can include a variety of suitable constituents, including iron carbide, tungsten carbide, titanium carbide, boron carbide, and/or boron nitride. These materials, as well as the materials forming the spaced-apart structures 2158, can be selected on the basis of several properties including corrosion resistance and/or compressive loading. For example, loading a carbon structure with any of the foregoing carbides or nitrides can produce a compressive structure. An advantage of a compressive structure is that it is less subject to corrosion than is a structure that is under tensile forces. In addition, the inherent corrosion resistance of the constituents of the structure (e.g., the foregoing carbides and nitrides) can be enhanced because, under compression, the structure is less permeable to corrosive agents, including steam which may well be present as a reactant in the reaction zone 2112 and as a constituent of the combustion products 2105 in the passage 2118. The foregoing constituents can be used alone or in combination with phosphorus, calcium fluoride and/or another phosphorescent material so that the energy re-radiated by the re-radiative material 2152 may be delayed. This feature can smooth out at least some irregularities or intermittencies with which the radiant energy is supplied to the reaction zone 2112.

[0088] Another suitable re-radiative material 2152 includes spinel or another composite of magnesium and/or aluminum oxides. Spinel can provide the compressive stresses described above and can shift absorbed radiation to the infrared so as to facilitate heating the reaction zone 2112. For example, sodium or potassium can emit visible radiation (e.g., red/orange/yellow radiation) that can be shifted by spinel or another alumina-bearing material to the IR band. If both magnesium and aluminum oxides, including compositions with colorant additives such as magnesium, aluminum, titanium, chromium, nickel, copper and/or vanadium, are present in the re-radiative material 2152, the re-radiative material 2152 can emit radiation having multiple peaks, which can in turn allow multiple constituents within the reaction zone 2112 to absorb the radiative energy.

[0089] The particular structure of the re-radiation component 2150 shown in Figure 6 includes gaps 2153 that can allow not only radiation to pass through, but can also allow constituents to pass through. Accordingly, the re-radiation component 2150 can also form the transmissive surface 2119, which, as described above with reference to Figure 5, can further facilitate the reaction in the reaction zone 2112 by admitting reactants.

[0090] Still further embodiments of suitable reactors with re-radiative components are disclosed in pending U.S. Application No. 13/027,015, filed February 14, 2011, and incorporated herein by reference.

Representative Reactors with Heat Pipes and Heat Pumps

[0091] Figure 8 is a schematic cross-sectional view of a thermal transfer device 3100 ("device 3100") configured in accordance with an embodiment of the present technology. As shown in Figure 8, the device 3100 can include a conduit 3102 that has an input portion 3104, an output portion 3106 opposite the input portion 3104, and a sidewall 3120 between the input and output portions 3104 and 3106. The device 3100 can further include a first end cap 3108 at the input portion 3104 and a second end cap 3110 at the output portion 3106. The device 3100 can enclose a working fluid 3122 (illustrated by arrows) that changes between a vapor phase 3122a and a liquid phase 3122b during a vaporization-condensation cycle.

[0092] In selected embodiments, the device 3100 can also include one or more architectural constructs 3112. Architectural constructs 3112 are synthetic matrix characterizations of crystals that are primarily comprised of graphene, graphite, boron nitride, and/or another suitable crystal. The configuration and the treatment of these crystals heavily influence the properties that the architectural construct 3112 will exhibit when it experiences certain conditions. For example, as explained in further detail below, the device 3100 can utilize architectural constructs 3112 for their thermal properties, capillary properties, sorbtive properties, catalytic properties, and electromagnetic, optical, and acoustic properties. As shown in Figure 7, the architectural construct 3112 can be arranged as a plurality of substantially parallel layers 3114 spaced apart from one another by a gap 3116. In various embodiments, the layers 3114 can be as thin as one atom. In other embodiments, the thickness of the individual layers 3114 can be greater and/or less than one atom and the width of the gaps 3116 between the layers 3114 can vary. Methods of fabricating and configuring architectural constructs, such as the architectural constructs 3112 shown in Figure 8, are described in U.S. Patent Application No. 12/857,228 previously incorporated herein by reference.

[0093] As shown in Figure 8, the first end cap 3108 can be installed proximate to a heat source (not shown) such that the first end cap 3108 serves as a hot interface that vaporizes the working fluid 3122. Accordingly, the first end cap 3108 can include a material with a high thermal conductivity and/or transmissivity to absorb or deliver heat from the heat source. In the embodiment illustrated in Figure 7, for example, the first end cap 3108 includes the architectural construct 3112 made from a thermally conductive crystal (e.g., graphene). The architectural construct 3112 can be arranged to increase its thermal conductively by configuring the layers 3114 to have a high concentration of thermally conductive pathways (e.g., formed by the layers 3114) substantially parallel to the influx of heat. For example, in the illustrated embodiment, the layers 3114 generally align with the incoming heat flow such that heat enters the architectural construct 3112 between the layers 3114. This configuration exposes the greatest surface area of the layers 3114 to the heat and thereby increases the heat absorbed by the architectural construct 3112. Advantageously, despite having a much lower density than metal, the architectural construct 3112 can conductively and/or radiatively transfer a greater amount of heat per unit area than solid silver, raw graphite, copper, or aluminum.

[0094] As further shown in Figure 8, the second end cap 3110 can expel heat from the device 3100 to a heat sink (not shown) such that the second end cap 3110 serves as a cold interface that condenses the working fluid 3122. The second end cap 3110, like the first end cap 3108, can include a material with a high thermal conductivity (e.g., copper, aluminum) and/or transmissivity to absorb and/or transmit latent heat from the working fluid 3122. Accordingly, like the first end cap 3108, the second end cap 3110 can include the architectural construct 3112. However, rather than bringing heat into the device 3100 like the first end cap 3108, the second end cap 3110 can convey latent heat out of the device 3100. In various embodiments, the architectural constructs 3112 of the first and second end caps 3108 and 3110 can be made from the similar materials and/or arranged to have substantially similar thermal conductivities. In other embodiments, the architectural constructs 3112 can include different materials, can be arranged in differing directions, and/or otherwise configured to provide differing thermal conveyance capabilities including desired conductivities and transmissivities. In further embodiments, neither the first end cap 3108 nor the second end cap 3110 includes the architectural construct 3112.

[0095] In selected embodiments, the first end cap 3108 and/or the second end cap 3110 can include portions with varying thermal conductivities. For example, a portion of the first end cap 3108 proximate to the conduit 3102 can include a highly thermally conductive material (e.g., the architectural construct 3112 configured to promote thermal conductivity, copper, etc.) such that it absorbs heat from the heat source and vaporizes the working fluid 3122. Another portion of the first end cap 3108 spaced apart from the conduit 3102 can include a less thermally conductive material to insulate the high conductivity portion. In certain embodiments, for example, the insulative portion can include ceramic fibers, sealed dead air space, and/or other materials or structures with high radiant absorptivities and/or low thermal conductivities. In other embodiments, the insulative portion of the first end cap 3108 can include the architectural construct 3112 arranged to include a low concentration of thermally conductive pathways (e.g., the layers 3114 are spaced apart by large gaps 3116) such that it has a low availability for conductively transferring heat.

[0096] In other embodiments, the configurations of the architectural constructs 3112 may vary from those shown in Figure 8 based on the dimensions of the device 3100, the temperature differential between the heat source and the heat sink, the desired heat transfer, the working fluid 3122, and/or other suitable thermal transfer characteristics. For example, architectural constructs 3112 having smaller surface areas may be suited for microscopic applications of the device 3100 and/or high temperature differentials, whereas architectural constructs 3112 having higher surface areas may be better suited for macroscopic applications of the device 3100 and/or higher rates of heat transfer. The thermal conductivities of the architectural constructs 3112 can also be altered by coating the layers 3114 with dark colored coatings to increase heat absorption and with light colored coatings to reflect heat away and thereby decrease heat absorption.

[0097] Referring still to Figure 8, the device 3100 can return the liquid phase 3122b of the working fluid 3122 to the input portion 3104 by capillary action. The sidewall 3120 of the conduit 3102 can thus include a wick structure that exerts a capillary pressure on the liquid phase 3122b to drive it toward a desired location (e.g., the input portion 3104). For example, the sidewall 3120 can include cellulose, ceramic wicking materials, sintered or glued metal powder, nanofibers, and/or other suitable wick structures or materials that provide capillary action.

[0098] In the embodiment shown in Figure 8, the architectural construct 3112 is aligned with the longitudinal axis 3118 of the conduit 3102 and configured to exert the necessary capillary pressure to direct the liquid phase 3122b of the working fluid 3122 to the input portion 3104. The composition, dopants, spacing, and/or thicknesses of the layers 3114 can be selected based on the surface tension required to provide capillary action for the working fluid 3122. Advantageously, the architectural construct 3112 can apply sufficient capillary pressure on the liquid phase 3122b to drive the working fluid 3122 short and long distances (e.g., millimeters to kilometers). Additionally, in selected embodiments, the surface tension of the layers 3114 can be manipulated such that the architectural construct 3112 rejects a preselected fluid. For example, the architectural construct 3112 can be configured to have a surface tension that rejects any liquid other than the liquid phase 3122b of the working fluid 3122. In such an embodiment, the architectural construct 3112 can function as a filter that prevents any fluid other than the working fluid 3122 (e.g., fluids tainted by impurities that diffused into the conduit 3102) from interfering with the vaporization-condensation cycle.

[0099] In other embodiments, the selective capillary action of the architectural construct 3112 separates substances at far lower temperatures than conventional distillation technologies. The faster separation of substances by the architectural construct 3112 can reduce or eliminates substance degradation caused if the substance reaches higher temperatures within the device 3100. For example, a potentially harmful substance can be removed from the working fluid 3122 by the selective capillary action of the architectural construct 3112 before the working fluid 3122 reaches the higher temperatures proximate to the input portion 3104.

[00100] The conduit 3102 and the first and second end caps 3108 and 3110 can be sealed together using suitable fasteners able to withstand the temperature differentials of the device 3100. In other embodiments, the device 3100 is formed integrally. For example, the device 3100 can be molded using one or more materials. A vacuum can be used to remove any air within the conduit 3102, and then the conduit 3102 can be filled with a small volume of the working fluid 3122 chosen to match the operating temperatures.

[00101] In operation, the device 3100 utilizes a vaporization-condensation cycle of the working fluid 3122 to transfer heat. More specifically, the first end cap 3108 can absorb heat from the heat source, and the working fluid 3122 can in turn absorb the heat from the first end cap 3108 to produce the vapor phase 3122a. The pressure differential caused by the phase change of the working fluid 3122 can drive the vapor phase 3122a of the working fluid 3122 to fill the space available and thus deliver the working fluid 3122 through the conduit 3102 to the output portion 3104. At the output portion 3104, the second end cap 3110 can absorb heat from the working fluid 3122 to change the working fluid 3122 to the liquid phase 3122b. The latent heat from the condensation of the working fluid 3122 can be transferred out of the device 3100 via the second end cap 3110. In general, the heat influx to the first end cap 3108 substantially equals the heat removed by the second end cap 3110. As further shown in Figure 8, capillary action provided by the architectural construct 3112 or other wick structure can return the liquid phase 3122b of the working fluid 3122 to the input portion 3104. In selected embodiments, the termini of the layers 3114 can be staggered or angled toward the conduit 3102 to facilitate entry of the liquid phase 3122b between the layers 3114 and/or to facilitate conversion of the liquid phase 3122b to the vapor phase 3122b at the input portion 3104. At the input portion 3104, the working fluid 3122 can again vaporize and continue to circulate through the conduit 3102 by means of the vaporization-condensation cycle.

[00102] The device 3100 can also operate the vaporization-condensation cycle described above in the reverse direction. For example, when the heat source and heat sink are reversed, the first end cap 3108 can serve as the cold interface and the second end cap 3110 can serve as the hot interface. Accordingly, the input and output portions 3104 and 3106 are inverted such that the working fluid 3122 vaporizes proximate to the second end cap 3110, condenses proximate to the first end cap 3108, and returns to the second end cap 3110 using the capillary action provided by the sidewall 3120. The reversibility of the device 3100 allows the device 3100 to be installed irrespective of the positions of the heat source and heat sink. Additionally, the device 3100 can accommodate environments in which the locations of the heat source and the heat sink may reverse. For example, as described further below, the device 3100 can operate in one direction during the summer to utilize solar energy and the device 3100 can reverse direction during the winter to utilize heat stored during the previous summer.

[00103] Embodiments of the device 3100 including the architectural construct 3112 at the first end cap 3108 and/or second end cap 3110 have higher thermal conductivity per unit area than conventional conductors. This increased thermal conductivity can increase process rate and the temperature differential between the first and second end caps 3108 and 3110 to produce greater and more efficient heat transfer. Additionally, embodiments including the architectural construct 3112 at the first and/or second end caps 3108 and 3110 require less surface area to absorb the heat necessary to effectuate the vaporization-condensation cycle. Thus, the device 3100 can be more compact than a conventional heat pipe that transfers an equivalent amount of heat and provide considerable cost reduction.

[00104] Referring still to Figure 8, in various embodiments, the device 3100 can further include a liquid reservoir 3124 in fluid communication with the conduit 3102 such that the liquid reservoir 3124 can collect and store at least a portion of the working fluid 3122. As shown in Figure 8, the liquid reservoir 3124 can be coupled to the input portion 3104 of the conduit 3102 via a pipe or other suitable tubular shaped structure. The liquid phase 3122b can thus flow from the sidewall 3120 (e.g., the architectural construct 3112, wick structure, etc.) into the liquid reservoir 3124. In other embodiments, the liquid reservoir 3124 is in fluid communication with another portion of the conduit 3102 (e.g., the output portion 3106) such that the liquid reservoir 3124 collects the working fluid 3122 in the vapor phase 3122a or in mixed phases.

[00105] The liquid reservoir 3124 allows the device 3100 to operate in at least two modes: a heat accumulation mode and a heat transfer mode. During the heat accumulation mode, the vaporization-condensation cycle of the working fluid 3122 can be slowed or halted by funneling the working fluid 3122 from the conduit 3102 to the liquid reservoir 3124. The first end cap 3108 can then function as a thermal accumulator that absorbs heat without the vaporization-condensation cycle dissipating the accumulated heat. After the first end cap 3108 accumulates a desired amount of heat and/or the heat source (e.g., the sun) no longer supplies heat, the device 3100 can change to the heat transfer mode by funneling the working fluid 3122 into the conduit 3102. The heat stored in first end cap 3108 can vaporize the incoming working fluid 3122 and the pressure differential can drive the vapor phase 3122a toward the output portion 3106 of the conduit 3102 to restart the vaporization-condensation cycle described above. In certain embodiments, the restart of the vaporization-condensation cycle can be monitored to analyze characteristics (e.g., composition, vapor pressure, latent heat, efficiency) of the working fluid 3122.

[00106] As shown in Figure 8, a controller 3126 can be operably coupled to the liquid reservoir 3124 to modulate the rate at which the working fluid 3122 enters the conduit 3102 and/or adjust the volume of the working fluid 3122 flowing into or out of the conduit 3102. The controller 3126 can thereby change the pressure within the conduit 3102 such that the device 3100 can operate at varying temperature differentials between the heat source and sink. Thus, the device 3100 can provide a constant heat flux despite a degrading heat source (e.g., first end cap 3108) or intermittent vaporization-condensation cycles.

[00107] Figures 9A and 9B are schematic cross-sectional views of thermal transfer devices 3200a, 3200b ("devices 3200") in accordance with other embodiments of the present technology. Several features of the devices 3200 are generally similar to the features of the device 3100 shown in Figure 8. For example, each device 3200 can include the conduit 3102, the sidewall 3120, and the first and second end caps 3108 and 3110. The device 3200 also transfers heat from a heat source to a heat sink utilizing a vaporization-condensation cycle of the working fluid 3122 generally similar to that described with reference to Figure 7. Additionally, as shown in Figures 9A and 9B, the device 3200 can further include the liquid reservoir 3124 and the controller 3126 such that the device 3200 can operate in the heat accumulation mode and the heat transfer mode.

[00108] The devices 3200 shown in Figures 9A and 9B can utilize gravity, rather than the capillary action described in Figure 7, to return the liquid phase 3122b of the working fluid 3122 to the input portion 3104. Thus, as shown in Figures 9A and 9B, the heat inflow is below the heat output such that gravity can drive the liquid phase 3122b down the sidewall 3120 to the input portion 3104. Thus, as shown in Figure 9A, the sidewall 3120 need only include an impermeable membrane 3228, rather than a wick structure necessary for capillary action, to seal the working fluid 3122 within the conduit 3102. The impermeable membrane 3228 can be made from a polymer such as polyethylene, a metal or metal alloy such as copper and stainless steel, and/or other suitable impermeable materials. In other embodiments, the devices 3200 can utilize other sources of acceleration (e.g., centrifugal force, capillary action) to return the liquid phase 3122b to the input portion 3104 such that the positions of the input and output portions 3104 and 3106 are not gravitationally dependent.

[00109] As shown in Figure 9B, in other embodiments, the sidewall 3120 can further include the architectural construct 3112. For example, the architectural construct 3112 can be arranged such that the layers 3114 are oriented orthogonal to the longitudinal axis 3118 of the conduit 3102 to form thermally conductive passageways that transfer heat away from the conduit 3102. Thus, as the liquid phase 3122b flows along the sidewall 3120, the architectural construct 3112 can draw heat from the liquid phase 3122b, along the layers 3114, and away from the sidewall 3120 of the device 3200. This can increase the temperature differential between the input and output portions 3104 and 3106 to increase the rate of heat transfer and/or facilitate the vaporization-condensation cycle when the temperature gradient would otherwise be insufficient. In other embodiments, the layers 3114 can be oriented at a different angle with respect to the longitudinal axis 3118 to transfer heat in a different direction. In certain embodiments, the architectural construct 3112 can be positioned radially outward of the impermeable membrane 3228. In other embodiments, the impermeable membrane 3228 can be radially outward of architectural construct 3112 or the architectural construct 3112 itself can provide a sufficiently impervious wall to seal the working fluid 3122 within the conduit 3102.

[00110] The first and second end caps 3108 and 3110 shown in Figures 9A and 9B can also include the architectural construct 3112. As shown in Figures 9A and 9B, the layers 3114 of the architectural constructs 3112 are generally aligned with the direction heat input and heat output to provide thermally conductive passageways that efficiently transfer heat. Additionally, the architectural constructs 3112 of the first and/or second end caps 3108 and 3110 can be configured to apply a capillary pressure for a particular substance entering or exiting the conduit. For example, the composition, spacing, dopants, and/or thicknesses of the layers 3114 of the architectural constructs 3112 can be modulated to selectively draw a particular substance between the layers 3114. In selected embodiments, the architectural construct 3112 can include a first zone of layers 3114 that are configured for a first substance and a second zone of layers 3114 that are configured for a second substance to selectively remove and/or add two or more desired substances from the conduit 3102.

[00111] In further embodiments, the second end cap 3110 can utilize the sorbtive properties of the architectural constructs 3112 to selectively load a desired constituent of the working fluid 3122 between the layers 3114. The construction of the architectural construct 3112 can be manipulated to obtain the requisite surface tension to load almost any element or soluble. For example, the layers 3114 can be preloaded with predetermined dopants or materials to adjust the surface tension of adsorption along these surfaces. In certain embodiments, the layers 3114 can be preloaded with CO_2 such that the architectural construct 3112 can selectively mine CO_2 from the working fluid 3122 as heat releases through the second end cap 3110. In other embodiments, the layers 3114 can be spaced apart from one another by a predetermined distance, include a certain coating, and/or otherwise be arranged to selectively load the desired constituent. In some embodiments, the desired constituent adsorbs onto the surfaces of individual layers 3114, while in other embodiments the desired constituent absorbs into zones between the layers 3114. In further embodiments, substances can be purposefully fed into the conduit 3102 from the input portion 3104 (e.g., through the first end cap 3108) such that the added substance can combine or react with the working fluid 3122 to produce the desired constituent. Thus, the architectural construct 3112 at the second end cap 3110 can facilitate selective mining of constituents. Additionally, the architectural construct 3112 can remove impurities and/or other undesirable solubles that may have entered the conduit 3102 and potentially interfere with the efficiency of the device 3200.

[00112] Similarly, in selected embodiments, the architectural construct 3112 at the first end cap 3110 can also selectively load desired compounds and/or elements to prevent them from ever entering the conduit 3102. For example, the architectural construct 3112 can filter out paraffins that can impede or otherwise interfere with the heat transfer of the device 3200. In other embodiments, the devices 3200 can include other filters that may be used to prevent certain materials from entering the conduit 3102.

[00113] Moreover, similar to selective loading of compounds and elements, the architectural construct 3112 at the first and second end caps 3108 and 3110 may also be configured to absorb radiant energy of a desired wavelength. For example, the layers 3114 can have a certain thickness, composition, spacing to absorb a particular wavelength of radiant energy. In selected embodiments, the architectural construct 3112 absorbs radiant energy of a first wavelength and converts it into radiant energy of a second wavelength, retransmitting at least some of the absorbed energy. For example, the layers 3114 may be configured to absorb ultraviolet radiation and convert the ultraviolet radiation into infrared radiation.

[00114] Additionally, the layers 3114 can also catalyze a reaction by transferring heat to a zone where the reaction is to occur. In other implementations, the layers 3114 catalyze a reaction by transferring heat away from a zone where a reaction is to occur. For example, heat may be conductively transferred into the layers 3114 (e.g., as discussed in U.S. Patent Application No. 12/857,515, filed August 16, 2010, entitled "APPARATUSES AND METHODS FOR STORING AND/OR FILTERING A SUBSTANCE" which is incorporated by reference herein in its entirety) to supply heat to an endothermic reaction within a support tube of the layers 3114. In some implementations, the layers 3114 catalyze a reaction by removing a product of the reaction from the zone where the reaction is to occur. For example, the layers 3114 may absorb alcohol from a biochemical reaction within a central support tube in which alcohol is a byproduct, thereby expelling the alcohol on outer edges of the layers 3114, and prolonging the life of a microbe involved in the biochemical reaction.

[00115] Figure 10A is schematic cross-sectional view of a thermal transfer device 3300 ("device 3300") operating in a first direction in accordance with a further embodiment of the present technology, and Figure 10B is a schematic cross-sectional view of the device 3300 of Figure 10A operating in a second direction opposite the first direction. Several features of the device 3300 are generally similar to the features of the devices 3100 and 3200 shown in Figures 8-10B. For example, the device 3300 can include the conduit 3102, the first and second end caps 3108 and 3110, and the architectural construct 3112. As shown in Figures 10A and 10B, the sidewall 3120 of the device 3300 can include two architectural constructs 3112: a first architectural construct 3112a having layers 3114 oriented parallel to the longitudinal axis 3118 of the conduit 3102 and a second architectural construct 3112b radially inward from the first architectural construct 3112a and having layers 3114 oriented perpendicular to the longitudinal axis 3118. The layers 3114 of the first architectural construct 3112a can perform a capillary action, and the layers 3114 of the second architectural construct 3112b can form thermally conductive passageways that transfer heat away from the side of the conduit 3102 and thereby increase the temperature differential between the input and output portions 3104 and 3106.

[00116] Similar to the device 3100 shown in Figure 8, the device 3300 can also operate when the direction of heat flow changes and the input and output portions 3104 and 3106 are inverted. As shown in Figure 10A, for example, the device 3300 can absorb heat at the first end cap 3108 to vaporize the working fluid 3122 at the input portion 3104, transfer the heat via the vapor phase 3122a of the working fluid 3122 through the conduit 3102, and expel heat from the second end cap 3110 to condense the working fluid 3122 at the output portion 3106. As further shown in Figure 10A, the liquid phase 3122b of the working fluid 3122 can move between the layers 3114 of the first architectural construct 3112b by capillary action as described above with reference to Figure 8. In other embodiments, the sidewall 3120 can include a different capillary structure (e.g., cellulose) that can drive the liquid phase 3122b from the output portion 3106 to the input portion 3104. As shown in Figure 10B, the conditions can be reversed such that heat enters the device 3300 proximate to the second end cap 3110 and exits the device 3300 proximate to the first end cap 3108. Advantageously, as discussed above, the dual-direction vapor-condensation cycle of the working fluid 3122 accommodates environments in which the locations of the heat source and the heat sink reverse.

[00117] In at least some embodiments, a heat pump can be used to transfer heat, in addition to or in lieu of a heat pipe, and the transferred heat can be used to enhance the efficiency and/or performance of a reactor to which the heat pump is coupled. In particular embodiments, the heat is extracted from a permafrost, geothermal, ocean and/or other source. Figure 11 is a partially schematic illustration of a reversible heat pump 3150 positioned to receive heat from a source 3202 (e.g., a geothermal source), as indicated by arrow H1, and deliver the heat at a higher temperature than that of the source, as indicated by arrow H2. The heat pump 3150 transfers heat via a working fluid that can operate in a closed loop refrigeration cycle. Accordingly, the heat pump 3150 can include a compressor 3154, an expansion valve 3162, supply and return conduits 3156, 3160, and first and second heat exchangers 3152, 3158. In operation, the working fluid receives heat from the source 3202 via the second heat exchanger 3158. The working fluid passes through the supply conduit 3156 to the compressor 3154 where it is compressed, and delivers heat (e.g., to a non-combustion reactor) at the first heat exchanger 3152. The working fluid then expands through the expansion valve 3162 and returns to the second heat exchanger 3158 via the return conduit 3160.

[00118] The working fluid can be selected based at least in part on the temperature of the source 3202 and the required delivery temperature. For example, the working fluid can be a relatively inert fluid such as Freon, ammonia, or carbon dioxide. Such fluids are compatible with various polymer and metal components. These components can include tube liner polymers such as fluorinated ethylene-propylene, perfluoroalkoxy, polyvinylidene fluoride, tetraflouroethylene, an ethylene-propylene dimer, and/or many other materials that may be reinforced with fibers such as graphite, E-glass, S-glass, glass-ceramic or various organic filaments to form the conduits 3156, 3160. The heat exchangers 3158 can be made from metal alloys, e.g., Type 304 or other "300" series austenitic stainless steels, aluminum alloys, brass or bronze selections. The compressor 3154 can be a positive displacement or turbine type compressor depending upon factors that include the scale of the application. The expansion valve 3162 can be selected to meet the pressure drop and flow requirements of a particular application.

[00119] In a representative embodiment for which the source 3202 is at a moderate temperature (e.g., 125°F (52°C)), the working fluid can include carbon dioxide that is expanded through the valve 3162 to a reduced temperature (e.g., 115°F (46°C)). The working fluid receives heat at the source 3202 to achieve a representative temperature of 120°F (49°C). At the compressor 3154, the temperature of the working fluid is elevated to a representative value of 325°F (163°C) or higher. In particular embodiments, one or more additional heat pump cycles (not shown) can be used to further elevate the delivery temperature. It can be particularly advantageous to use heat pump cycles to deliver heat at a higher temperature than the source 3202 because such cycles typically deliver two to ten times more heat energy compared to the energy required for operation of the compressor 3154.

[00120] In a generally similar manner, it can be advantageous to use one or more heat pump cycles in reverse to cool a working fluid to a temperature below the ambient temperature and thus "refrigerate" the substance being cooled. For example, permafrost or methane hydrates in lake bottoms or ocean deposits can be cooled to a temperature far below the ambient temperature of the air or surrounding water in such applications.

[00121] Still further embodiments of suitable reactors with transmissive surfaces are disclosed in pending U.S. Application No. 13/027,244, filed February 14, 2011, and incorporated herein by reference.

Representative Reactors with Solar Conveyors

[00122] Figure 12 is a partially schematic illustration of a system 4100 including a reactor vessel 4110 having a reaction zone 4111. The system 4100 further includes a solar collector 4101 that directs solar energy 4103 to the reaction zone 4111. The solar collector 4101 can include a dish, trough, heliostat arrangement, fresnel lens and/or other radiation-focusing element. The reactor vessel 4110 and the solar collector 4101 can be mounted to a pedestal 4102 that allows the solar collector 4101 to rotate about at least two orthogonal axes in order to continue efficiently focusing the solar energy 4103 as the earth rotates. The system 4100 can further include multiple reactant/product vessels 4170, including first and second reactant vessels 4170a, 4170b, and first and second product vessels, 4170c, 4170d. In particular embodiments, the first reactant vessel 4170a can provide a reactant that contains hydrogen and carbon, such as methane, which is processed at the reaction zone 4111 in an endothermic reaction to produce hydrogen and carbon which is provided to the first and second product vessels 4170c, 4170d, respectively. In other embodiments, other reactants, for example, municipal solid waste streams, biomass reactants, and/or other waste streams can be provided at a hopper 4171 forming a portion of the second reactant vessel 4170b. In any of these embodiments, an internal reactant delivery system and product removal system provide the reactants to the reaction zone 4111 and remove the products from the reaction zone 4111, as will be described in further detail later with reference to Figure 14.

[00123] The system 4100 can further include a supplemental heat source 4180 that provides heat to the reaction zone 4111 when the available solar energy 4103 is insufficient to sustain the endothermic reaction at the reaction zone 4111. In a particular embodiment, the supplemental heat source 4180 can include an inductive heater 4181 that is positioned away from the reaction zone 4111 during the day to allow the concentrated solar energy 4103 to enter the reaction zone 4111, and can slide over the reaction zone 4111 at night to provide heat to the reaction zone 4111. The inductive heater 4181 can be powered by a renewable clean energy source, for example, hydrogen produced by the reactor vessel 4110 during the day, or falling water, geothermal energy, wind energy, or other suitable sources.

[00124] In any of the foregoing embodiments, the system 4100 can further include a controller 4190 that receives input signals 4191 and directs the operation of the devices making up the system 4100 via control signals or other outputs 4192. For example, the controller 4190 can receive a signal from a radiation sensor 4193 indicating when the incident solar radiation is insufficient to sustain the reaction at the reaction zone 4111. In response, the controller 4190 can issue a command to activate the supplemental heat source 4180. The controller 4190 can also direct the reactant delivery and product removal systems, described further below with reference to Figure 14.

[00125] Figure 13 is a partially schematic illustration of an embodiment of the reactor vessel 4110 shown in Figure 12, illustrating a transmissive component 4112 positioned to allow the incident solar energy 4103 to enter the reaction zone 4111. In a particular embodiment, the transmissive component 4112 can include a glass or other suitably transparent, high temperature material that is easily transmissible to solar radiation, and configured to withstand the high temperatures in the reaction zone 4111. For example, temperatures at the reaction zone 4111 are in some embodiments expected to reach 44000°F, and can be higher for the reactants and/or products.

[00126] In other embodiments, the transmissive component 4112 can include one or more elements that absorb radiation at one wavelength and re-radiate it at another. For example, the transmissive component 4112 can include a first surface 4113a that receives incident solar energy at one wavelength and a second surface 4113b that re-radiates the energy at another wavelength into the reaction zone 4111. In this manner, the energy provided to the reaction zone 4111 can be specifically tailored to match or approximate the absorption characteristics of the reactants and/or products placed within the reaction zone 4111. Further details of representative re-radiation devices were described above.

[00127] In other embodiments, the reactor vessel 4110 can include other structures that perform related functions. For example, the reactor vessel 4110 can include a Venetian blind arrangement 4114 having first and second surfaces 4113a, 4113b that can be pivoted to present one surface or the other depending upon external conditions, e.g., the level of incident solar energy 4103. In a particular aspect of this embodiment, the first surface 4113a can have a relatively high absorptivity and a relatively low emissivity. This surface can accordingly readily absorb radiation during the day. The second surface 4113b can have a relatively low absorptivity and a relatively high emissivity and can accordingly operate to cool the reaction zone 4111 (or another component of the reactor 4110), e.g., at night. A representative application of this arrangement is a reactor that conducts both endothermic and exothermic reactions, as is described further below. Further details of other arrangements for operating the solar collector 4101 (Figure 12) in a cooling mode are described below.

[00128] In still further embodiments, the reactor 4110 can include features that redirect radiation that "spills" (e.g., is not precisely focused on the transmissive component 4112) due to collector surface aberrations, environmental defects, non-parallel radiation, wind and/or other disturbances or distortions. These features can include additional Venetian blinds 4114a that can be positioned and/or adjusted to redirect radiation (with or without wavelength shifting) into the reaction zone 4111.

[00129] Figure 14 is a partially schematic, cross-sectional illustration of a portion of a reactor vessel 4110 configured in accordance with an embodiment of the present disclosure. In one aspect of this embodiment, the reactor 4110 includes a reactant delivery system 4130 that is positioned within a generally cylindrical, barrel-shaped reactor vessel 4110, and a product removal system 4140 positioned annularly inwardly from the reactant delivery system 4130. For example, the reactant delivery system 4130 can include an outer screw 4131, which in turn includes an outer screw shaft 4132 and outwardly extending outer screw threads 4133. The outer screw 4131 has an axially extending first axial opening 4135 in which the product removal system 4140 is positioned. The outer screw 4131 rotates about a central rotation axis 4115, as indicated by arrow O. As it does so, it carries at least one reactant 4134 (e.g., a gaseous, liquid, and/or solid reactant) upwardly and to the right as shown in Figure 14, toward the reaction zone 4111. As the reactant 4134 is carried within the outer screw threads 4133, it is also compacted, potentially releasing gases and/or liquids, which can escape through louvers and/or other openings 4118 located annularly outwardly from the outer screw 4131. As the reactant 4134 becomes compacted in the outer screw threads 4133, it forms a seal against an inner wall 4119 of the vessel 4110. This arrangement can prevent losing the reactant 4134, and can instead force the reactant 4134 to move toward the reaction zone 4111. The reactant delivery system 4130 can include other features, in addition to the outer screw threads 4133, to force the reactant 4134 toward the reaction zone 4111. For example, the inner wall 4119 of the reactor vessel 4110 can include one or more spiral rifle grooves 4116 that tend to force the reactant 4134 axially as the outer screw 4131 rotates. In addition to, or in lieu of this feature, the entire outer screw 4131 can reciprocate back and forth, as indicated by arrow R to prevent the reactant 4134 from sticking to the inner wall 4119, and/or to release reactant 4134 that may stick to the inner wall 4119. A barrel heater 4117 placed near the inner wall 4119 can also reduce reactant sticking, in addition to or in lieu of the foregoing features. In a least some embodiments, it is expected that the reactant 4134 will be less likely to stick when warm.

[00130] The reactant 4134 can include a variety of suitable compositions, e.g., compositions that provide a hydrogen donor to the reaction zone 4111. In representative embodiments, the reactant 4134 can include biomass constituents, e.g., municipal solid waste, commercial waste, forest product waste or slash, cellulose, lignocellulose, hydrocarbon waste (e.g., tires), and/or others. After being compacted, these waste products can be highly subdivided, meaning that they can readily absorb incident radiation due to rough surface features and/or surface features that re-reflect and ultimately absorb incident radiation. This property can further improve the efficiency with which the reactant 4134 heats up in the reaction zone 4111.

[00131] Once the reactant 4134 has been delivered to the reaction zone 4111, it receives heat from the incident solar energy 4103 or another source, and undergoes an endothermic reaction. The reaction zone 4111 can have an annular shape and can include insulation 4120 to prevent heat from escaping from the vessel 4110. In one embodiment, the endothermic reaction taking place at the reaction zone 4111 includes dissociating methane, and reforming the carbon and hydrogen constituents into elemental carbon and diatomic hydrogen, or other carbon compounds (e.g., oxygenated carbon in the form of carbon monoxide or carbon dioxide) and hydrogen compounds. The resulting product 4146 can include gaseous portions (indicated by arrow G), which passed annularly inwardly from the reaction zone 4111 to be collected by the product removal system 4140. Solid portions 4144 (e.g., ash and/or other byproducts) of the product 4146 are also collected by the product removal system 4140.

[00132] The product removal system 4140 can include an inner screw 4141 positioned in the first axial opening 4135 within the outer screw 4131. The inner screw 4141 can include an inner screw shaft 4142 and inner screw threads 4143. The inner screw 4141 can also rotate about the rotation axis 4115, as indicated by arrow I, in the same direction as the outer screw 4131 or in the opposite direction. The inner screw 4141 includes a second axial passage 4145 having openings that allow the gaseous product G to enter. The gaseous product G travels down the second axial opening 4145 to be collected and, in at least some instances, further processed (e.g., to isolate the carbon produced in the reaction from the hydrogen produced in the reaction). In particular embodiments, the gaseous product G can exchange additional heat with the incoming reactant 4134 via an additional heat exchanger (not shown in Figure 14) to cool the product G and heat the reactant 4134. In other embodiments, the gaseous product G can be cooled by driving a Stirling engine or other device to generate mechanical and/or electric power. As the inner screw 4141 rotates, it carries the solid portions 4144 of the product 4146 downwardly and to the left as shown in Figure 14. The solid products 4144 (and the gaseous product G) can convey heat via conduction to the outer screw 4131 to heat the incoming reactant 4134, after which the solid portions 4144 can be removed for use. For example, nitrogenous and/or sulfurous products from the reaction performed at the reaction zone 4111 can be used in agricultural or industrial processes. The products and therefore the chemical and physical composition of the solid portions can depend on the characteristics of the incoming reactants, which can vary widely, e.g., from municipal solid waste to industrial waste to biomass.

[00133] As discussed above with reference to Figures 12 and 13, the system 4100 can include features that direct energy (e.g., heat) into the reaction zone 4111 even when the available solar energy is insufficient to sustain the reaction. In an embodiment shown in Figure 13, the supplemental heat source 4180 can include combustion reactants 4182 (e.g., an oxidizer and/or a hydrogen-containing combustible material) that is directed through a delivery tube 4184 positioned in the second axial opening 4145 to a combustor or combustor zone 4183 that is in thermal communication with the reaction zone 4111. During the night or other periods of time when the incident solar energy is low, the supplemental heat source 4180 can provide additional heat to the reaction zone 4111 to sustain the endothermic reaction taking place therein.

[00134] One feature of an embodiment described above with reference to Figure 14 is that the incoming reactant 4134 can be in close or intimate thermal communication with the solid product 4144 leaving the reaction zone. In particular, the outer screw shaft 4132 and outer screw threads 4133 can be formed from a highly thermally conductive material, so as to receive heat from the solid product 4144 carried by the inner screw 4141, and deliver the heat to the incoming reactant 4134. An advantage of this arrangement is that it is thermally efficient because it removes heat from products that would otherwise be cooled in a manner that wastes the heat, and at the same time heats the incoming reactants 4134, thus reducing the amount of heat that must be produced by the solar collector 4101 (Figure 12) and/or the supplemental heat source 4180. By improving the efficiency with which hydrogen and/or carbon or other building blocks are produced in the reactor vessel 4110, the reactor system 4100 can increase the commercial viability of the renewable reactants and energy sources used to produce the products.

[00135] Still further embodiments of suitable reactors with solar conveyors are disclosed in issued U.S. Patent No. 8,187,549, incorporated herein by reference.

Representative Reactors with Solar Concentrators

[00136] Figure 15 is a partially schematic, partial cross-sectional illustration of a system 5100 having a reactor 5110 coupled to a solar concentrator 5120 in accordance with the particular embodiment of the technology. In one aspect of this embodiment, the solar concentrator 5120 includes a dish 5121 mounted to pedestal 5122. The dish 5121 can include a concentrator surface 5123 that receives incident solar energy 5126, and directs the solar energy as focused solar energy 5127 toward a focal area 5124. The dish 5121 can be coupled to a concentrator actuator 5125 that moves the dish 5121 about at least two orthogonal axes in order to efficiently focus the solar energy 5126 as the earth rotates. As will be described in further detail below, the concentrator actuator 5125 can also be configured to deliberately position the dish 5121 to face away from the sun during a cooling operation.

[00137] The reactor 5110 can include one or more reaction zones 5111, shown in Figure 15 as a first reaction zone 5111a and second reaction zone 5111b. In a particular embodiment, the first reaction zone 5111a is positioned at the focal area 5124 to receive the focused solar energy 5127 and facilitate a dissociation reaction or other endothermic reaction. Accordingly, the system 5100 can further include a distribution/collection system 5140 that provides reactants to the reactor 5110 and collects products received from the reactor 5110. In one aspect of this embodiment, the distribution/collection system 5140 includes a reactant source 5141 that directs a reactant to the first reaction zone 5111a, and one or more product collectors 5142 (two are shown in Figure 15 as a first product collector 5142a and a second product collector 5142b) that collect products from the reactor 5110. When the reactor 5110 includes a single reaction zone (e.g. the first reaction zone 5111a) the product collectors 5142a, 5142b can collect products directly from the first reaction zone 5111a. In another embodiment, intermediate products produced at the first reaction zone 5111a are directed to the second reaction zone 5111b. At the second reaction zone 5111b, the intermediate products can undergo an exothermic reaction, and the resulting products are then delivered to the product collectors 5142a, 5142b along a product flow path 5154. For example, in a representative embodiment, the reactant source 5141 can include methane and carbon dioxide, which are provided (e.g., in an individually controlled manner) to the first reaction zone 5111a and heated to produce carbon monoxide and hydrogen. The carbon monoxide and hydrogen are then provided to the second reaction zone 5111b to produce methanol in an exothermic reaction. Further details of this arrangement and associated heat transfer processes between the first reaction zone 5111a and second reaction zone 5111b are described in more detail below.

[00138] In at least some instances, it is desirable to provide cooling to the reactor 5110, in addition to the solar heating described above. For example, cooling can be used to remove heat produced by the exothermic reaction being conducted at the second reaction zone 5111b and thus allow the reaction to continue. When the product produced at the second reaction zone 5111b includes methanol, it may desirable to further cool the methanol to a liquid to provide for convenient storage and transportation. Accordingly, the system 5100 can include features that facilitate using the concentrator surface 5123 to cool components or constituents at the reactor 5110. In a particular embodiment, the system 5100 includes a first heat exchanger 5150a operatively coupled to a heat exchanger actuator 5151b that moves the first heat exchanger 5150a relative to the focal area 5124. The first heat exchanger 5150a can include a heat exchanger fluid that communicates thermally with the constituents in the reactor 5110, but is in fluid isolation from these constituents to avoid contaminating the constituents and/or interfering with the reactions taking place in the reactor 5110. The heat exchanger fluid travels around a heat exchanger fluid flow path 5153 in a circuit from the first heat exchanger 5150a to a second heat exchanger 5150b and back. At the second heat exchanger 5150b, the heat exchanger fluid receives heat from the product (e.g. methanol) produced by the reactor 5110 as the product proceeds from the second reaction zone 5111b to the distribution/collection system 5140. The heat exchanger fluid flow path 5153 delivers the heated heat exchanger fluid back to the first heat exchanger 5150a for cooling. One or more strain relief features 5152 in the heat exchanger fluid flow path 5153 (e.g., coiled conduits) facilitate the movement of the first heat exchanger 5150a. The system 5100 can also include a controller 5190 that receives input signals 5191 from any of a variety of sensors, transducers, and/or other elements of the system 5100, and, in response to information received from these elements, delivers control signals 5192 to adjust operational parameters of the system 5100.

[00139] Figure 16 illustrates one mechanism by which the heat exchanger fluid provided to the first heat exchanger 5150a is cooled. In this embodiment, the controller 5190 directs the heat exchanger actuator 5151 to drive the first heat exchanger 5150a from the position shown in Figure 15 to the focal area 5124, as indicated by arrows A. In addition, the controller 5190 can direct the concentrator actuator 5125 to position the dish 5121 so that the concentrator surface 5123 points away from the sun and to an area of the sky having very little radiant energy. In general, this process can be completed at night, when it is easier to avoid the radiant energy of the sun and the local environment, but in at least some embodiments, this process can be conducted during the daytime as well. A radiant energy sensor 5193 coupled to the controller 5190 can detect when the incoming solar radiation passes below a threshold level, indicating a suitable time for positioning the first heat exchanger 5150a in the location shown in Figure 16.

[00140] With the first heat exchanger 5150a in the position shown in Figure 16, the hot heat transfer fluid in the heat exchanger 5150a radiates emitted energy 5128 that is collected by the dish 5121 at the concentrator surface 5123 and redirected outwardly as directed emitted energy 5129. An insulator 5130 positioned adjacent to the focal area 5124 can prevent the radiant energy from being emitted in direction other than toward the concentrator surface 5123. By positioning the concentrator surface 5123 to point to a region in space having very little radiative energy, the region in space can operate as a heat sink, and can accordingly receive the directed emitted energy 5129 rejected by the first heat exchanger 5150a. The heat exchanger fluid, after being cooled at the first heat exchanger 5150a returns to the second heat exchanger 5150b to absorb more heat from the product flowing along the product flow path 5154. Accordingly, the concentrator surface 5123 can be used to cool as well as to heat elements of the reactor 5110.

[00141] In a particular embodiment, the first heat exchanger 5150a is positioned as shown in Figure 15 during the day, and as positioned as shown in Figure 16 during the night. In other embodiments, multiple systems 5100 can be coupled together, some with the corresponding first heat exchanger 5150a positioned as shown in

Figure 15, and others with the first heat exchanger 5150a positioned as shown in Figure 16, to provide simultaneous heating and cooling. In any of these embodiments, the cooling process can be used to liquefy methanol, and/or provide other functions. Such functions can include liquefying or solidifying other substances, e.g., carbon dioxide, ethanol, butanol or hydrogen.

[00142] In particular embodiments, the reactants delivered to the reactor 5110 are selected to include hydrogen, which is dissociated from the other elements of the reactant (e.g. carbon, nitrogen, boron, silicon, a transition metal, and/or sulfur) to produce a hydrogen-based fuel (e.g. diatomic hydrogen) and a structural building block that can be further processed to produce durable goods. Such durable goods include graphite, graphene, and/or polymers, which may be produced from carbon structural building blocks, and other suitable compounds formed from hydrogenous or other structural building blocks. Further details of suitable processes and products are disclosed in the following co-pending U.S. Patent Applications: 13/027,208 titled "CHEMICAL PROCESSES AND REACTORS FOR EFFICIENTLY PRODUCING HYDROGEN FUELS AND STRUCTURAL MATERIALS, AND ASSOCIATED SYSTEMS AND METHODS"; 13/027,214 titled "ARCHITECTURAL CONSTRUCT HAVING FOR EXAMPLE A PLURALITY OF ARCHITECTURAL CRYSTALS" (Attorney Docket No. 69545.8701US); and 12/027,068 titled "CARBON-BASED DURABLE GOODS AND RENEWABLE FUEL FROM BIOMASS WASTE DISSOCIATION" (Attorney Docket No. 69545.9002US), all of which were filed February 14, 2011 and are incorporated herein by reference.

[00143] Figure 17 illustrates a system 5300 having a reactor 5310 with a movable dish 5321 configured in accordance another embodiment of the disclosed technology. In a particular aspect of this embodiment, the reactor 5310 includes a first reaction zone 5311a and a second reaction zone 5311b, with the first reaction zone 5311a receiving focused solar energy 5127 when the dish 5321 has a first position, shown in solid lines in Figure 16. The dish 5321 is coupled to a dish actuator 5331 that moves the dish 5321 relative to the reaction zones 5311a, 5311b. Accordingly, during a second phase of operation, the controller 5190 directs the dish actuator 5331 to move the dish 5321 to the second position shown in dashed lines in Figure 17. In one embodiment, this arrangement can be used to provide heat to the second reaction zone 5311b when the dish 5321 is in the second position. In another embodiment, this arrangement can be used to cool the second reaction zone 5311b. Accordingly, the controller 5190 can direct the concentrator actuator 5125 to point the dish 5321 to a position in the sky having little or no radiant energy, thus allowing the second reaction zone 5311b to reject heat to the dish 5321 and ultimately to space, in a manner generally similar to that described above with reference to Figures 15 and 16.

[00144] Still further embodiments of suitable reactors with solar concentrators are disclosed in issued U.S. Patent No. 8,187,550, incorporated herein by reference.

Representative Reactors with Induction Heating

[00145] Figure 18 is a partially schematic, partial cross-sectional illustration of a system 6100 having a reactor 6110 configured in accordance with an embodiment of the presently disclosed technology. In one aspect of this embodiment, the reactor 6110 includes a reactor vessel 6111 having a reaction or induction zone 6123 which is heated by an induction coil 6120. The induction coil 6120 can be a liquid-cooled, high frequency alternating current coil coupled to a suitable electrical power source 6121. The reactor vessel 6111 can further include an entrance port 6112 coupled to a precursor gas source 6101 to receive a suitable precursor gas, and an exit port 6113 positioned to remove spent gas and/or other constituents from the vessel 6111. In a particular embodiment, the precursor gas source 6101 carries a hydrocarbon gas (e.g., methane), which is dissociated into carbon and hydrogen at the induction zone 6123. The carbon is then deposited on a substrate to form a product, as is described further below, and the hydrogen and/or other constituents are removed for further processing, as is also described further below.

[00146] The reaction vessel 6111 houses a first support 6114a having a first support surface 6115a, and a second support 6114b having a second support surface 6115b facing toward the first support surface 6115a. Each support 6114a, 6114b can carry a substrate upon which one or more constituents of the precursor gas are deposited. For example, the first support 6114a can carry a first substrate 6130a and the second support 6114b can carry a second substrate 6130b. In a representative embodiment in which the precursor gas is selected to deposit carbon, the first and second substrates 6130a, 6130b can also include carbon, e.g., in the form of graphite or a constituent of steel. When the precursor gas includes a different deposition element (e.g., nitrogen and/or boron), the composition of the first and second substrates 6130a, 6130b can be different. Each of the substrates 6130a, 6130b can have an initially exposed surface facing the other. Accordingly, the first substrate 6130a can have an exposed first surface 6131a facing toward a second exposed surface 6131b of the second substrate 6130b. The remaining surfaces of each substrate 6130a, 6130b can be insulated to prevent or significantly restrict radiation losses from these surfaces. The supports 6114a, 6114b can insulate at least one surface of each of the substrates 6130a, 6130b. The other surfaces (other than the exposed first and second substrates 6131a, 6131b) can be protected by a corresponding insulator 6132. The insulator 6132 can be formed from a suitable high temperature ceramic or other material.

[00147] The system 6100 can further include a controller 6190 that receives input signals 6191 from any of a variety of sensors, transducers, and/or other elements of the system 6100, and in response to information received from these elements, delivers control signals 6192 to adjust operational parameters of the system 6100. These parameters can include the pressures and flow rates with which the gaseous constituents are provided to and/or removed from the reactor vessel 6111, the operation of the induction coil 6120 and associated power source 6121, and the operation of a separator 6103 (described below), among others.

[00148] In operation, the precursor gas source 6101 supplies gas to the induction zone 6123, the induction coil 6120 is activated, and the precursor gas dissociates into at least one constituent (e.g., carbon) that is deposited onto the first and second substrates 6130a, 6130b. The constituent can be deposited in an epitaxial process that preserves the crystal grain orientation of the corresponding substrate 6130a, 6130b. Accordingly, the deposited constituent can also have a crystal and/or other self-organized structure. As the constituent is deposited, it forms a first formed structure or product 6140a at the first substrate 6130a, and a second formed structure or product 6140b at the second substrate 6130b. The first and second formed structures 6140a, 6140b each have a corresponding exposed surface 6141a, 6141b facing toward the other. The structures 6140a, 6140b can have the same or different cross-sectional shapes and/or areas, and/or can have non-crystalline, single crystal or multicrystal organizations, depending upon the selected embodiment. Radiation emitted by the first exposed surface 6131a of the first substrate 6130a, and/or by the first exposed surface 6141a of the first formed structure 6140a (collectively identified by arrow R1) is received at the second exposed surface 6141b of the second formed structure 6140b, and/or the second exposed surface 6131b of the second substrate 6130b. Similarly, radiation emitted by the second exposed surface 6141b of the second formed structure 6140b and/or the second exposed surface 6131b of the second substrate 6130b (collectively identified by arrow R2) is received at the first formed structure 6140a and/or the first substrate 6130a.

[00149] As the formed structures 6140a, 6140b grow, the exit port 6113 provides an opening through which residual constituents from the dissociated precursor gas and/or non-dissociated quantities of the precursor gas can pass. These constituents are directed to a collection system 6102, which can include a separator 6103 configured to separate the constituents into two or more flow streams. For example, the separator 6103 can direct one stream of constituents to a first product collector 6104a, and a second stream of constituents to a second product collector 6104b. In a particular embodiment, the first product collector 6104a can collect pure or substantially pure hydrogen, which can be delivered to a hydrogen-based fuel cell 6105 or other device that requires hydrogen at a relatively high level of purity. The second stream of constituents directed to the second product collector 6104b can include hydrogen mixed with other elements or compounds. Such elements or compounds can include methane or another undissociated precursor gas, and/or carbon (or another element or compound targeted for deposition) that was not deposited on the first substrate 6130a or the second substrate 6130b. These constituents can be directed to an engine 6106, for example, a turbine engine or another type of internal combustion engine that can burn a mixture of hydrogen and the other constituents. The engine 6106 and/or the fuel cell 6105 can provide power for any number of devices, including the electrical power source 6121 for the induction coil 6120. In another aspect of this embodiment, at least some of the constituents (e.g., undissociated precursor gas) received at the second collector 6104b can be directed back into the reactor 6110 via the entrance port 6112.

[00150] An advantage of the foregoing arrangement is that the radiation losses typically encountered in a chemical vapor deposition apparatus can be avoided by positioning multiple substrates in a manner that allows radiation emitted from one surface to be received by another surface that is also targeted for deposition. In a particular embodiment shown in Figure 18, two substrates are shown, each having a single exposed surface facing the other. In other embodiments, additional substrates can be positioned (e.g., in a plane extending inwardly and/or outwardly transverse to the plane of Figure 17) to allow additional exposed surfaces of a formed product to radiate heat to corresponding surfaces of other formed products.

[00151] Another advantage of the foregoing arrangement is that it can be used to produce a structural building block and/or an architectural construct, as well as clean burning hydrogen fuel from a hydrogen donor. When the precursor gas includes a hydrocarbon, the architectural construct can include graphene and/or another carbon-bearing material, for example, a material that can be further processed to form a carbon-based composite or a carbon-based polymer. In other embodiments, the precursor gas can include other elements (e.g., boron, nitrogen, sulfur, silicon, and/or a transition metal) than can also be used to form structural building blocks that contain the element, and/or architectural constructs formed from the building blocks. Suitable processes and representative architectural constructs are further described in the following co-pending U.S. Patent Applications, all of which were filed on February 14, 2011 and are incorporated herein by reference: Application No. 13/027,208; Application No. 13/027,214; and Application No. 13/027,068.

[00152] One feature of an embodiment described above with reference to Figure 18 is that it may be conducted in a batch process. For example, each of the first and second formed structures 6140a, 6140b can be grown by a particular amount and then removed from the reaction vessel 6111. In other embodiments, the products can be formed in a continuous manner, without the need for halting the reaction to remove the product.

[00153] Still further embodiments of suitable reactors with induction heating are disclosed in pending U.S. Application No. 13/027,215, filed February 14, 2011, and incorporated herein by reference.

Representative Reactors Using Engine Heat

[00154] Figure 19 is a partially schematic illustration of system 7100 that includes a reactor 7110 in combination with a radiant energy/reactant source 7150 in accordance with another embodiment of the technology. In this embodiment, the radiant energy/reactant source 7150 includes an engine 7180, e.g., an internal combustion engine having a piston 7182 that reciprocates within a cylinder 7181. In other embodiments, the engine 7180 can have other configurations, for example, an external combustion configuration. In an embodiment shown in Figure 18, the engine 7180 includes an intake port 7184a that is opened and closed by an intake valve 7183a to control air entering the cylinder 7181 through an air filter 7178. The air flow can be unthrottled in an embodiment shown in Figure 19, and can be throttled in other embodiments. A fuel injector 7185 directs fuel into the combustion zone 7179 where it mixes with the air and ignites to produce the combustion products 7152. Additional fuel can be introduced by an injection valve 7189a. The combustion products 7152 exit the cylinder 7181 via an exhaust port 7184b controlled by an exhaust valve 7183b. Further details of representative engines and ignition systems are disclosed in co-pending U.S. Application No. 12/653,085 filed on December 7, 2010, and incorporated herein by reference.

[00155] The engine 7180 can include features specifically designed to integrate the operation of the engine with the operation of the reactor 7110. For example, the engine 7180 and the reactor 7110 can share fuel from a common fuel source 7130 which is described in further detail below. The fuel is provided to the fuel injector 7185 via a regulator 7186. The engine 7180 can also receive end products from the reactor 7110 via a first conduit or passage 7177a, and water (e.g., liquid or steam) from the reactor 7110 via a second conduit or passage 7177b. Further aspects of these features are described in greater detail below, following a description of the other features of the overall system 7100.

[00156] The system 7100 shown in Figure 19 also includes heat exchangers and separators configured to transfer heat and segregate reaction products in accordance with the disclosed technology. In a particular aspect of this embodiment, the system 7100 includes a steam/water source 7140 that provides steam to the reactor vessel 7111 to facilitate product formation. Steam from the steam/water source 7140 can be provided to the reactor 7110 via at least two channels. The first channel includes a first water path 7141a that passes through a first heat exchanger 7170a and into the reactor vessel 7111 via a first steam distributor 7116a. Products removed from the reactor vessel 7111 pass through a reactor product exit port 7117 and along a products path 7161. The products path 7161 passes through the first heat exchanger 7170a in a counter-flow or counter-current manner to cool the products and heat the steam entering the reactor vessel 7111. The products continue to a reaction product separator 7171a that segregates useful end products (e.g., hydrogen and carbon or carbon compounds). At least some of the products are then directed back to the engine 7180, and other products are then collected at a products collector 7160a. A first valve 7176a regulates the product flow. Water remaining in the products path 7161 can be separated at the reaction product separator 7171a and returned to the steam/water source 7140.

[00157] The second channel via which the steam/water source 7140 provides steam to the reactor 7110 includes a second water path 7141b that passes through a second heat exchanger 7170b. Water proceeding along the second water path 7141b enters the reactor 7110 in the form of steam via a second stream distributor 7116b. This water is heated by combustion products that have exited the combustion zone 7179 and passed through the transfer passage 7118 (which can include a transmissive surface 7119) along a combustion products path 7154. The spent combustion products 7152 are collected at a combustion products collector 7160b and can include nitrogen compounds, phosphates, re-used illuminant additives (e.g., sources of sodium, magnesium and/or potassium), and/or other compositions that may be recycled or used for other purposes (e.g., agricultural purposes). The illuminant additives can be added to the combustion products 7152 (and/or the fuel used by the engine 7180) upstream of the reactor 7110 to increase the amount of radiant energy available for transmission into the reaction zone 7112.

[00158] In addition to heating water along the second water path 7141b and cooling the combustion products along the combustion products path 7154, the second heat exchanger 7170b can heat the hydrogen donor passing along a donor path 7131 to a donor distributor 7115 located within the reactor vessel 7111. The donor vessel 7130 houses a hydrogen donor, e.g., a hydrocarbon such as methane, or a nitrogenous donor such as ammonia. The donor vessel 7130 can include one or more heaters 7132 (shown as first heater 7132a and a second heater 7132b) to vaporize and/or pressurize the hydrogen donor within. A three-way valve 7133 and a regulator 7134 control the amount of fluid and/or vapor that exits the donor vessel 7130 and passes along the donor path 7131 through the second heat exchanger 7170b and into the reactor vessel 7111. As discussed above, the hydrogen donor can also serve as a fuel for the engine 7180, in at least some embodiments, and can be delivered to the engine 7180 via a third conduit or passage 7177c.

[00159] In the reactor vessel 7111, the combustion products 7152 pass through the combustion products passage 7118 while delivering radiant energy and/or reactants through the transmissive surface 7119 into the reaction zone 7112. After passing through the second heat exchanger 7170b, the combustion products 7152 can enter a combustion products separator 7171b that separates water from the combustion products. The water returns to the steam/water source 7140 and the remaining combustion products are collected at the combustion products collector 7160b. In a particular embodiment, the separator 7171b can include a centrifugal separator that is driven by the kinetic energy of the combustion product stream. If the kinetic energy of the combustion product stream is insufficient to separate the water by centrifugal force, a motor/generator 7172 can add energy to the separator 7171b to provide the necessary centrifugal force. If the kinetic energy of the combustion product stream is greater than is necessary to separate water, the motor/generator 7172 can produce energy, e.g., to be used by other components of the system 7100. The controller 7190 receives inputs from the various elements of the system 7100 and controls flow rates, pressures, temperatures, and/or other parameters.

[00160] The controller 7190 can also control the return of reactor products to the engine 7180. For example, the controller can direct reaction products and/or recaptured water back to the engine 7180 via a series of valves. In a particular embodiment, the controller 7190 can direct the operation of the first valve 7176a which directs hydrogen and carbon monoxide obtained from the first separator 7171a to the engine 7180 via the first conduit 7177a. These constituents can be burned in the combustion zone 7179 to provide additional power from the engine 7180. In some instances, it may be desirable to cool the combustion zone 7179 and/or other elements of the engine 7180 as shown. In such instances, the controller 7190 can control a flow of water or steam to the engine 7180 via second and third valves 7176b, 7176c and the corresponding second conduit 7177b.

[00161] In some instances, it may be desirable to balance the energy provided to the reactor 7110 with energy extracted from the engine 7180 used for other proposes. According, the system 7100 can included a proportioning valve 7187 in the combustion products stream that can direct some combustion products 7152 to a power extraction device 7188, for example, a turbo-alternator, turbocharger or a supercharger. When the power extraction device 7188 includes a supercharger, it operates to compress air entering the engine cylinder 7181 via the intake port 7184a. When the extraction device 7188 includes a turbocharger, it can include an additional fuel injection valve 7189b that directs fuel into the mixture of combustion products for further combustion to produce additional power. This power can supplement the power provided by the engine 7180, or it can be provided separately, e.g., via a separate electrical generator.

[00162] As is evident from the forgoing discussion, one feature of the system 7100 is that it is specifically configured to conserve and reuse energy from the combustion products 7152. Accordingly, the system 7100 can include additional features that are designed to reduce energy losses from the combustion products 7152. Such features can include insulation positioned around the cylinder 7181, at the head of the piston 7182, and/or at the ends of the valves 7183a, 7183b. Accordingly, the insulation prevents or at least restricts heat from being conveyed away from the engine 7180 via any thermal channel other than the passage 7118.

[00163] One feature of at least some of the foregoing embodiments is that the reactor system can include a reactor and an engine linked in an interdependent manner. In particular, the engine can provide waste heat that facilitates a dissociation process conducted at the reactor to produce a hydrogen-based fuel and a non-hydrogen based structural building block. The building block can include a molecule containing carbon, boron, nitrogen, silicon and/or sulfur, and can be used to form an architectural construct. Representative examples of architectural constructs, in addition to the polymers and composites described above are described in further detail in co-pending U.S. Application No. 12/027,214, previously incorporated herein by reference. An advantage of this arrangement is that it can provide a synergy between the engine and the reactor. For example, the energy inputs normally required by the reactor to conduct the dissociation processes described above can be reduced by virtue of the additional energy provided by the combustion product. The efficiency of the engine can be improved by adding clean-burning hydrogen to the combustion chamber, and/or by providing water (e.g., in steam or liquid form) for cooling the engine. Although both the steam and the hydrogen-based fuel are produced by the reactor, they can be delivered to the engine at different rates and/or can vary in accordance with different schedules and/or otherwise in different manners.

[00164] Still further embodiments of suitable reactors with using engine heat are disclosed in pending U.S. Application No. 13/027,198, filed February 14, 2011, and incorporated herein by reference.

Representative Exothermic/Endothermic Reactors

[00165] Figure 20 is a partially schematic, cross-sectional illustration of particular components of the system 8100, including the reactor vessel 8101. The reactor vessel 8101 includes the first reaction zone 8110 positioned toward the upper left of Figure 20 (e.g., at a first reactor portion) to receive incident solar radiation 8106, e.g., through a solar transmissive surface 8107. The second reaction zone 8120 is also positioned within the reactor vessel 8101, e.g., at a second reactor portion, to receive products from the first reaction zone 8110 and to produce an end product, for example, methanol. Reactant sources 8153 provide reactants to the reactor vessel 8101, and a product collector 8123 collects the resulting end product. A regulation system 8150, which can include valves 8151 or other regulators and corresponding actuators 8152, is coupled to the reactant sources 8153 to control the delivery of reactants to the first reaction zone 8110 and to control other flows within the system 8100. In other embodiments, the valves can be replaced by or supplemented with other mechanisms, e.g., pumps.

[00166] In a particular embodiment, the reactant sources 8153 include a methane source 8153a and a carbon dioxide source 8153b. The methane source 8153a is coupled to a first reactant valve 8151a having a corresponding actuator 8152a, and the carbon dioxide source 8153b is coupled to a second reactant valve 8151b having a corresponding actuator 8152b. The reactants pass into the reaction vessel 8101 and are conducted upwardly around the second reaction zone 8120 and the first reaction zone 8110 as indicated by arrows A. As the reactants travel through the reactor vessel 8101, they can receive heat from the first and second reaction zones 8110, 8120 and from products passing from the first reaction zone 8110 to the second reaction zone 8120, as will be described in further detail later. The reactants enter the first reaction zone 8110 at a first reactant port 8111. At the first reaction zone 8110, the reactants can undergo the following reaction:

$$CH_4 + CO_2 + \text{HEAT} \rightarrow 2CO + 2H_2 \quad \text{[Equation 13]}$$

[00167] In a particular embodiment, the foregoing endothermic reaction is conducted at about 900°C and at pressures of up to about 1,500 psi. In other embodiments, reactions with other reactants can be conducted at other temperatures at the first reaction zone 8110. The first reaction zone 8110 can include any of a variety of suitable catalysts, for example, a nickel/aluminum oxide catalyst. In particular embodiments, the reactants and/or the first reaction zone 8110 can be subjected to acoustic pressure fluctuation (in addition to the overall pressure changes caused by introducing reactants, undergoing the reaction, and removing products from the first reaction zone 8110) to aid in delivering the reactants to the reaction sites of the catalyst. In any of these embodiments, the products produced at the first reaction zone 8110 (e.g. carbon monoxide and hydrogen) exit the first reaction zone 8110 at a first product port 8112 and enter a first heat exchanger 8140a. The first products travel through the first heat exchanger 8140a along a first flow path 8141 and transfer heat to the incoming reactants traveling along a second flow path 8142. Accordingly, the incoming reactants can be preheated at the first heat exchanger 8140a, and by virtue of passing along or around the outside of the first reaction zone 8110. In particular embodiments, one or more surfaces of the first heat exchanger 8140a can include elements or materials that absorb radiation at one frequency and re-radiate it at another. Further details of suitable materials and arrangements are disclosed above.

[00168] The first products enter the second reaction zone 8120 via a second reactant port 8121 and a check valve 8156 or other flow inhibitor. The check valve 8156 is configured to allow a one-way flow of the first products into the second reaction zone 8120 when the pressure of the first products exceeds the pressure in the second reaction zone 8120. In other embodiments, the check valve 8156 can be replaced with another mechanism, e.g., a piston or pump that conveys the first products to the second reaction zone 8120.

[00169] At the second reaction zone 8120, the first products from the first reaction zone 8110 undergo an exothermic reaction, for example:

$$2CO + 2H_2 + 2'H_2 \rightarrow CH_3OH + HEAT \qquad \text{[Equation 14]}$$

[00170] The foregoing exothermic reaction can be conducted at a temperature of approximately 250°C and in many cases at a pressure higher than that of the endothermic reaction in the first reaction zone 8110. To increase the pressure at the second reaction zone 8120, the system 8100 can include an additional constituent source 8154 (e.g. a source of hydrogen) that is provided to the second reaction zone 8120 via a valve 8151c and corresponding actuator 8152c. The additional constituent (e.g. hydrogen, represented by $2'H_2$ in Equation 21) can pressurize the second reaction zone with or without necessarily participating as a consumable in the reaction identified in Equation 14. In particular, the additional hydrogen may be produced at pressure levels beyond 1,500 psi, e.g., up to about 5,000 psi or more, to provide the increased pressure at the second reaction zone 8120. In a representative embodiment, the additional hydrogen may be provided in a separate dissociation reaction using methane or another reactant. For example, the hydrogen can be produced in a separate endothermic reaction, independent of the reactions at the first and second reaction zones 8110, 8120, as follows:

$$CH_4 + HEAT \rightarrow C + 2H_2 \qquad \text{[Equation 15]}$$

[00171] In addition to producing hydrogen for pressurizing the second reaction zone 8120, the foregoing reaction can produce carbon suitable to serve as a building block in the production of any of a variety of suitable end products, including polymers, self-organizing carbon-based structures such as graphene, carbon composites, and/or other materials. Further examples of suitable products are included in co-pending U.S. Application No. 12/027,214 previously concurrently herewith and incorporated herein by reference.

[00172] The reaction at the second reaction zone 8120 can be facilitated with a suitable catalyst, for example, copper, zinc, aluminum and/or compounds including one or more of the foregoing elements. The product resulting from the reaction at the second reaction zone 8120 (e.g. methanol) is collected at the product collector 8123. Accordingly, the methanol exits the second reaction zone 8120 at a second product port 8122 and passes through a second heat exchanger 8140b. At the second heat exchanger 8140b, the methanol travels along a third flow path 8143 and transfers heat to the incoming constituents provided to the first reaction zone 8110 along a fourth flow path 8144. Accordingly, the two heat exchangers 8140a, 8140b can increase the overall efficiency of the reactions taking place in the reactor vessel 8101 by conserving and recycling the heat generated at the first and second reaction zones.

[00173] In a particular embodiment, energy is provided to the first reaction zone 8110 via the solar concentrator 8103 described above with reference to Figure 20. Accordingly, the energy provided to the first reaction zone 8110 by the solar collector 8103 will be intermittent. The system 8100 can include a supplemental energy source that allows the reactions to continue in the absence of sufficient solar energy. In particular, the system 8100 can include a supplemental heat source 8155. For example, the supplemental heat source 8155 can include a combustion reactant source 8155a (e.g. providing carbon monoxide) and an oxidizer source 8155b (e.g. providing oxygen). The flows from the reactant source 8155a and oxidizer source 8155b are controlled by corresponding valves 8151d, 8151e, and actuators 8152d, 8152e. In operation, the reactant and oxidizer are delivered to the reactor vessel 8101 via corresponding conduits 8157a, 8157b. The reactant and oxidizer can be preheated within the reactor vessel 8101, before reaching a combustion zone 8130, as indicated by arrow B. At the combustion zone 8130, the combustion reactant and oxidizer are combusted to provide heat to the first reaction zone 8110, thus supporting the endothermic reaction taking place within the first reaction zone 8110 in the absence of sufficient solar energy. The result of the combustion can also yield carbon dioxide, thus reducing the need for carbon dioxide from the carbon dioxide source 8153b. The controller 8190 can control when the secondary heat source 8155 is activated and deactivated, e.g., in response to a heat or light sensor.

[00174] In another embodiment, the oxygen provided by the oxidizer source 8155b can react directly with the methane at the combustion zone 8130 to produce carbon dioxide and hydrogen. This in turn can also reduce the amount of carbon dioxide required at the first reaction zone 8110. Still further embodiments of suitable exothermic/endothermic reactors are disclosed in pending U.S. Application No. 13/027,060, filed February 14, 2011, and incorporated herein by reference.

[00175] From the foregoing, it will be appreciated that specific embodiments of the disclosure have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the various embodiments of the disclosure. For example, several embodiments may include various suitable combinations of components, devices and/or systems from any of the embodiments described herein. Further, while various advantages associated with certain embodiments of the disclosure have been described above in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages to fall within the scope of the disclosure.

CLAIMS

I/We claim:

1. A gas turbine comprising:

a compressor section including:

a rotor operably coupled to a shaft;

a stator positioned adjacent to the rotor; and

a coolant line extending at least partially through the stator to transfer heat out of an air flow within the compressor section.

2. The gas turbine of claim 1, further comprising a fuel supply system, wherein the coolant line is operably coupled to the fuel supply system, and wherein fuel from the fuel supply system flows through the coolant line.

3. The gas turbine of claim 1, further comprising a thermochemical regeneration system having a reactor, wherein the reactor produces hydrogen for combustion within the gas turbine.

4. The gas turbine of claim 1, further comprising an injection port positioned to inject fuel into the compressor section.

5. The gas turbine of claim 1, further comprising:

a plurality of combustors;

a thermochemical regeneration system having a reactor configured to produce hydrogen-characterized fuels; and

a fuel injection system operably coupled to the reactor and having a plurality of fuel injectors, wherein individual fuel injectors are positioned to inject fuel into corresponding combustors.

6. The gas turbine of claim 1, further comprising a plurality of injector-igniters positioned to inject and ignite fuel within the gas turbine.

7. The gas turbine of claim 1 wherein the coolant line carries fuel, and wherein the fuel is combusted within the gas turbine after passing through the coolant line.

8. A gas turbine comprising:

a combustion section having a plurality of combustors;

a plurality of injectors, individual injectors positioned within corresponding combustors;

a compressor section having a stator; and

a cooling system having a coolant line that extends at least partially through the stator, wherein fuel is directed through the coolant line to cool airflow within the compressor prior to injection of the fuel into the combustors via the injectors.

9. The gas turbine of claim 8 wherein the injectors comprise injector-igniters configured to inject the fuel into the combustors and ignite the fuel.

10. The gas turbine of claim 8, further comprising:

a fuel supply system; and

a thermochemical regeneration system operably coupled to the fuel supply system, the thermochemical regeneration system including:

a plurality of fin tubes extending through an exhaust section, wherein fuel is directed through the fin tubes and heated by exhaust from the gas turbine;

an exducer positioned to capture water from the exhaust; and

a reactor positioned to receive the fuel from the fin tubes and receive the water from the exducer, wherein the reactor is configured to react the fuel and the water to produce hydrogen for combustion in the gas turbine.

11. The gas turbine of claim 8, further comprising an exhaust section having an exducer positioned to capture water from an exhaust stream of the gas turbine.

12. The gas turbine of claim 11 wherein the exducer comprises a plurality of stator volutes.

13. The gas turbine of claim 8, further comprising an injection port positioned to inject fuel into the compressor section.

14. The gas turbine of claim 8 wherein individual injectors include corresponding insulator tubes.

15. A method for operating a gas turbine, the method comprising:

cooling an air flow in a compressor section of the gas turbine by directing fuel through an internal coolant line extending through at least a portion of the compressor section;

injecting the fuel into a combustor via an injector; and

igniting the fuel within the combustor.

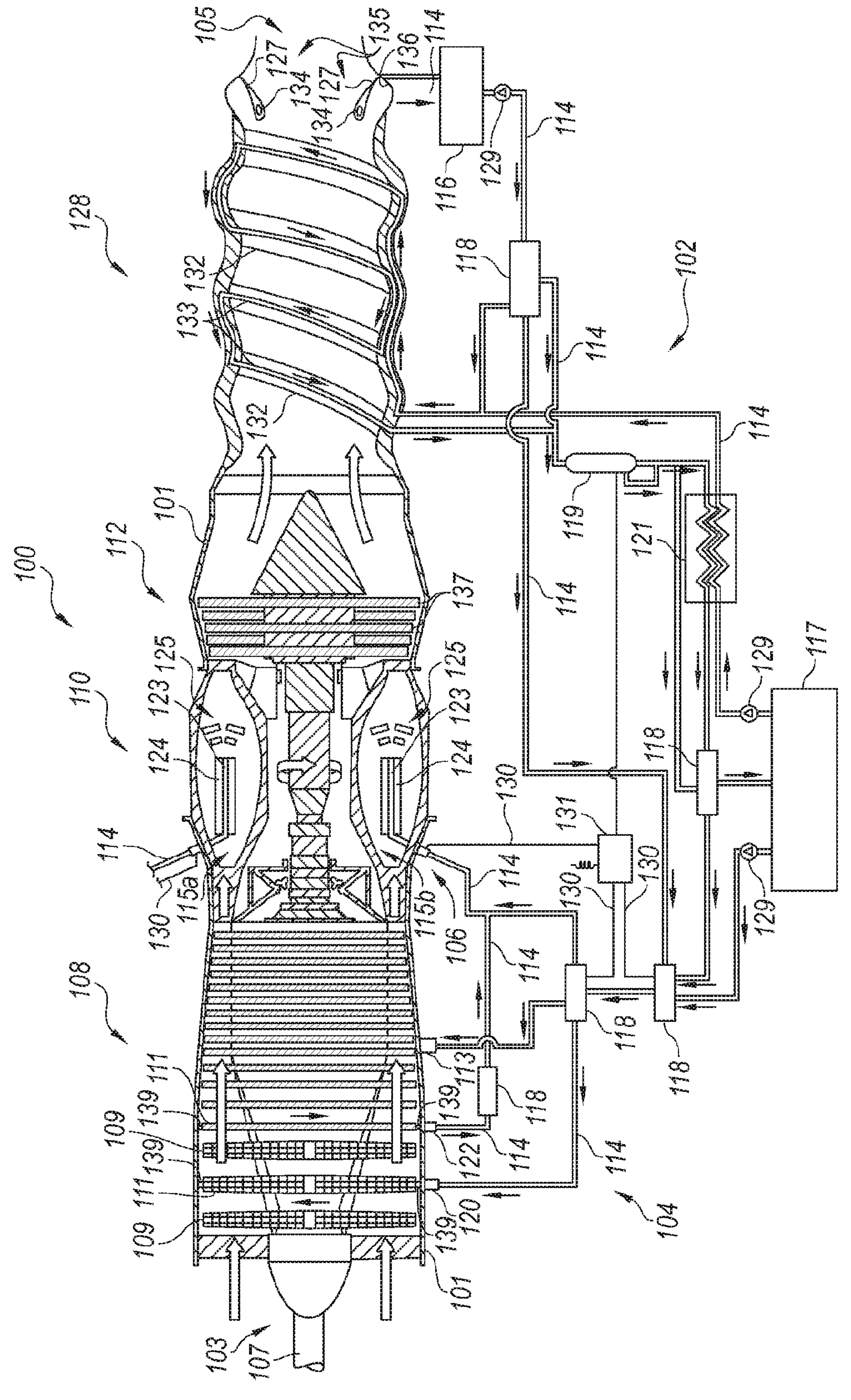
16. The method of claim 15, further comprising producing hydrogen in a thermochemical regeneration system that is operably coupled to the gas turbine and injecting the hydrogen into the combustor via the injector.

17. The method of claim 15, further comprising capturing water from an exhaust stream of the gas turbine and directing the water to a thermochemical regeneration system.

18. The method of claim 15, further comprising pre-heating fuel in a counter-current heat exchanger positioned to utilize heat transfer from the exhaust of the gas turbine and directing the fuel through a thermochemical regeneration system.

19. The method of claim 15, further comprising injecting fuel into the compressor section via an injection port.

20. The method of claim 15, further comprising combining fuel with water from the exhaust stream of the gas turbine to produce hydrogen for combustion within the gas turbine.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110
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112
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114
115a
115b
116
117
118
119
120
121
122
123
124
125
127
128
129
130
131
132
133
134
135
136
137
139

Fig. 1

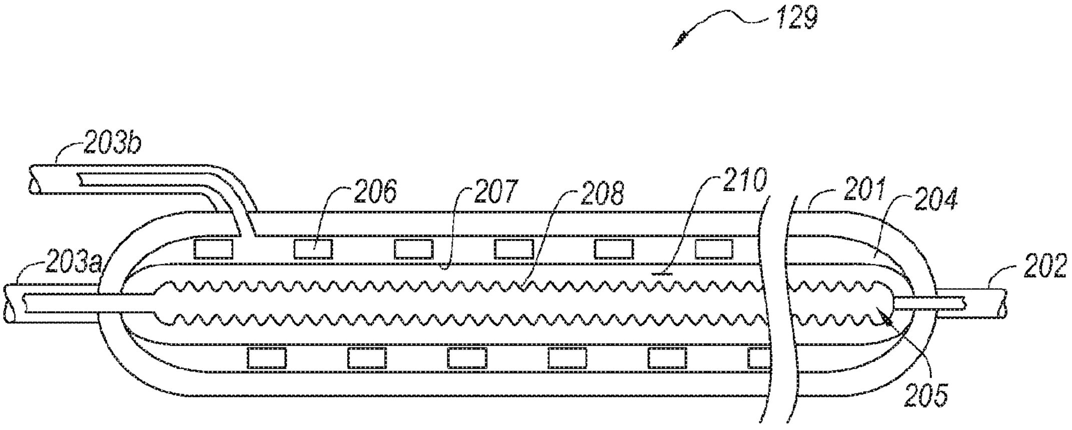


Fig. 2

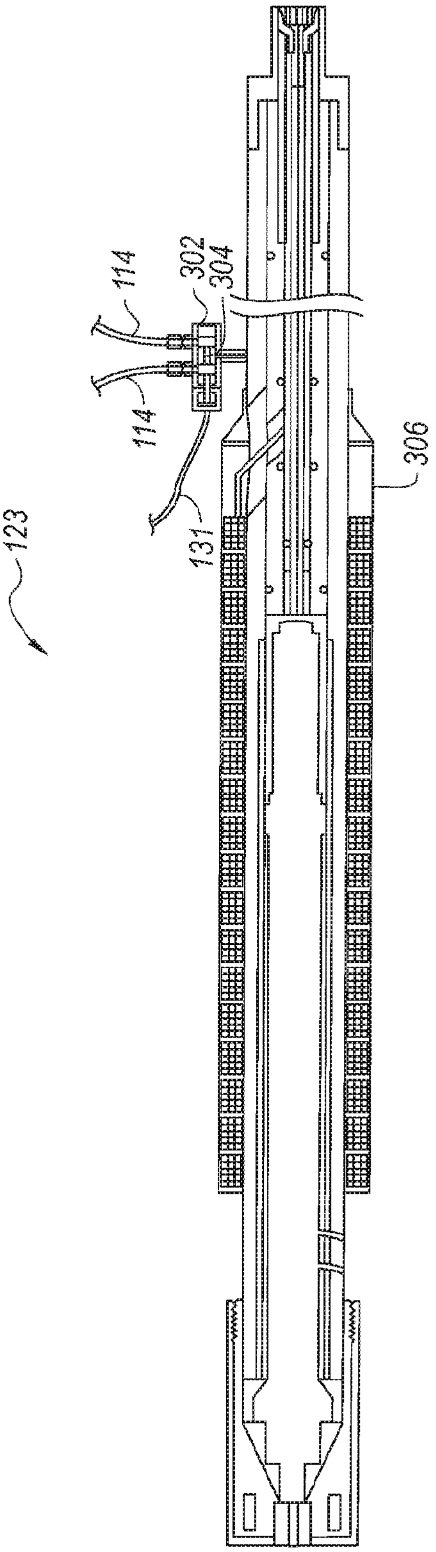
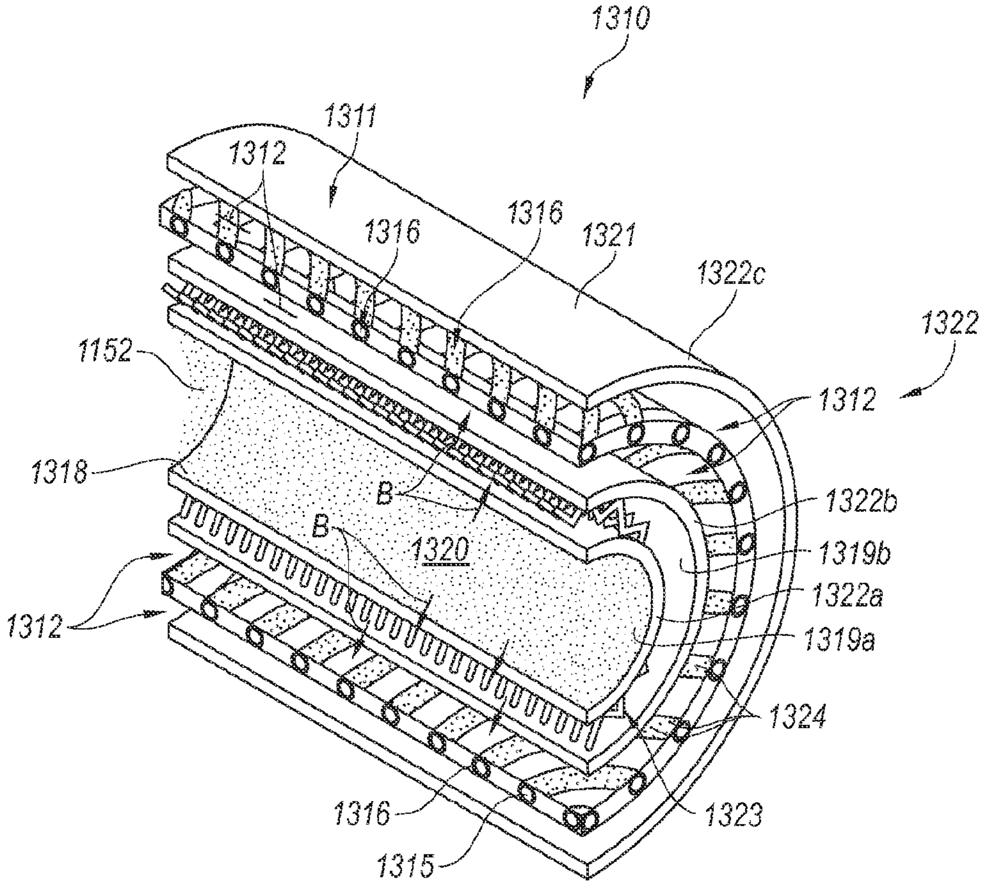


Fig. 3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1321
1322c
1322
1152
1312
1318
B
B
1322b
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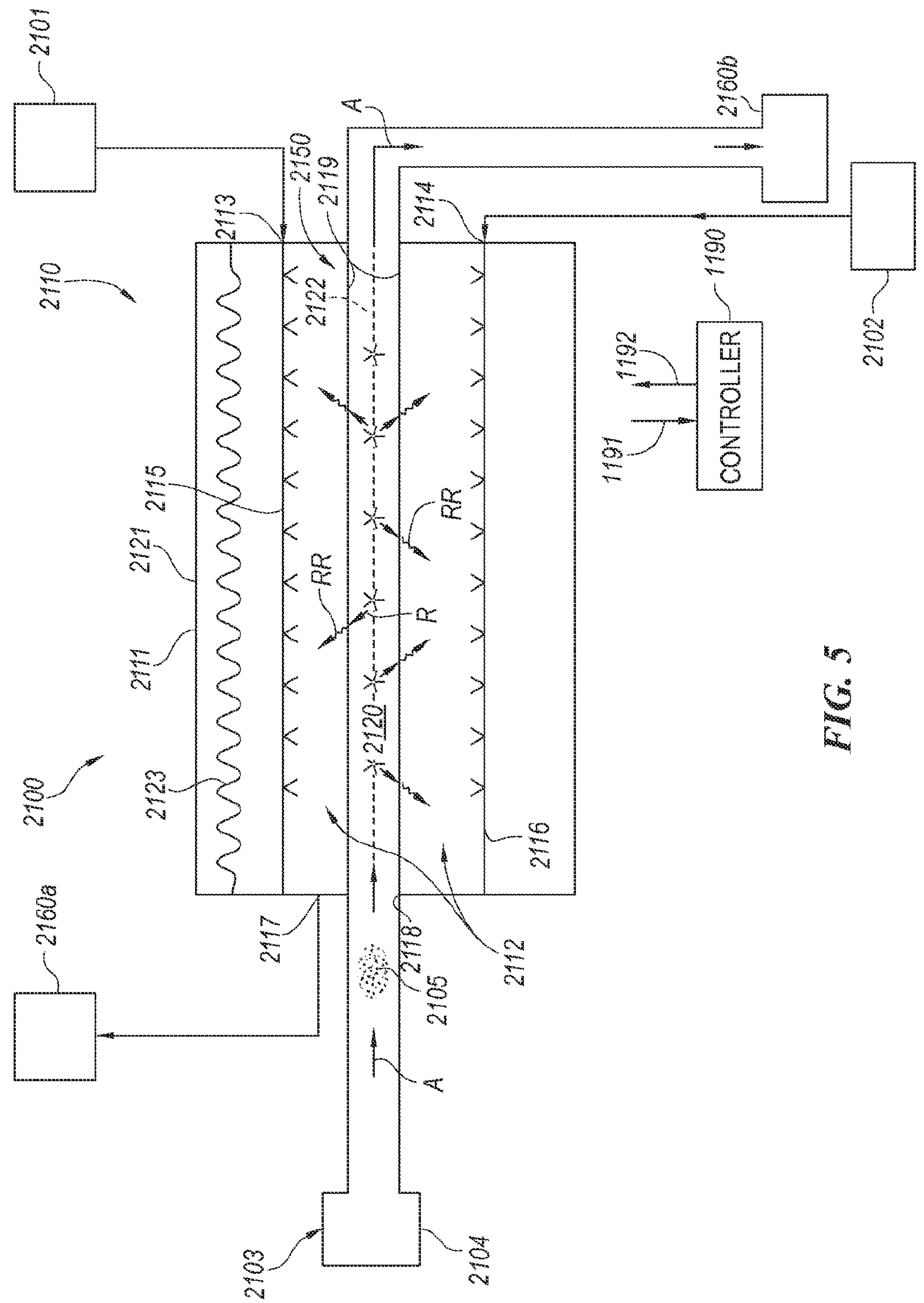
1316
1323
1315

FIG. 4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2110
2122
1190
1192
CONTROLLER
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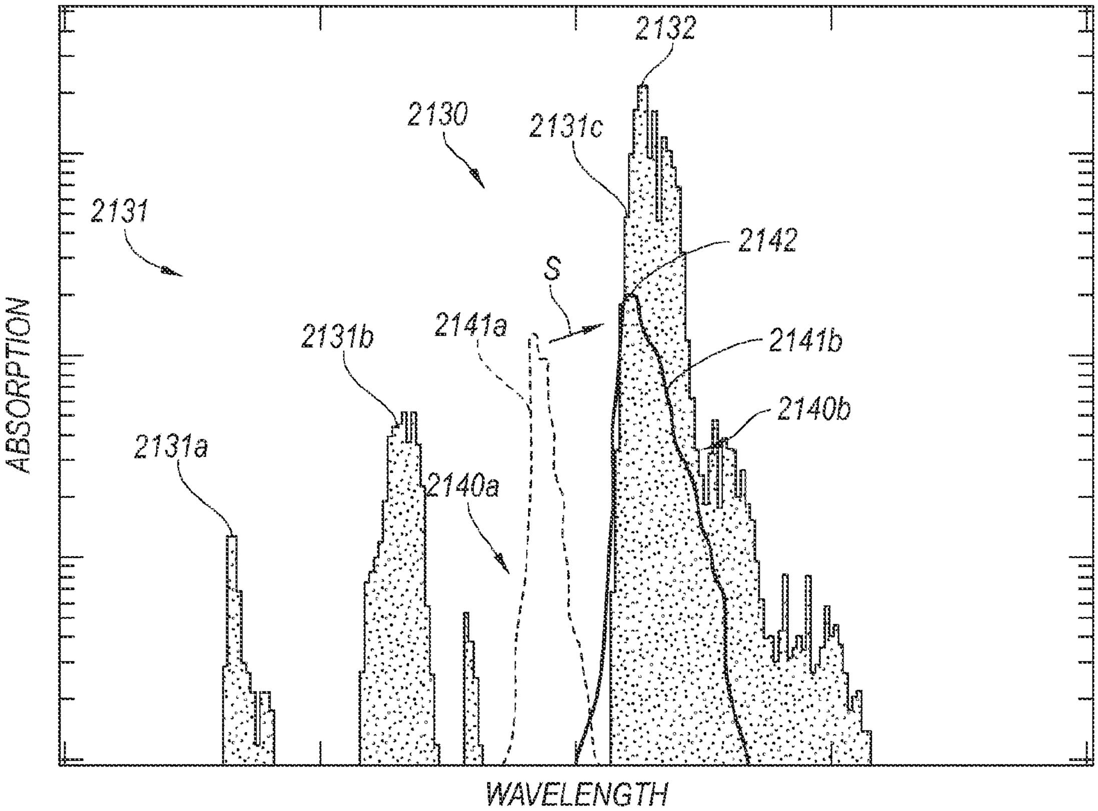
2102
2115
RR
2121
RR
R
2111
2120
2123
2100
2116
2160a
2117
2118
2112
2105
A
2103
2104

FIG. 5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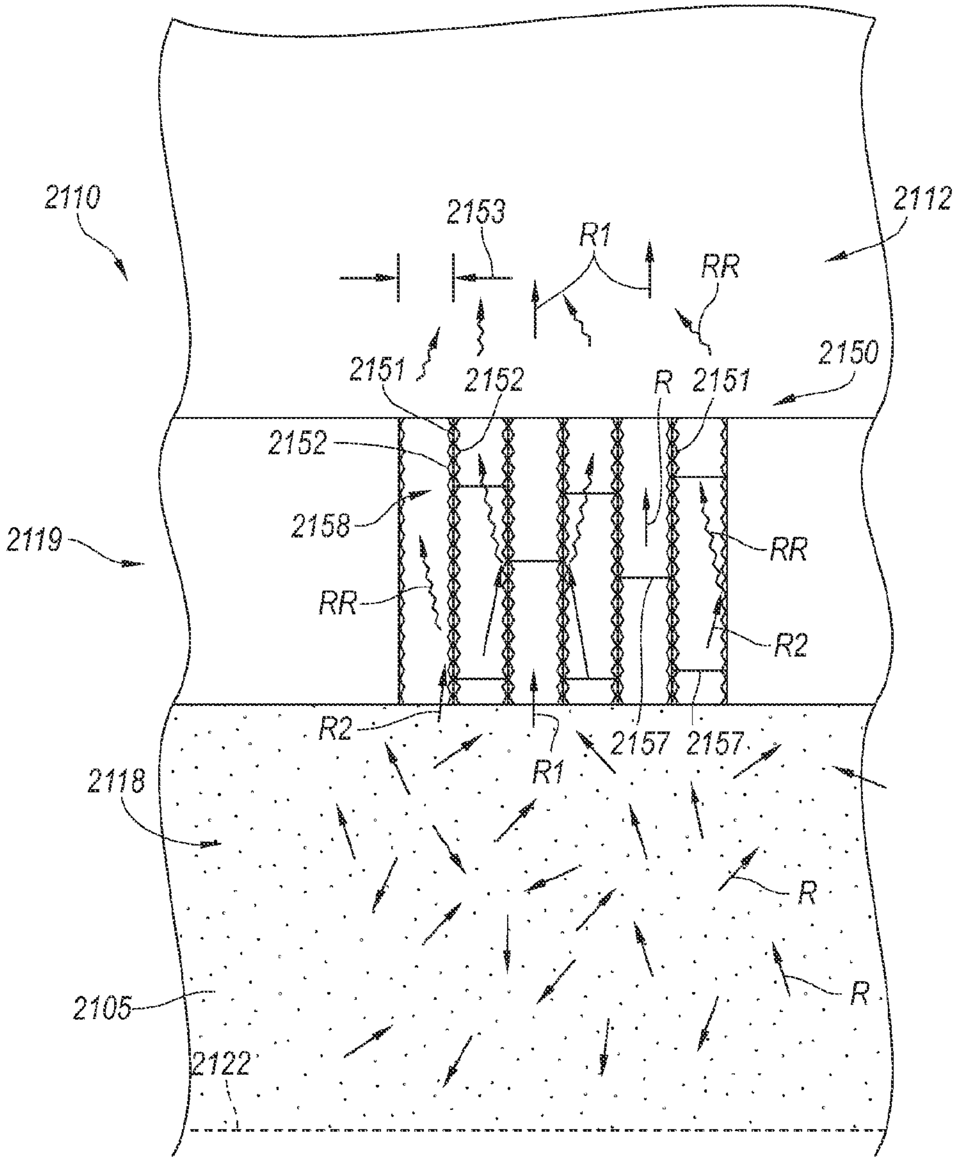
2140a
ABSORPTION
WAVELENGTH

FIG. 6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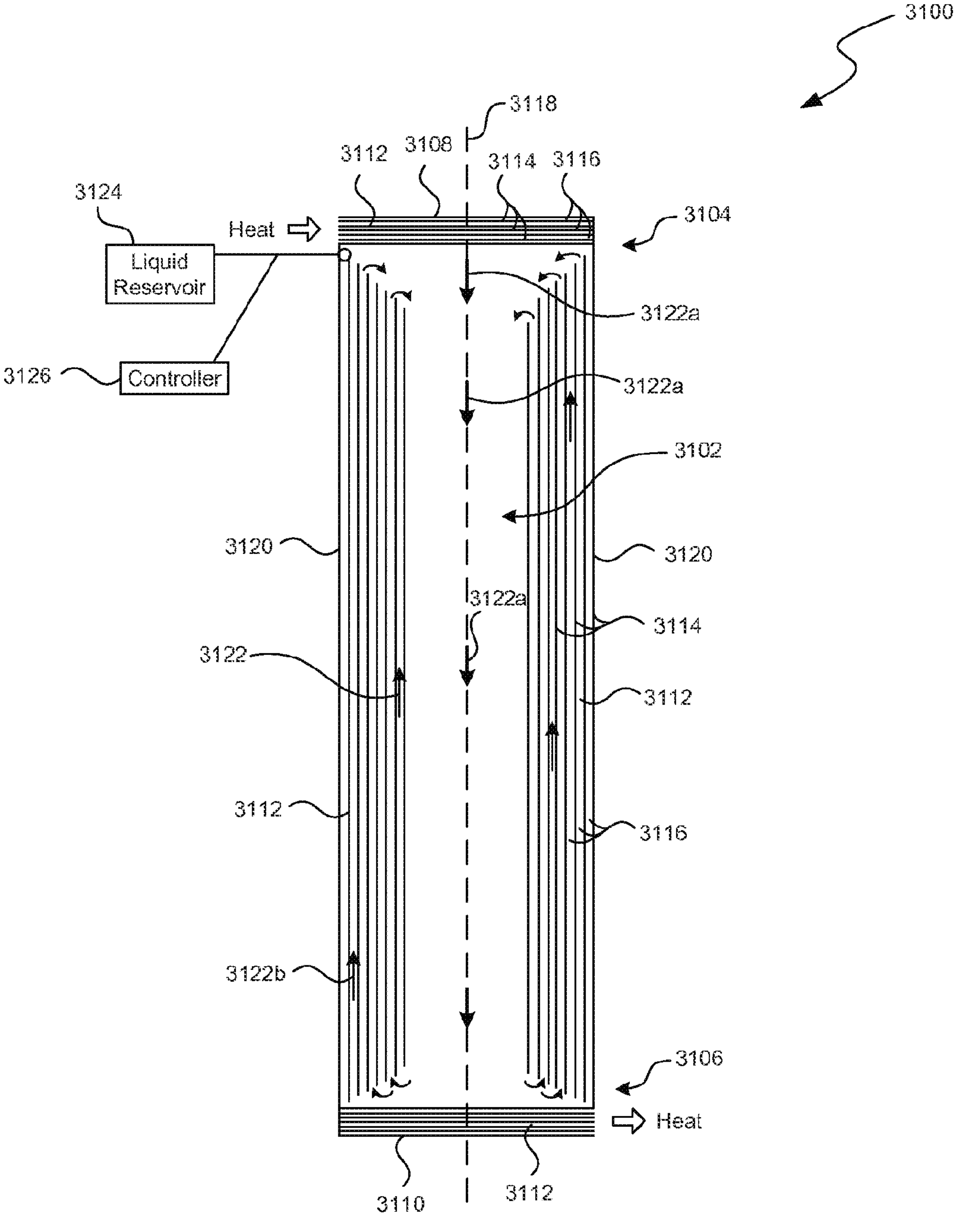
RR
2112
2151
2152
2150
R
2151
2152
2158
2119
RR
RR
R2
R2
R1
2157
2157
2118
R
2105
R
2122

FIG. 7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3118
3112
3108
3114
3116
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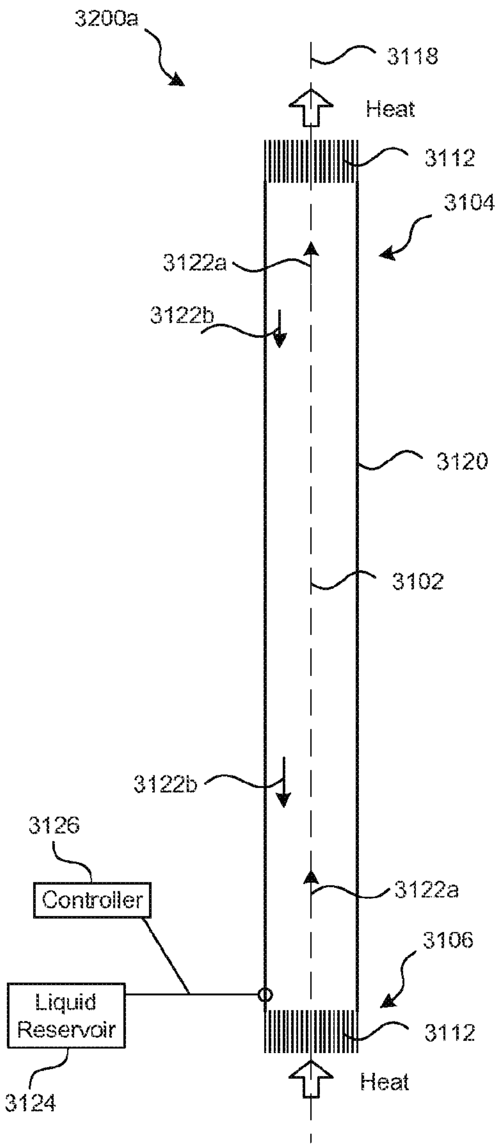
3124
Heat
Liquid Reservoir
3122a
3126
Controller
3122a
3102
3120
3120
3122a
3114
3122
3112
3112
3116
3122b
3106
Heat
3110
3112

FIG. 8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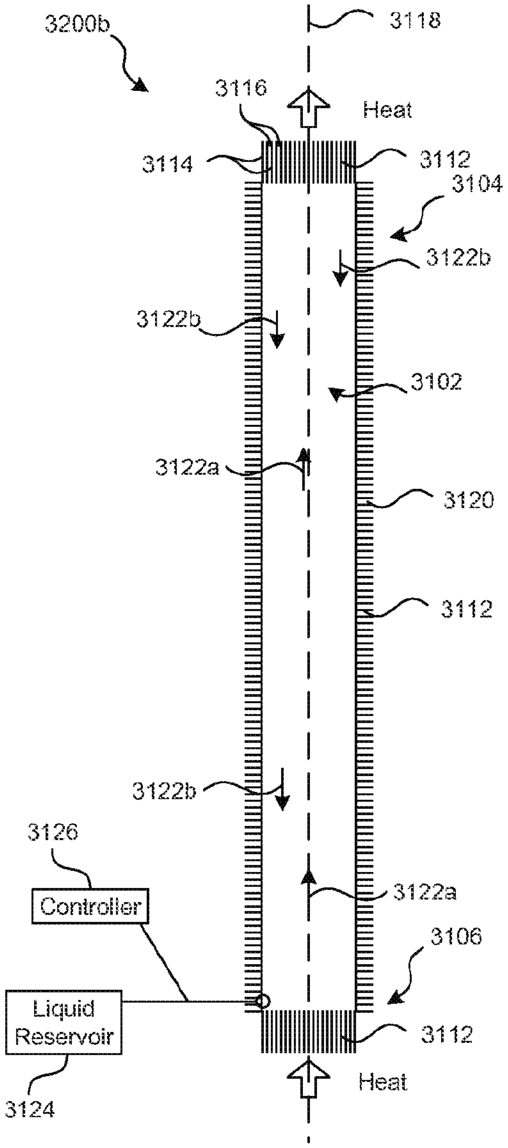
3118
Heat
3112
3104
3122a
3122b
3120
3102
3122b
3126
Controller
3122a
3106
Liquid Reservoir
3112
Heat
3124

FIG. 9A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3104
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3122b
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3122b
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Controller
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3106
Liquid Reservoir
3112
Heat
3124

FIG. 9B

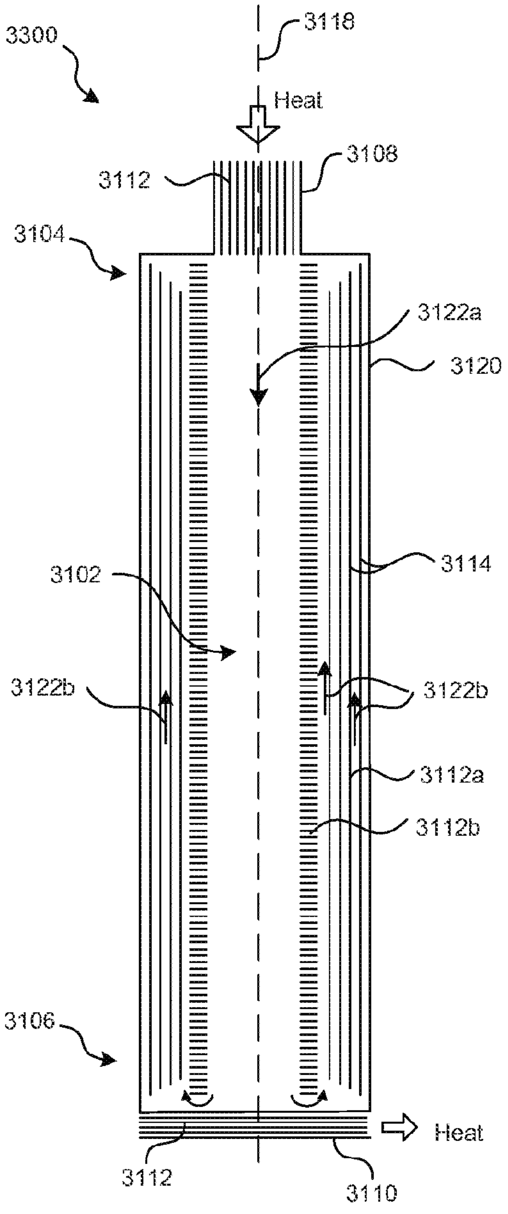


FIG. 10A

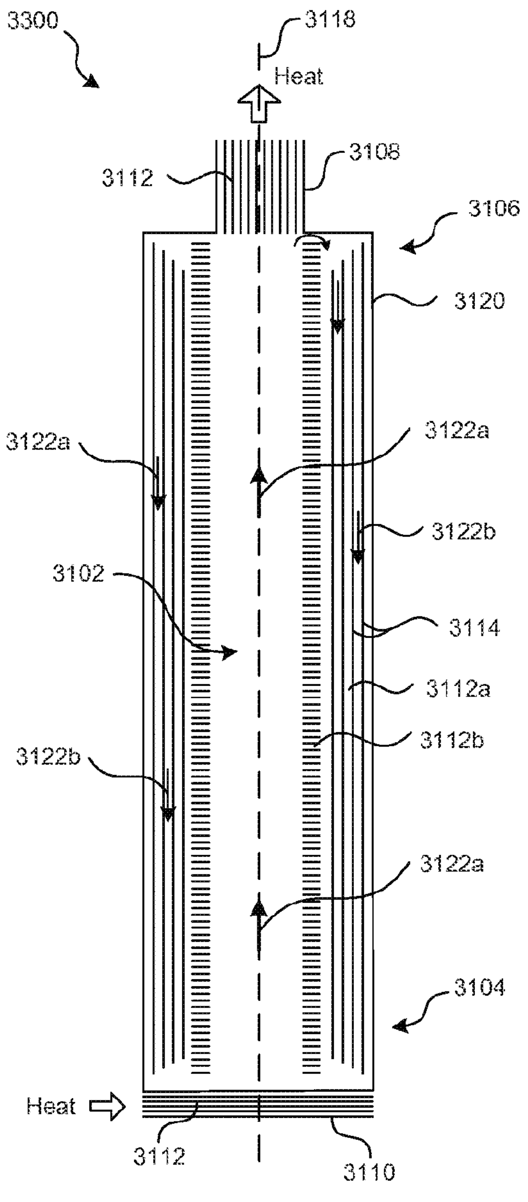


FIG. 10B

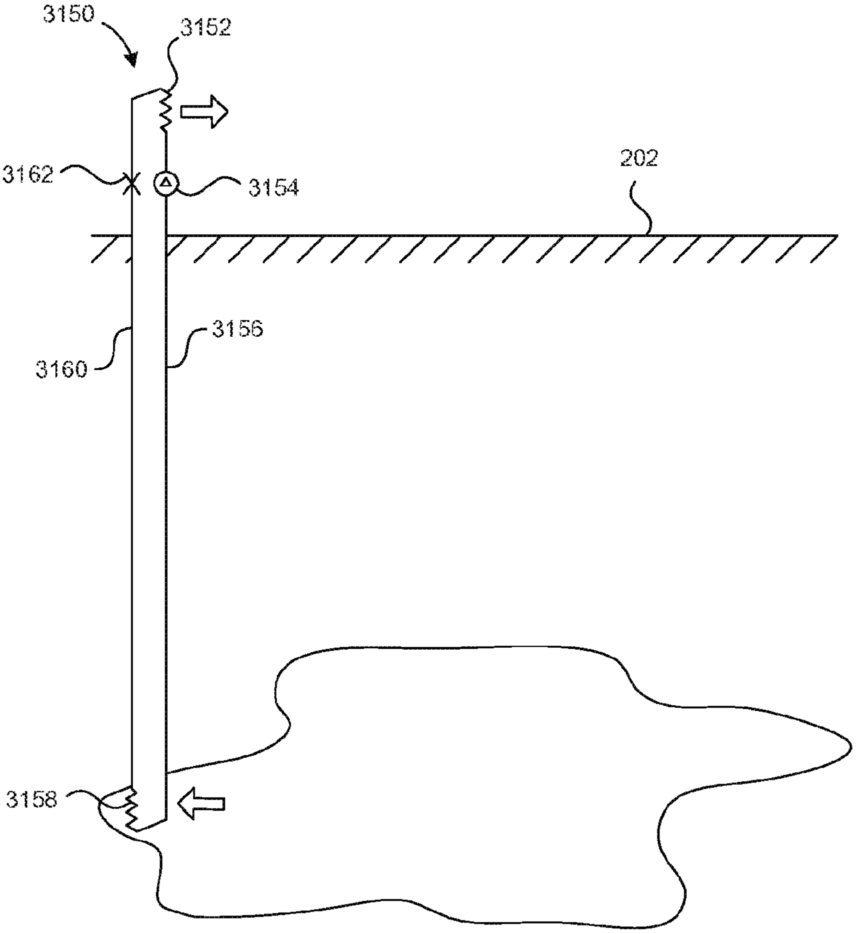
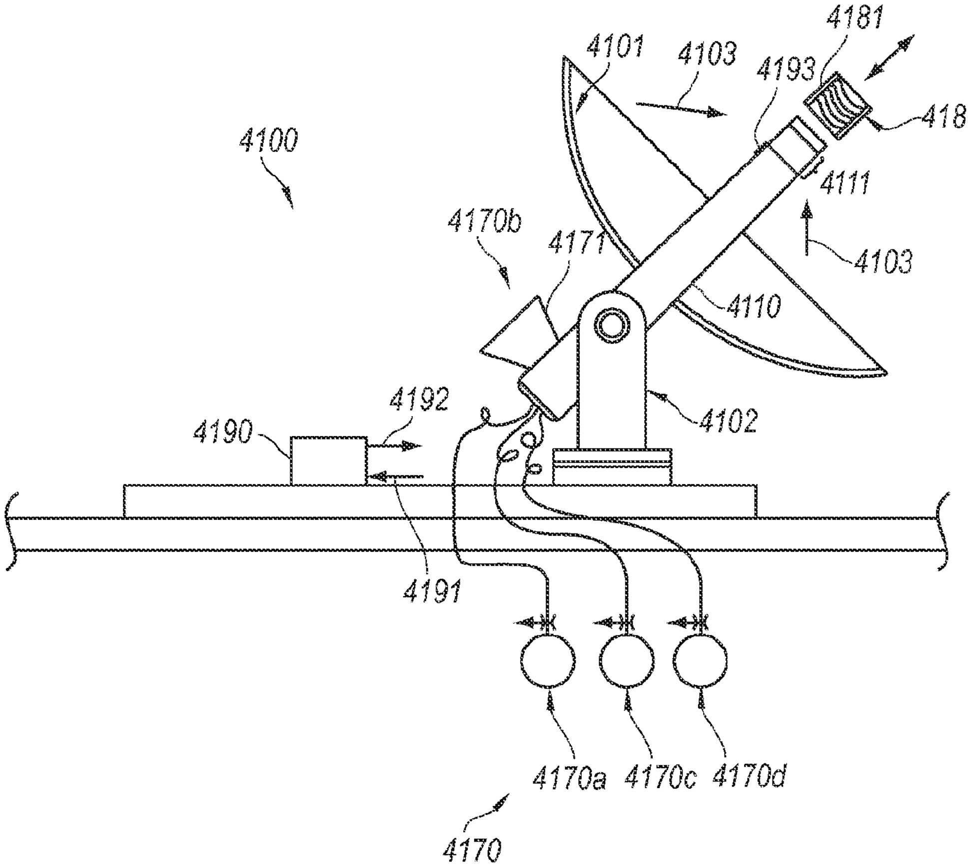


FIG. 11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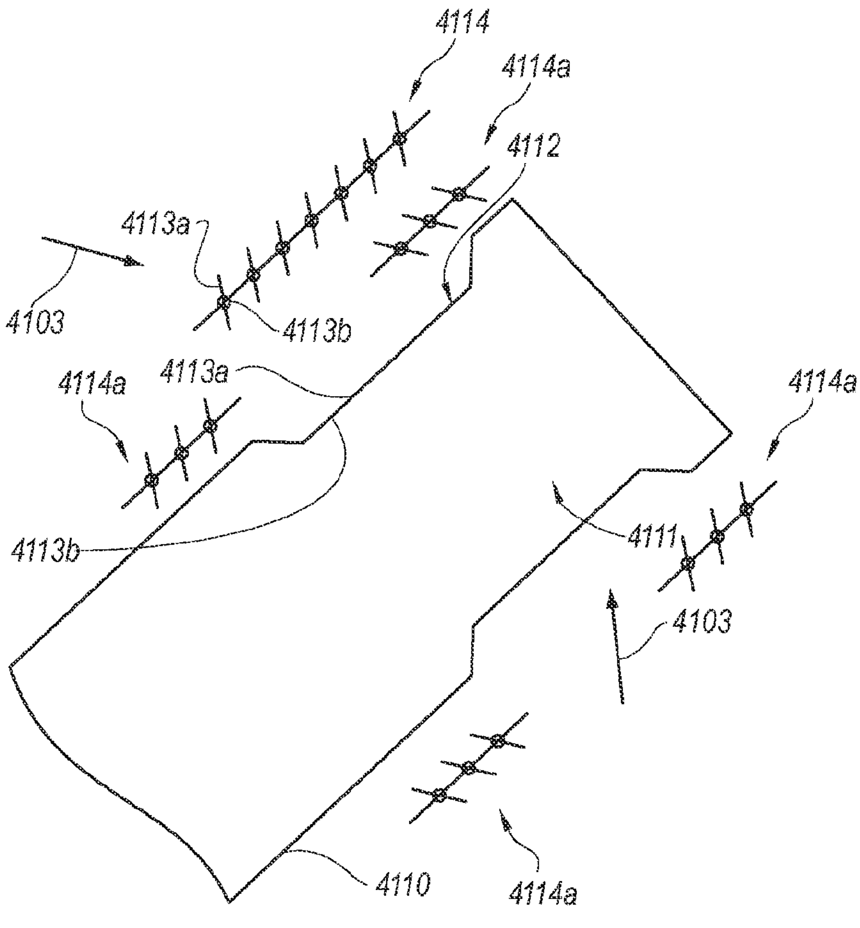
4170c
4170d
4170

FIG. 12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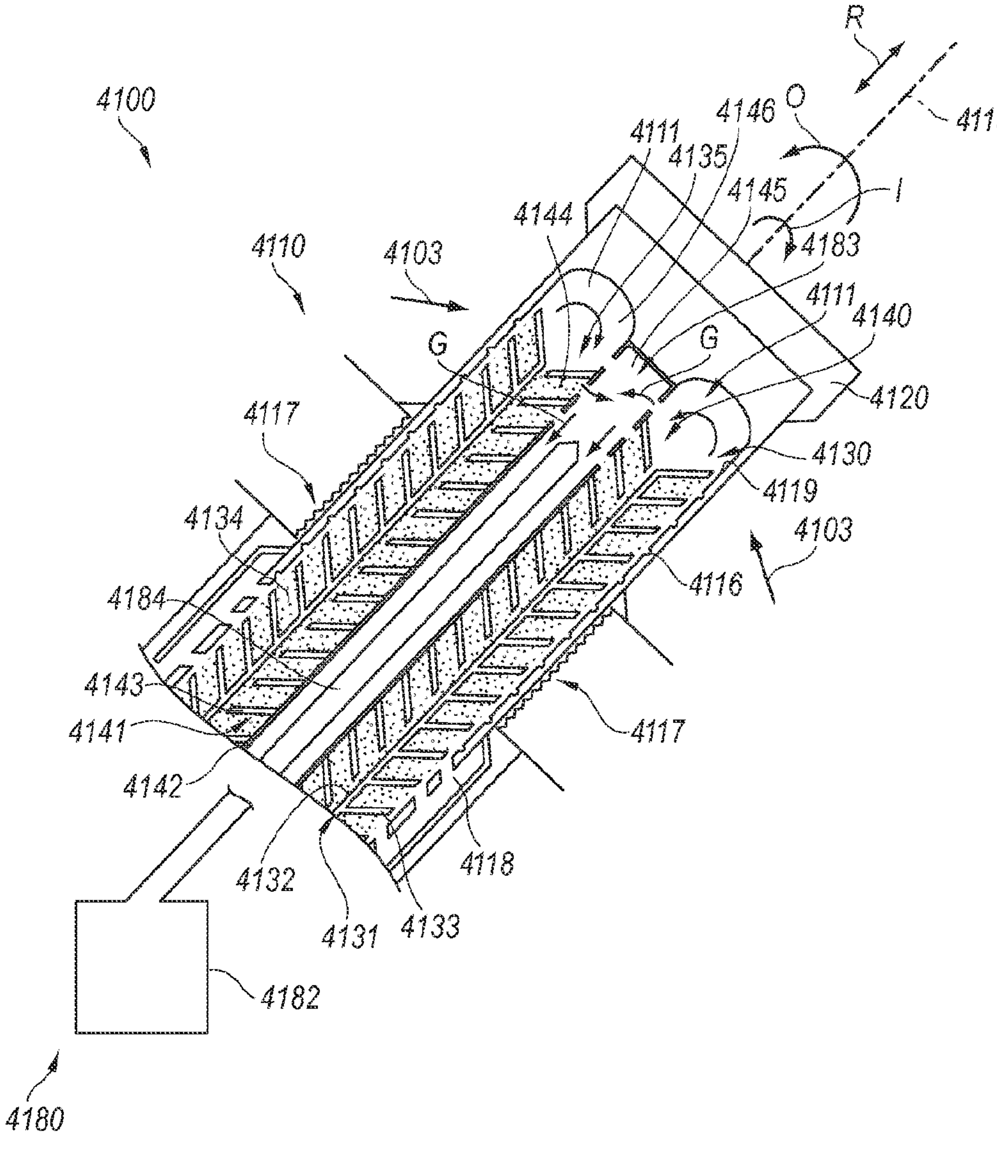
4114a

FIG. 13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G
G
4120
4117
4130
4119
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4184
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4132
4131
4133
4182
4180

FIG. 14

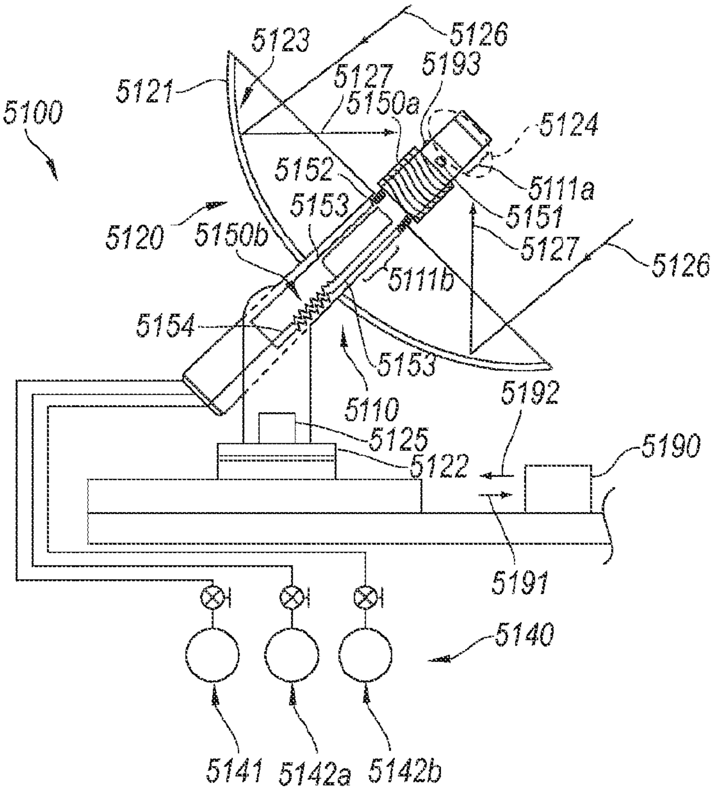
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FIG. 15

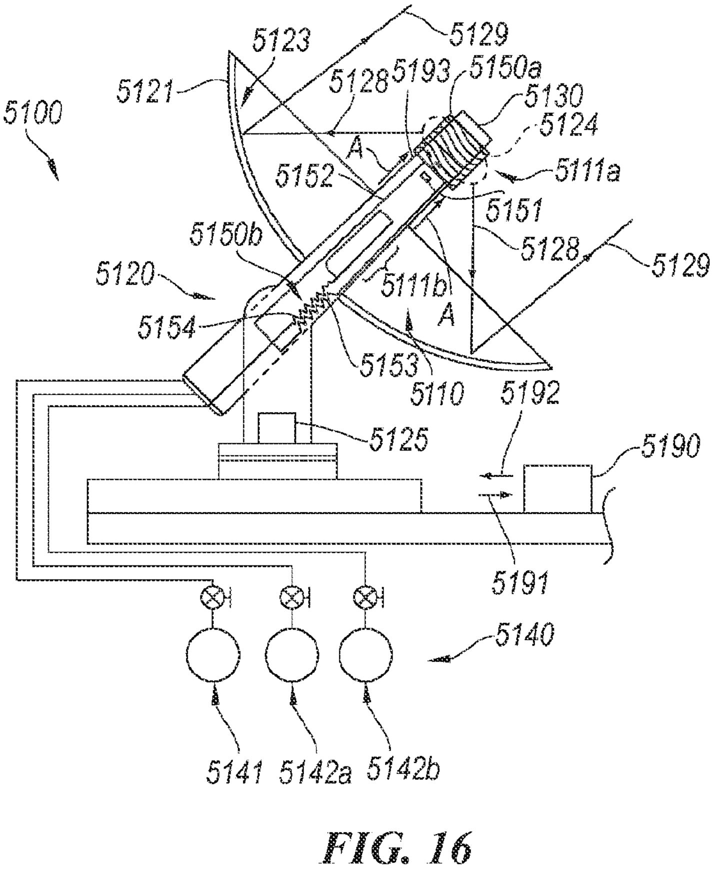
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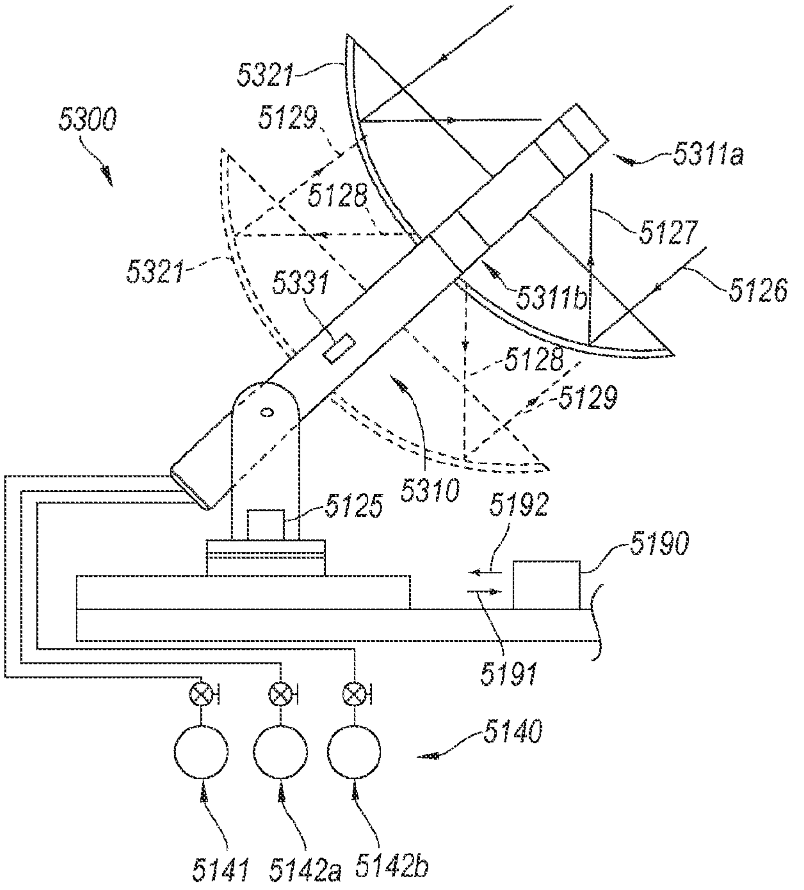
FIG. 16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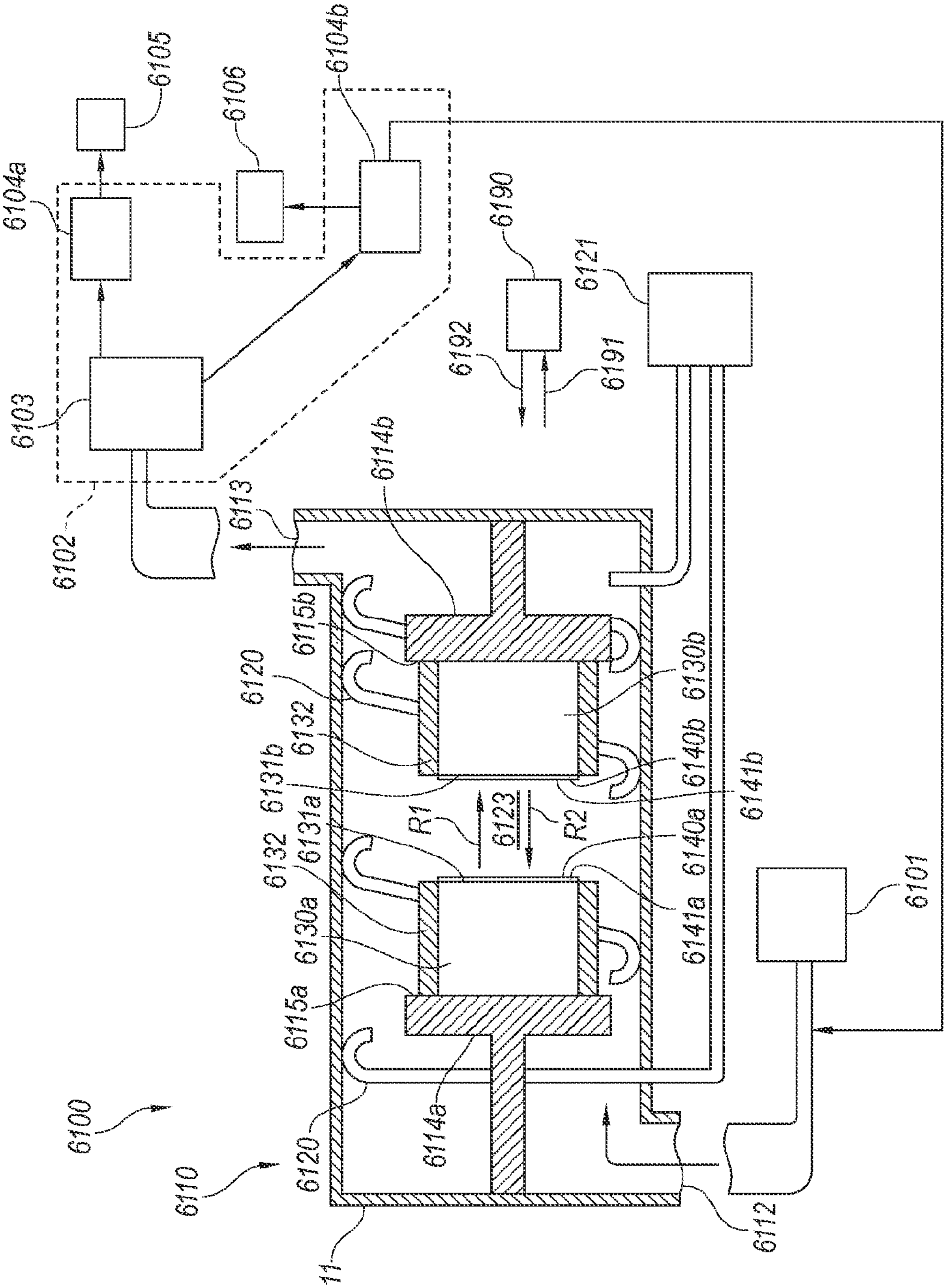
5142b

FIG. 17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6104b
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R1
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6141b
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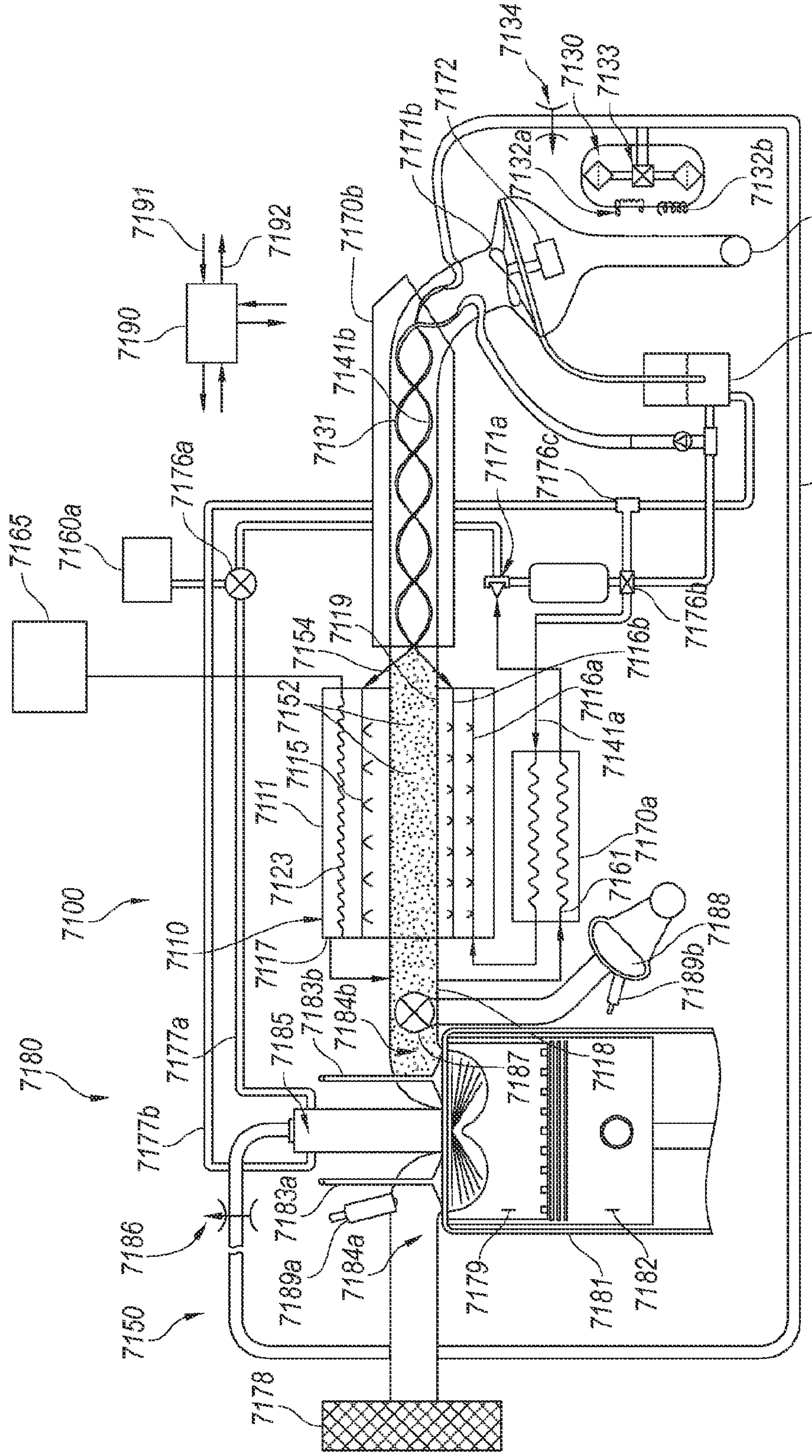
6112

FIG. 18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7170a
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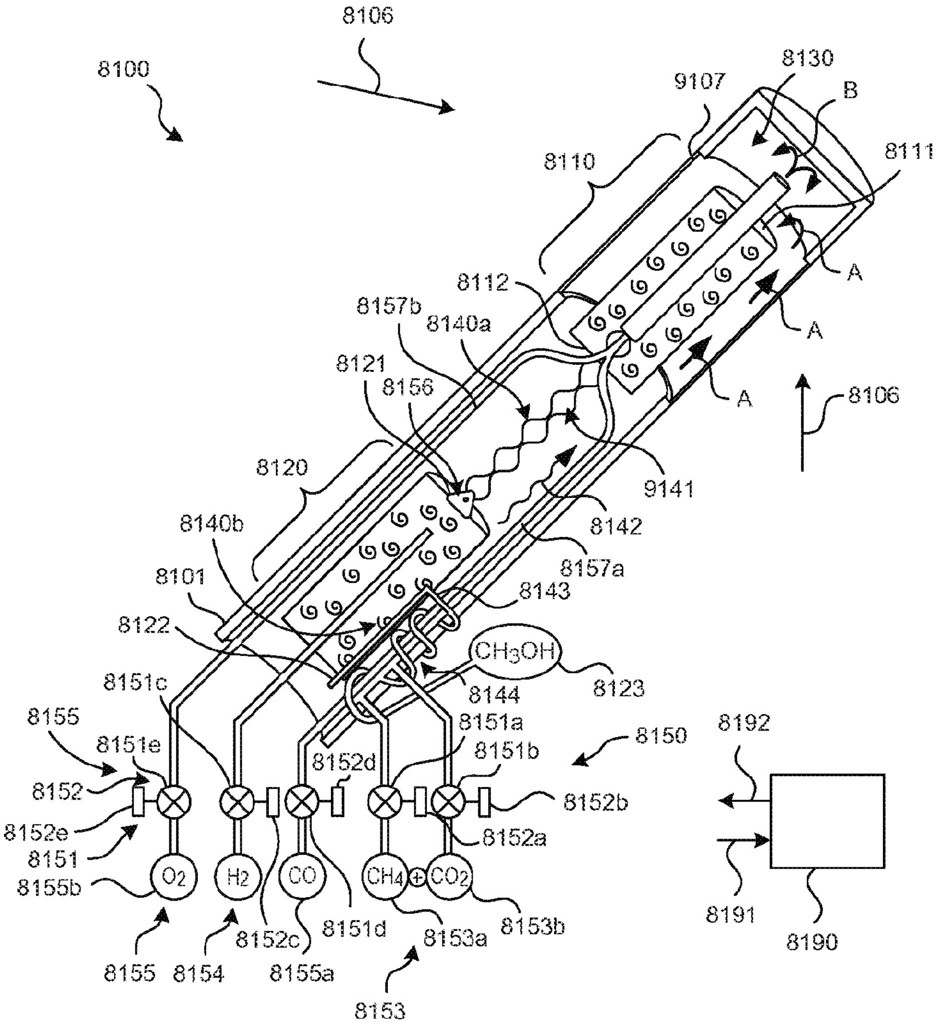
FIG. 19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8122
CH_3OH
8123
8151c
8144
8155
8151a
8150
8192
8151e
8152d
8151b
8152
8152b
8152e
8152a
8151
8155b
O_2
H_2
CO
CH_4
+
CO_2
8152c
8151d
8153a
8153b
8191
8190
8155
8154
8155a
8153

FIG. 20